ASSESSMENT OF ECONOMIC AND HYDROLOGIC IMPACTS OF REDUCED SURFACE WATER SUPPLY FOR IRRIGATION VIA REMOTE SENSING

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ABSTRACT

Reduced surface water supplies in the Southern San Joaquin Valley of California in recent years have forced growers to make difficult decisions regarding cropping, irrigation practices, and groundwater use. There is interest in objectively quantifying economic and hydrologic impacts of these reductions at levels ranging from locally-affected communities to the State and Federal governments. However, the ability to analyze impacts is limited by the unavailability of timely disaggregated data. This paper explores the opportunity to apply satellite remote sensing of crop evapotranspiration and biomass production to increase information available and perform objective analysis of the actual economic and hydrologic impacts incurred.

INTRODUCTION

According to the California Department of Water Resources Water Plan Update 2009[3], of the 82 million acre-feet (maf) of water used (applied water) in California in 2005, 8.9 maf went to urban uses, 32 maf went to agriculture, and 41.1 maf went to other (including environmental) uses. Put into percentage terms, urban uses, agriculture, and the environment account for 11, 39, and 50 percent, respectively, with agriculture representing 78 percent of non-environmental usage. The future balance between uses will be largely shaped by urban growth and climate change (Howitt, Medellin-Azuara and MacEwan 2009), water quality (Howitt et al. 2009), environmental needs (Lund et al. 2010), and the policies that California adopts in response. These factors, combined with the stochastic nature of precipitation, have generated a growing demand for efficient and timely agricultural policy analysis. Satellite remote sensing offers real-time spatial data which can be instrumental for formulating effective policy. We explore the value of this data for defining spatial agricultural production and water use, cropped area, and economic value of precise information measures using a case study region of the San Joaquin Valley of California.

The San Joaquin Valley of California is in the Southern Central Valley bordered by the Sacramento-San Joaquin Delta to the North and the Tehachapi Mountains to the South, as seen below in Figure 1. The economy in the region is driven by agriculture, representing

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[3] http://www.waterplan.water.ca.gov/docs/cwpu2009/0310final/highlights_cwp2009_spread.pdf

Figure 1. Map of the San Joaquin Valley.

approximately 24 percent of statewide gross agricultural revenues and 16 percent of statewide agricultural acres[4] in 2005. The most prevalent crops in terms of total acres planted in 2005 include (excluding pasture/rangeland) alfalfa, almonds, pistachios, grapes, cotton, and processing tomatoes. Table 1 (a, b, and c) summarizes these crops in terms of total acres, total harvested production, and total gross revenues between the state and the San Joaquin Valley in 2005. As the data show, this region produces a large proportion of production across the state, including high-value fruit and nut crops.

Table 1a. Total Harvested Acres

Select Crops	Harvested Acres in CA	Harvested Acres in San Joaquin	Percent of State Acres
Alfalfa Hay	2,189,558	557,060	25.4%
Almonds	1,223,446	483,856	39.5%
Pistachios	230,698	102,210	44.3%
Grapes (All)	1,667,288	538,117	32.3%
Cotton	1,445,256	465,535	32.2%
Processing Tomatoes	612,930	187,413	30.6%

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[4] Source: 2005 County Agricultural Commissioners' Reports

Table 1b. Total Production (Yield)

Select Crops	Production in CA	Production in San Joaquin	Percent of State Production
Alfalfa Hay	15,743,316	4,408,928	28.0%
Almonds	1,008,560	405,697	40.2%
Pistachios	336,134	148,341	44.1%
Grapes (All)	13,423,848	5,047,386	37.6%
Cotton	934,126	291,447	31.2%
Processing Tomatoes	23,176,516	7,239,241	31.2%

Table 1c. Total Gross Revenues ($M)

Select Crops	Gross Revenues in CA	Gross Revenues in San Joaquin	Percent of State Gross Revenues
Alfalfa Hay	2,100	616	29.3%
Almonds	5,738	2,309	40.2%
Pistachios	1,434	625	43.6%
Grapes (All)	8,292	2,076	25.0%
Cotton	1,464	494	33.7%
Processing Tomatoes	1,177	371	31.5%

The climate of the San Joaquin Valley is semi-arid, consisting of cold and damp winters and hot and dry summers. With summer representing the main growing season there is a heavy dependence on irrigation water from both groundwater and surface water supplies. Surface water supplies come from three main sources, including local agency supplies, the State Water Project (SWP), and the Central Valley Project (CVP). The CVP and SWP were developed in order to provide water for the southern part of the state because 70 percent of yearly runoff occurs north of the San Joaquin Valley. SWP and CVP supplies are pumped from the northern border of the San Joaquin Valley, the Sacramento-San Joaquin Delta utilizing the Delta as a central hub for conveying California's water.

