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Calculating California Cropping Patterns in 2050

Technical Memo

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1.0 Introduction

This technical memo explores a likely development of cropping patterns and water use in California by the year 2050. Given the very long time horizon required in this study, the results should not be considered a projection or forecast, but as a probable outcome of the interaction of several uncertain driving forces. California agriculture has always been driven by the interactions between technology, resources and market demands, and future production can be viewed as a balance between the rates of change in these three variables. Accordingly, we have attempted to make the assumptions, mathematics and parameter values used in this study as transparent as possible to enable the reader to assess the basis for the results.

In performing this analysis we explore yield increases due to technological change, shifts in demand for California crops and reductions in agricultural land availability due to urban conversion. All of these effects are considered with respect to a base year of 2005. The spatial regions in this analysis include twenty-six (26) Central Valley Production Model regions (CVPMs after Hatchett 1998). All analysis is based on the CVPM regions. These results are then aggregated into five regions including Sacramento River, Tulare, Colorado River, Southern California and San Joaquin River. Finally, we extrapolate the results to an additional five regions defined by the California Department of Water Resources (DWR) namely the North Coast, Central Coast, San Francisco Bay, North Lahontan and South Lahontan regions.

A modified version of the Statewide Agricultural Production Model, (SWAP after Howitt et al. 2001) is used to generate the results that follow in this report. Data from a geo-referenced land use survey from the California Department of Water Resources (DWR) is combined with information from United State Department of Agriculture (USDA) surveys and corroborated by county Agricultural Commissioner's reports. Cost information was obtained from crop production budgets from the UC Davis Cooperative Extension and the Agricultural Issues Center (AIC).

2.0 Model and Data Description

The Statewide Agricultural Production Model (SWAP) was developed by Howitt and collaborators (2001) and continues to be improved upon. The original use for this model was to provide 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 (http://cee.engr.ucdavis.edu/CALVIN). More recently, SWAP has been used to estimate economic losses due to salinity in the Central Valley (Howitt et al. 2008), economic losses to agriculture in the San Joaquin Delta (Appendix to Lund et al. 2007) and economic losses for agriculture and confined animal operations in California's Central Valley (Appendix to Lund et al. 2008).

SWAP, at its root, is a mathematical programming model for major crops and regions in California and uses Positive Mathematical Programming (or PMP after Howitt 1995). Implicit in this model is the assumption that farmer's optimize their production input use to maximize their own profit.

To generate more accurate results this version of SWAP contains several innovations including:

- Endogenous crop group prices for year 2050
- Geo-referenced land use information
- Updated price and production cost information
- Use of an exponential constant elasticity PMP cost function
- Updated information on yield reduction due to climate warming

Positive mathematical programming (PMP after Howitt 1995) 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 programming model that assumes 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 we use the optimization first order conditions to derive the parameters for an exponential cost function and a non-linear CES production function. The third and last step incorporates the parameterized functions from step 2 into a non-linear profit maximization program, with constraints on resource use.

2.0.1 Model Regions and Crop Groups

Agricultural regions in SWAP include twenty-one CVPM regions (Hatchett 1997) plus irrigated agriculture in Coachella, Imperial, Ventura, San Diego and Palo Verde in

Southern California for a total of twenty-six regions. These are shown in Figure 1. Areas in green show coverage from previous studies (Howitt et al. 2001), whereas grey areas for Ventura and north of San Diego have been incorporated recently into SWAP. For clarity in reporting results these twenty-six regions are aggregated into five larger hydrological regions. Specifically, the Sacramento region includes CVPM regions 1 thru 7, the San Joaquin region includes CVPM regions 8 thru 13 and the Tulare Basin is represented by CVPM regions 14 thru 21. Southern California is comprised of agriculture in the Imperial Valley, Palo Verde, Coachella, San Diego and Ventura plus some additional agriculture in Los Angeles and San Bernardino.

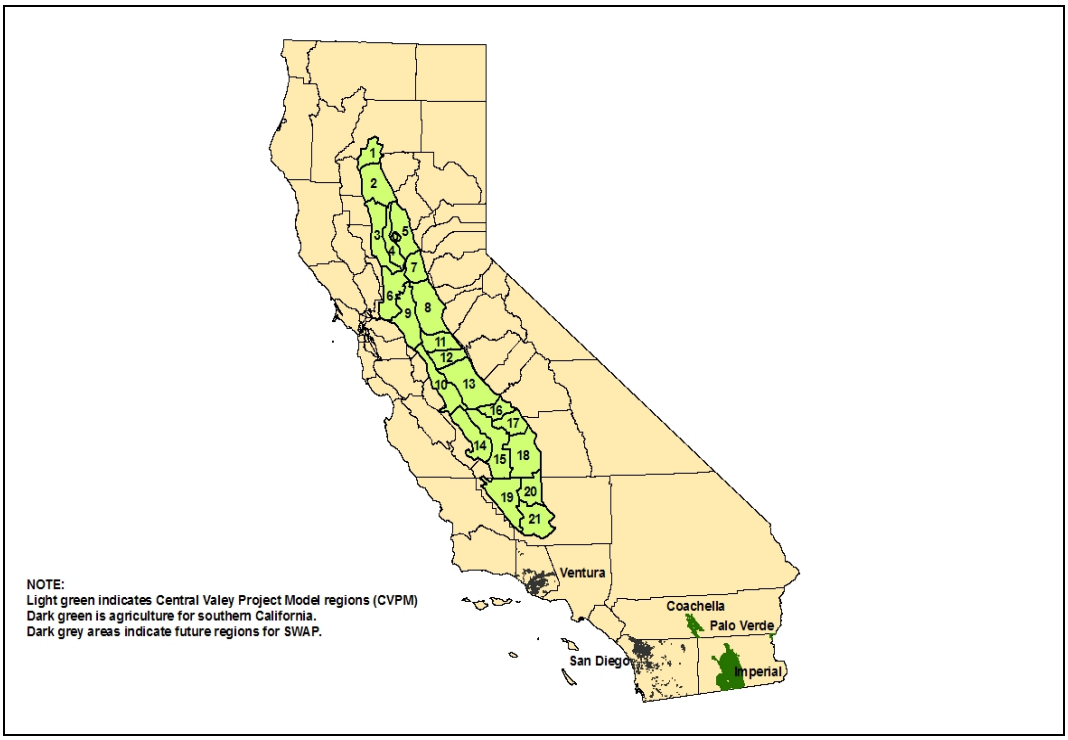

Figure 1 Map of Coverage of the Statewide Agricultural Production Model (SWAP).

This report also includes five additional regions specified by DWR. These include North Lahontan, South Lahontan, North Coast, Central