There is significant heterogeneity in water availability within the San Joaquin Valley. On the eastern side of the valley, runoff from the Sierra Nevada Mountains is captured in reservoirs and used to supply irrigation water for agriculture on the valley floor. In the west, limited runoff from the Coastal Range is available leading to a higher dependence on state and federal conveyance projects. Additionally, there are significant differences in groundwater quality due to the presence of shallow groundwater salinity. Salinity problems are concentrated on the west side of the San Joaquin Valley and have significant effects on profitability through reduced crop yields and increased costs of abatement (Howitt et al. 2008b). To highlight the differences between the east and west sides of the San Joaquin Valley, Table 2 summarizes water supply availability (in thousands of acre feet) from six main sources in 2005. Sources include CVP, SWP, groundwater, local agency water, settlement and exchange contractor water (part of CVP with different water rights), and Friant Kern (also part of CVP). According to the California Department of Water Resources (DWR) classification by the composite river index for the San Joaquin Valley, 2005 represents a "wet" water year type[5]. As such, Table 2 shows above average deliveries of CVP and SWP water. East- and west-side regions are classified according to Statewide Agricultural Production Model (SWAP[6])

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[5] http://cdec.water.ca.gov/cgi-progs/iodir/wsihist

[6] swap.ucdavis.edu

regions which represent homogenous agriculture sub-regions within the Central Valley of California.

Table 2. San Joaquin Water Availability for 2005

Water Source	West San Joaquin (kaf)	East San Joaquin (kaf)
CVP	1,533	1,239
Settlement and Exchange (CVP)	768	0
Friant	41	256
SWP	1,376	1
Local	1,196	4,061
Groundwater	1,874	2,267

As Table 2 indicates, there is significant variability in water deliveries within the San Joaquin Valley. East-side regions see nearly four times the surface water availability from local agencies than the west side, in addition to 20 percent more groundwater availability. Consequently, west-side regions have higher reliance on CVP and SWP deliveries relative to the east side. Water availability for west-side San Joaquin Valley regions and, in turn, agricultural production, hinges critically on the ability of the Sacramento-San Joaquin Delta to convey water from the northern part of the state. During periods of dry water years this places significant strain on the Delta ecosystem. In addition to being a hub for water conveyance, the Delta is the largest estuary in the Western U.S. and home to a wide variety of unique wildlife. The related issues are consistently at the forefront of environmental policy debate in California.

In response to increasing environmental awareness regarding the Delta ecosystem and concerns over environmental protection for Delta Smelt, Judge Oliver Wanger issued an Interim Remedial Order Following Summary Judgment and Evidentiary Hearing (2007) on December 14, 2007. The Interim Order effectively restricted Delta exports to users south of the Sacramento-San Joaquin Delta. Initial analysis found that expected economic impacts to San Joaquin Valley agriculture in 2008 were over $1 million in lost profits due to expected export restrictions for Delta Smelt with 800 direct agricultural job losses (Sunding et al. 2008). Subsequent analysis based on realized export restrictions estimated losses in gross revenues in 2009 of $586 million with 4,800 direct agricultural job losses due to pumping restrictions (Howitt, Medellin-Azuara and MacEwan 2009). Due to the heavy reliance on state and federal project deliveries, these impacts are largely concentrated along the west side of the San Joaquin Valley.

A limitation of studies like those cited above is the ability to capture spatial variation in agricultural production and water use and measure these changes in real time. To the extent that export restrictions affect localized regions differently there is some error in the analysis based on aggregate data. For example, Westlands Water District on the west side of the San Joaquin Valley is heavily dependent on CVP deliveries due to a lack of local surface water availability and limited access to good-quality groundwater. The region produces high value agriculture including fruit and nut orchards which require a continuous supply of water. As such, interruptions in deliveries due to export restrictions have relatively larger effects in regions such as Westlands relative to east-side regions with more access to groundwater and local surface supplies. Remote-sensing data offers the ability to accurately quantify these spatial differences and properly determine localized effects. Furthermore, these data are collected in real time, thus eliminating the need for forecasts of expected effects.

In addition to facilitating accurate analysis of localized effects remote-sensing data offer insights into spatial variation in production and water use across fields. To the extent that there are differences in human and physical capital across fields within an otherwise homogenous agricultural region there are likely differences in production and water use. Policies based on aggregate (county level) data omit these potentially important differences which can lead to extra costs incurred by government.

SEBAL ANALYSIS OF CHANGES IN CONSUMPTIVE USE AND BIOMASS PRODUCTION

Available datasets developed using the Surface Energy Balance Algorithm for Land (SEBAL®) were analyzed in order to explore the ability of remote sensing to evaluate spatial variability in agricultural production and water use. Additional information describing SEBAL and its validation are available from Bastiaanssen et. al (2005) and Bastiaanssen and Ali (2003). Specifically, cumulative crop consumptive use and total dry biomass production were extracted for selected water districts within the southern San Joaquin Valley for a base year (2005) and for 2008. Within each area, total consumptive use of water and biomass production were quantified. These results are compared with relative estimates of water supply across years to explore relationships between available surface water supplies and agricultural water use and resulting crop production and economic returns.

Selection of Analysis Areas

Areas were selected for analysis from a geographic coverage of water district boundaries provided by the DWR through the California Spatial Information Library (CaSIL). Coverage is provided for federal, state, and private water districts. Within the satellite image coverage area, the 10 largest water districts were selected for analysis, based on gross acreage from the geographic coverage. The 10 selected districts are listed in Table 3. The district boundaries and satellite image coverage area are shown in Figure 2.

Designation of Agricultural Areas and Extraction of Consumptive Use and Biomass Production Results

SEBAL estimates of crop evapotranspiration and biomass production were extracted for individual fields within the analysis areas. A geographic coverage of field polygons was developed by combining land-use shape files developed by the DWR for individual counties within the satellite coverage area. These shape files include polygons for agricultural, urban, and other land uses.

Table 3. Selected Water Districts.

Area	Water Supply	Gross Acres
Westlands Water District	CVP, groundwater	605,894
Kaweah Delta Water Conservation District	Local runoff, groundwater, limited CVP (Friant)	337,979
Fresno Irrigation District	Local runoff, groundwater, CVP (Friant)	247,774
Semitropic Water Storage District	SWP, groundwater	223,602
Tulare Lake Basin Water Storage District	SWP, groundwater	190,151
Consolidated Irrigation District	Local runoff, groundwater	160,704
Kings County Water District	SWP, groundwater	143,461
Alta Irrigation District	Local runoff, groundwater	134,356
Lower Tule River Irrigation District	Local runoff, CVP (Friant), groundwater	103,104
Belridge Water Storage District	SWP, groundwater	98,301
TOTALS		2,245,325

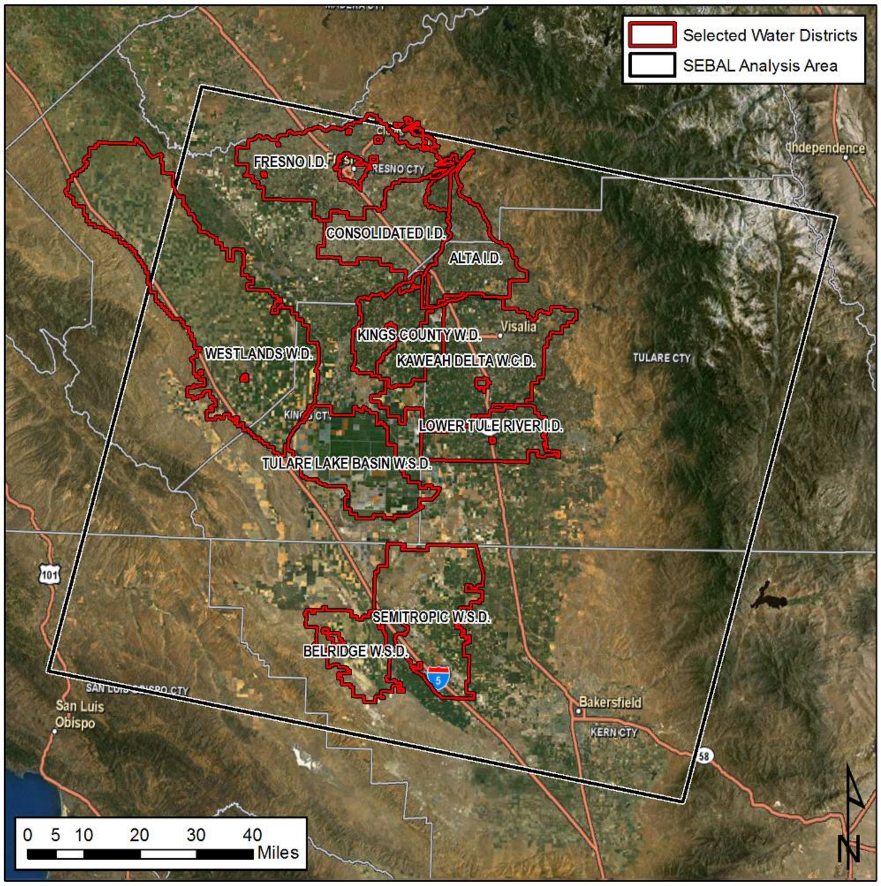

Figure 2. Selected Water Districts in the San Joaquin Valley

To isolate agricultural areas, the DWR land use polygons were overlain with a state-wide raster coverage of land use developed by the USDA NRCS for 2007. The majority land use type within each polygon was assumed to be representative of the polygon as a whole. Polygons with the majority land use classified as an agricultural crop were selected for extraction of the SEBAL results.

Prior to extracting the SEBAL results, the polygons were buffered inward by 60 meters to reduce or eliminate edge effects that could result from satellite pixels overlapping the field boundaries, or from slight mismatches between the field boundaries and satellite imagery. Polygons less than eight acres in size following buffering were excluded from the analysis to provide a sufficient number of pixels within each field to develop a representative estimate of mean actual ET and biomass production.

Mean actual evapotranspiration and biomass production were calculated for each polygon on an approximately monthly basis for the period from May to September for the years 2005 and 2008. Values for each field were stored in an MS Access database for further analysis.

Cumulative Consumptive Use and Biomass Production Estimates for Selected Areas

Cumulative consumptive use estimates for the study areas for the growing seasons of 2005 and 2008 are summarized in Table 4. Additionally, the percent difference in consumptive use of water from 2005 to 2008 is provided.

A reduction in consumptive use occurred between 2005 and 2008 for 8 of the 10 selected water use areas, with an overall reduction of approximately 6 percent. The change in consumptive use among areas ranged from a reduction of 21 percent for the Tulare Lake Basin Water Storage District to an increase of 15 percent for the Belridge Water Storage District.

Cumulative biomass production estimates for the study areas for the growing seasons of 2005 and 2008 are summarized in Table 5. Additionally, the percent difference in biomass production from 2005 to 2008 is provided.

A reduction in biomass production occurred between 2005 and 2008 for 5 of the 10 selected water use areas, with an overall reduction of approximately 3 percent. The change in biomass production among areas ranged from a reduction of 23 percent for the Tulare Lake Basin Water Storage District to an increase of 20 percent for the Belridge Water Storage District.

WATER SUPPLY ASSESSMENT FOR 2005 AND 2008

Federal, state and private water districts have different primary water sources. Private water districts’ main supply source is private water rights on local streams. Some of these private water districts have built storage reservoirs. The Central Valley Project (CVP) and the State Water Project (SWP) are the main supply sources for federal and

Table 4. Estimates of Growing Season Actual Evapotranspiration for Selected Areas for 2005 and 2008

				May-September Actual Evapotranspiration				
			Acres	2005		2008		%
Area	Water Supply	Gross Acres	Sampled	ac-ft	ac-ft/ac	ac-ft	ac-ft/ac	change
Westlands Water District	CVP, groundwater	605,894	316,449	438,876	1.4	435,629	1.4	-1%
Kaweah Delta Water Conservation District	Local runoff, groundwater, limited CVP (Friant)	337,979	126,349	417,367	3.3	400,019	3.2	-4%
Fresno Irrigation District	Local runoff, groundwater, CVP (Friant)	247,774	70,873	128,616	1.8	127,667	1.8	-1%
Semitropic Water Storage District	SWP, groundwater	223,602	116,609	231,266	2.0	209,524	1.8	-9%
Tulare Lake Basin Water Storage District	SWP, groundwater	190,151	161,436	298,616	1.8	235,799	1.5	-21%
Consolidated Irrigation District	Local runoff, groundwater	160,704	65,085	114,257	1.8	102,719	1.6	-10%
Kings County Water District	SWP, groundwater	143,461	89,333	194,794	2.2	188,217	2.1	-3%
Alta Irrigation District	Local runoff, groundwater	134,356	50,074	114,049	2.3	117,090	2.3	3%
Lower Tule River Irrigation District	Local runoff, CVP (Friant), groundwater	103,104	55,884	126,586	2.3	116,254	2.1	-8%
Belridge Water Storage District	SWP, groundwater	98,301	39,915	63,871	1.6	73,605	1.8	15%
TOTALS		2,245,325	1,092,008	2,128,297	1.9	2,006,524	1.8	-6%

Table 5. Estimates of Growing Season Biomass Production for Selected Areas for 2005 and 2008

				May-September Biomass Production				
			Acres	2005		2008		%
Area	Water Supply	Gross Acres	Sampled	tons	t/ac	tons	t/ac	change
Westlands Water District	CVP, groundwater	605,894	316,449	1,268,084	4.0	1,274,182	4.0	0%
Kaweah Delta Water Conservation District	Local runoff, groundwater, limited CVP (Friant)	337,979	126,349	1,233,601	9.8	1,262,685	10.0	2%
Fresno Irrigation District	Local runoff, groundwater, CVP (Friant)	247,774	70,873	398,524	5.6	394,149	5.6	-1%
Semitropic Water Storage District	SWP, groundwater	223,602	116,609	719,010	6.2	657,347	5.6	-9%
Tulare Lake Basin Water Storage District	SWP, groundwater	190,151	161,436	828,058	5.1	639,944	4.0	-23%
Consolidated Irrigation District	Local runoff, groundwater	160,704	65,085	365,943	5.6	338,079	5.2	-8%
Kings County Water District	SWP, groundwater	143,461	89,333	591,101	6.6	590,619	6.6	0%
Alta Irrigation District	Local runoff, groundwater	134,356	50,074	342,938	6.8	363,602	7.3	6%
Lower Tule River Irrigation District	Local runoff, CVP (Friant), groundwater	103,104	55,884	391,057	7.0	373,398	6.7	-5%
Belridge Water Storage District	SWP, groundwater	98,301	39,915	196,972	4.9	235,416	5.9	20%
TOTALS		2,245,325	1,092,008	6,335,289	5.8	6,129,420	5.6	-3%

state water districts, respectively. Additionally, all of these districts supplement their main source of supply with groundwater and water transferred from users in other areas of the state.

The goal of all these districts is a constant, reliable water supply for agriculture. In general, the water supply varies depending upon the amount of snow received in the winter and the amount of water available through the CVP and SWP (dependent on winter rain and snow in northern California). Generally, in even the wettest years, there is some volume of groundwater included in the supply. In years with limited surface water supplies, groundwater pumping is increased to supplement the surface supply. In these low surface supply years, efforts to purchase water from users in other areas also increase.

In 2007, the Wanger decision restricted pumping from the Delta by the CVP and SWP, adding an additional water supply constraint on the federal and state districts. In the short-term, it is likely that this reduced supply will be replaced with additional groundwater pumping. However, in the long term, this may not be sustainable.

Water supplies can be assessed for the federal and state districts by comparing the CVP and SWP allocations for 2005 and 2008. As general indicators of local surface water supply availability, the DWR defines San Joaquin River Basin water years types based on the measured unimpaired runoff of four rivers. The four rivers are: (1) Stanislaus River inflow to New Melones, (2) Tuolumne River inflow to New Don Pedro, (3) Merced River inflow to New Exchequer, and (4) San Joaquin River inflow to Millerton. For local districts, this index provides a convenient metric to assess the availability of water from the local streams.

The federal and state districts had 2008 allocations of 40 and 35 percent compared to 2005 allocations of 85 and 90 percent relative to their contract entitlements, respectively (Table 6). The private districts also had a significantly reduced supply with 2008 being a critical water year compared to a wet year in 2005 based on the San Joaquin Valley Water Year Index developed by the DWR[7].

Table 6. Relative Surface Water Supplies in 2005 and 2008

District Type	2005	2008
Federal	85%	40%
State	90%	35%
Private	Wet	Critical

These are significant reductions in the district’s main water supplies; however, districts have differing abilities to supplement these supplies with groundwater and additional supplies obtained through water transfers. In any given year, some districts may be able replace these reduced supplies through the two-pronged approach of increased groundwater use and increased water transfers. Additionally, when water supplies are scarce growers can maximize returns to water by applying the reduced supplies on their most fertile land.

ESTIMATION OF THE ECONOMIC VALUE OF EVAPOTRANSPIRATION

The economic value of water is by definition the shadow (scarcity) value of an additional unit of water. A farmer operating under a water constraint is willing to pay an amount in order to secure an additional unit of water, thereby relaxing the water constraint and

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[7] http://cdec.water.ca.gov/cgi-progs/iodir/wsihist

allowing for additional crops to be grown, and this value is called the shadow value of water. In general, this value depends on the types of crops being grown, production practices, and degree of water scarcity. For example, a farmer growing almonds will be willing to pay more than the same farmer growing alfalfa when facing an identical water shortage, all else being constant. This reflects the fact that stress irrigation is more feasible with alfalfa, and almonds are of relatively higher value. The economic value of water varies significantly between regions in the San Joaquin Valley with west-side regions seeing higher values than those on the east side in response to water availability.

To determine the economic value of evapotranspiration (ET) we use the Statewide Agricultural Production Model (SWAP) to quantify farmers' growing decisions and to determine the marginal value of an additional acre-foot of water. SWAP was developed by Howitt and collaborators (2001) for the original use of providing the economic scarcity cost of water for agriculture to CALVIN (Jenkins et al. 2001), a statewide economic engineering optimization model for water management in California.[8] More recently, SWAP has been used to estimate economic losses due to salinity in the Central Valley (Howitt et al. 2008a), economic losses to agriculture in the San Joaquin Delta (Appendix to Lund et al. 2007), economic losses for agriculture and confined animal operations in California's Central Valley (Appendix to Lund et al. 2008), and economic losses due to Delta export restrictions (Howitt et al. 2009).

SWAP, at its root, is a mathematical programming model for major crops and regions in California and uses Positive Mathematical Programming (PMP) (Howitt 1995). PMP is a deductive approach to evaluating the effects of policy changes on cropping patterns at the extensive and intensive margins. SWAP is a three-step, self-calibrating model that assumes that farmers behave in a profit-maximizing fashion. In the first step, a linear program for profit maximization is solved. In addition to the traditional resource and non-negativity constraints, a set of calibration constraints is added to restrict land use to observed values. In the second step, the optimization first-order conditions are used to derive the parameters for an exponential cost function and a non-linear Constant Elasticity of Substitution (CES) production function. The third and last step incorporates the parameterized functions from step two into a non-linear profit maximization program, with constraints on resource use.

SWAP is calibrated to agricultural data from 2005, representing the most recent comprehensive set of agricultural production data available for the state. Three scenarios are considered in order to generate a range of shadow values of water, a base case with no shortage, a case with a 10 percent reduction in total available irrigation water, and a case with a 20 percent reduction in total available irrigation water. Since SWAP is an economic model and production decisions are based on applied water, the model results generate the marginal value of an additional acre-foot of applied water. We used DWR regional water use efficiency estimates to generate the marginal value of an acre-foot of ET. Within each SWAP region there is a value of ET associated with each individual crop grown, based on this efficiency measure. We aggregated by weighted average over

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[8] http://cee.engr.ucdavis.edu/CALVIN.

all crops in the region to generate a region specific shadow value of ET. Results are summarized in Table 7 below for the 10 selected geographic regions.

Table 7. Economic Value per acre-foot of ET

Area	BASE $ET	10% Shortage $ET	20% Shortage $ET
Westlands WD	$246.99	$402.97	$938.17
Kaweah Delta Water CD	$159.71	$279.69	$318.66
Fresno ID	$193.80	$461.39	$764.88
Semitropic Water SD	$142.87	$275.11	$351.63
Tulare Lake Basin Water SD	$176.87	$282.28	$338.55
Consolidated ID	$168.30	$324.93	$859.59
Kings County WD	$176.87	$282.28	$338.55
Alta ID	$168.30	$324.93	$859.59
Lower Tule River ID	$341.61	$568.22	$869.25
Belridge Water SD	$306.15	$765.48	$915.02

As discussed previously, the shadow value of ET is based on the crop mix in the specific region as well as the level of the water shortage. Under no shortage, the average value of an acre-foot of ET ranges between $140 and $340 depending on the region. With severe drought equal to twenty percent of all available supplies, the marginal value of ET increases to a range of $340 to $930, with Westlands Water District representing the highest marginal value. There is a significant economic gradient for the value of water that could be exploited under functioning water markets, a situation that can be explored using remotely sensed data.

COMPARISON OF CHANGE IN EVAPOTRANSPIRATION AND BIOMASS PRODUCTION TO THE ECONOMIC VALUE OF EVAPOTRANSPIRATION

The economic value of ET corresponding to a 10 percent reduction in total water supply from SWAP is assumed to be reasonably representative of 2008. Analysis of percent reduction in consumptive use of water and biomass production by district and the corresponding economic value of ET provide insight into the response of growers to reductions in surface water supply. Differences in physical characteristics, management practices, and economic gradients across regions between 2005 and 2008 determine the relationship between economic value of water and changes in biomass production and consumptive use.

Table 8 summarizes the economic value of ET, percent change in biomass production, and percent change in consumptive use for selected regions between 2005 and 2008. There is significant variation in both changes in production and water use and the economic value of water across regions. Furthermore, taken individually, there is some correlation between the economic value of water and consumptive use and biomass. In general this correlation suggests regions with higher economic value of water see increases (or relatively lesser decreases) in consumptive use and biomass production between 2005 and 2008. Conversely, regions with low economic value of water realize relatively higher reductions in biomass production and consumptive use. For example, under a 10 percent shortage scenario, Belridge Storage District has an estimated economic value of water of $765 per af and realizes an increase of 20 and 15 percent in biomass production and ET, respectively, whereas Tulare Lake Storage District has a value of $282 per af and realizes a decrease of 23 and 21 percent in biomass and ET, respectively. We caution that this relationship is not causal as there are likely several factors acting simultaneously to determine changes in production and water use relative to the economic value of water; and we discuss these below.

Table 8. Summary of Economic Value of Water and Change in Biomass and ET

Area	Shadow Value of Water ($)	Pct Chg in Biomass	Pct Chg in ET
Westlands WD	403	0	-1
Kaweah Delta Water CD	280	2	-4
Fresno ID	461	-1	-1
Semitropic Water SD	275	-9	-9
Tulare Lake Basin Water SD	282	-23	-21
Consolidated ID	325	-8	-10
Kings County WE	282	0	-3
Alta ID	325	6	3
Lower Tule River ID	568	-5	-8
Belridge Water SD	765	20	15

Several factors are acting simultaneously to determine relative changes in water use and production across regions including, availability or unavailability of sufficient groundwater supplies or external transfers to offset reductions in surface water supply, changes in cropping due to market or other factors, and/or changes in water management practices across years. Additionally, changes in weather induce changes in evaporative demand and/or solar radiation to drive photosynthesis which have differential effects on consumptive use and biomass production, respectively, across regions.

In addition to variation in physical characteristics and weather across regions between 2005 and 2008 there are other potential differences between regions. We discuss two potential differences. Relative to regions with low economic value of water, regions with high value likely may grow a higher value crop mix and face an initial water constraint that is more restrictive. These two factors lead to opposite expected effects of water shortage, which we consider in turn. First, a higher value crop leads to a higher willingness to pay for additional water, thereby creating an economic gradient to transfer water from lower value uses in other regions into regions and fields with higher value crops. To the extent that water markets are available, this effect would cause regions with higher economic value of water (buyers of water) to import more water during critical years resulting in lower reductions (or increases) in production and water use relative to regions with low economic value of water (sellers of water)[9]. Working opposite this effect, a more restrictive initial water constraint in regions with high economic value of water would likely cause relatively larger reductions in production and consumptive use. The mechanics of this effect are intuitive; regions with tight initial water supplies are more likely to have to resort to fallowing in response to shortage. The net effect of water shortage on production and water use compared to the economic value of water depends on the balance of these forces and groundwater, water management, and other physical characteristics.

CASE STUDY: ECONOMIC VALUE OF PRECISE SPATIAL DATA

The value of precise spatial measurement of crop production and water use is directly tied to the ability of policy makers to use the information in real time. Spatial variability in land and water use indicates that there is spatial variability in the value of individual fields which translates into differences in the marginal value product of water. Currently, modeling the response of California crop production and water use to changes in policies, prices, and resources is restricted by the current dearth of disaggregated data. In practice, policies need to reflect the marginal adjustments by farmers and changes in the spatial distribution of agricultural production and water use. Spatial variation due to differences in physical and human capital of farmers is manifested through differences in water use and crop yields across fields. Understanding potential micro-level adjustments in response to these differences is fundamental to effective agricultural policies. In order to focus ideas, we quantify the potential economic value of this information by way of a case study and the example presented in this section.

We combine biomass, ET, and crop production geo-referenced data for Kern County, in the area of the Semi-tropic Water Storage District, in 2002. Kern County has an urban population of about 800,000 and is located in the southern part of the San Joaquin Valley of California. It represents a diverse region in terms of agricultural production with over forty unique crops produced in a given year. Since Kern is a large county, we controlled for heterogeneity by focusing on the Semi-tropic Water Storage District, which corresponds to SWAP model region 19b.

As an agricultural policy example we considered a policy designed to reduce agricultural water use by 20 percent in any given year. Specifically, consider a fallowing program whereby the government pays farmers to fallow certain crops, with the target of reducing water use by 20 percent. We consider a policy that specifically targets alfalfa for a 20 percent reduction in water use. We make this simplification in order to avoid the computational complexities of a variety of crop types, in essence allowing us to forgo the use of a full economic production model. Another reason for this simplification is that we can hypothesize a linear relationship between SEBAL biomass and crop yield in order to generate field-specific yield estimates. Specifically, we assume a linear relationship where the mean total dry biomass production from SEBAL is estimated at 11.4 tons per acre, whereas the average yield from the county estimates is 7.8 tons of dry alfalfa hay per acre. As such, each biomass estimate is scaled by 0.68 such that the mean total dry

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[9] See http://swap.ucdavis.edu for preliminary analysis of water transfers in the Central Valley

biomass production and mean dry yields coincide. We take these to represent estimates of alfalfa yield by field and assume uniform yield over all acres in a given field. We note that the qualitative results we derive from this analysis generalize to any other crop and across all other regions in California; however, the magnitude of the effect will differ due to regional differences and market effects.

An ideal land retirement policy targets acres with low marginal value product, thereby receiving the highest return per dollar of water saved. The extent of the variability in the distribution of production and water use across fields is an indicator of the degree of importance of precise spatial information. To highlight this fact and provide a basis for the following analysis we calculate the gross revenue per acre as the price of alfalfa in 2002, $113 per ton, multiplied by the yield per acre as calculated above, and divide by actual ET per acre in feet. The result is an estimate of gross revenue per foot of ET, and the distribution is shown in Figure 3. For comparison purposes, using county average survey data from 2002, crop yield is estimated at 7.74 tons per acre with 3.77 feet ET, implying $232 gross revenue per foot of ET.

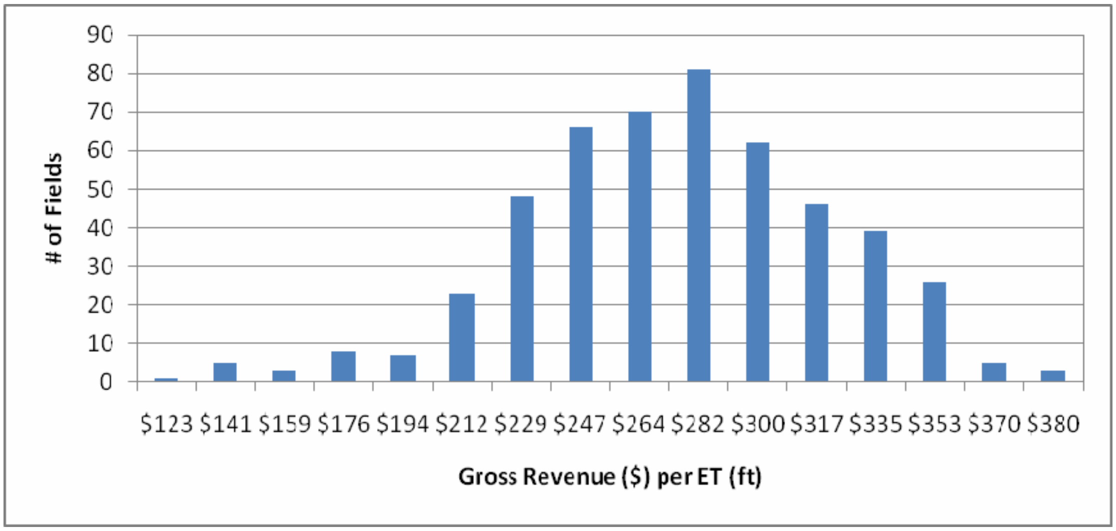

Figure 3. Distribution of Alfalfa Gross Revenue per ET by Field

As shown in Figure 3, there is significant variability in the gross revenue per foot ET across alfalfa fields in Kern County. This information is valuable to policymakers and has not, as of yet, been explicitly incorporated into policy analysis. Consider the hypothesized 20-percent alfalfa fallowing program. For simplicity we assume that costs are constant across all acres, thus gross revenue per acre is an exact proxy for total value per acre. Two situations are considered to illustrate the value of more precise information. First, consider a naïve case where the policy maker has no knowledge of the exact distribution and is only able to offer a constant price per acre. The second case allows for perfect information (in the economic sense) where the distribution is known by the policy maker with certainty and the policy maker is able to offer different prices between acres. In reality the policymaker likely has some knowledge of the distribution and might design a bidding mechanism for land retirement. We discuss this possibility as well, highlight some of the difficulties with implementation, and show potential value of remotely-sensed data in this setting. Figure 4 shows the cumulative acres over the lowest value 23,000 acres (total acres are 35,000) graphed against the county average.

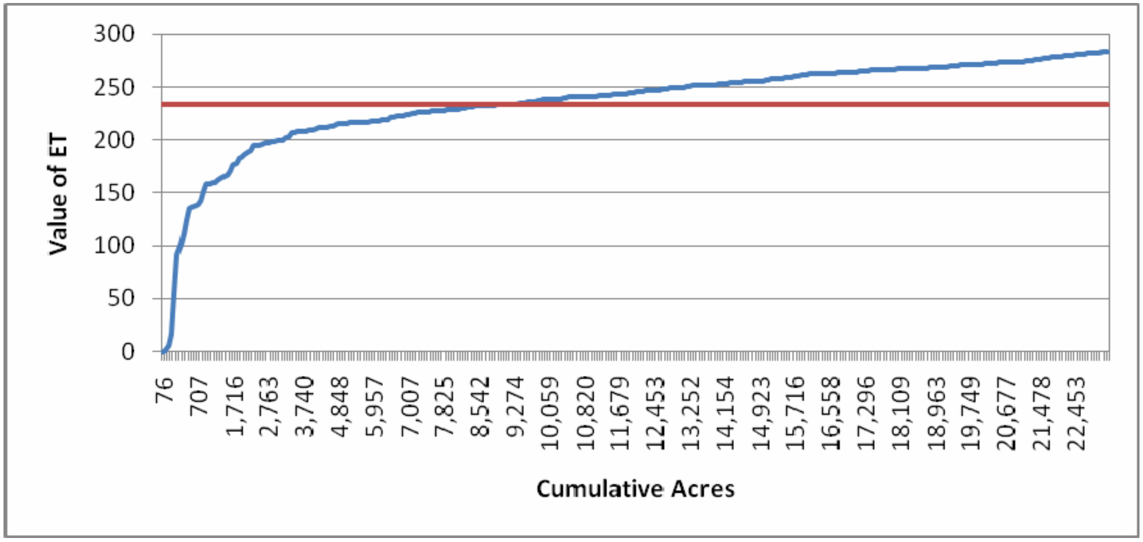

Figure 4. Observed and Average Gross Revenue of Alfalfa per foot ET: Cumulative Acres (County Average in Red)

First consider the naïve case where the government can only offer a constant price per acre for alfalfa land and has no knowledge of this distribution. The policy is designed based on the average measurements, namely 7.74 tons yield per acre at a value of $113 per ton and 3.77 feet of ET per acre. The county average data translates into value of $232 per acre and with 35,000 total acres of alfalfa, the program wants to buy back 7,000 acres (20 percent). Since the value per field is also the willingness of each farmer to accept this price, farmers are willing to retire land up to a maximum of 8,992 acres. This is shown by the intersection of the average and actual gross revenue curves in Figure 4 which reflects the fact that farmers have knowledge of their own land value and will only offer marginal land for the program. For simplicity, assume that the lowest value 7,000 acres are those that are actually fallowed, although in principal any of the 8,992 acres could be sold into the program. With this assumption 7,000 acres are fallowed at $232 per acre for a total cost of $1.63 million. Given the true distribution of value across acres the value per acre on the 7,000th acre is actually $220, as seen in Figure 4. Thus, the government could have offered $220 and fallowed the same 7,000 acres which translates into a saving of $84,000, representing a 5 percent reduction in total cost of the program due to having more precise information

As a second example, consider the case at the opposite extreme where the policy maker knows the exact distribution of gross revenues (value) across all acres. In this case the optimal policy is perfect price discrimination where the lowest value 7,000 acres are fallowed at an individualized price exactly equal to the value per acre. In this situation excess payments are exactly zero since each acre is paid its exact value and, furthermore, the lowest value acres are fallowed. Relative to the case where farmers are offered a constant price of $232 per acre, this program reduces the fallowing payments by $298,000, the difference between price paid and actual value on each of the 7,000 acres. This translates into an 18 percent reduction in fallowing expenditures and represents a significant value of the precise information. Note that $298,000 is an upper bound on the potential savings from knowledge of the value distribution. In practice, the ability of the policy maker to extract some of this excess value depends on the pricing design. For example, second degree price discrimination would allow the policy maker to extract some portion of the $298,000 potential savings.

A more realistic situation is that policy makers are aware of the existence of a distribution of value across acres but are unsure of its exact nature. One option is to accept bids from farmers of their willingness to accept to sell into the program. In theory, a properly designed bidding mechanism would encourage each farmer to bid the true value per field. However, there is often significant collusion among farmers in bidding the value of land, as was the case in the Conservation Reserve Program. Ferraro (2007) reviews some of the literature related to this result and summarizes the significant potential for collusion among farmers to fix bid prices for land fallowing. Knowledge of the actual distribution circumvents the need for auctions, and consequently eliminates the possibility of bidding collusion. In addition to savings from reduced overpayment per field there is an additional savings of administrative costs. This same idea extends to a variety of possible land fallowing program designs. In each case the value of remotely-sensed data is the difference between what is paid and the actual value per field, plus any costs associated with program implementation (auctions, etc). The two bounding cases are summarized in Table 9.

Table 9. Value of Precise Data

Policy	Cost with County Average Data	Cost with SEBAL Data	Cost Savings
Point Information	$1,624,000	$1,540,000	$84,000
Perfect Discrimination	$1,624,000	$1,325,254	$298,746

Spatial variability in crop water use and production has significant policy implications. In the context of Delta pumping restrictions, the lack of spatial data makes it unlikely that policymakers are accurately evaluating the highly localized effects of pumping restrictions. There is an economic incentive to transfer water from areas with a relatively low marginal value of water to areas with a relatively high marginal value of water. In essence accurate spatial data allows for structuring real time water markets that allow for transfers of available water supplies to those areas with the greatest marginal values of water.

CONCLUSION

The future balance of urban, environmental, and agricultural water use in California hinges critically on the decisions of policymakers which, in turn, depend on availability of accurate water use and agricultural production data. Recent rulings together with a series of critically dry water years have significantly reduced water availability in regions with heavy reliance on State and Federal project deliveries. In general, these regions are concentrated along the West-side of the San Joaquin Valley. Analysis of SEBAL data for selected regions found changes in biomass and consumptive use ranging from reductions of 23 percent to increases 20 percent. Comparing changes in biomass and water use to the economic value of water by region provides evidence that the most significant changes in biomass and water use are concentrated in regions with high/low economic value of water; however, water transfers and a shifting crop mix in regions across the entire Valley make a causal link between economic value of water and production and water use unlikely. The concluding case study highlights the importance of detailed spatial information for providing policymakers with an accurate representation of the localized effects of water shortage in real time. Future research should be focused on integrating remote sensing data directly into policy models, developing economic models that explicitly account for this detailed spatial variation, and developing policies that maximize benefits of this information.

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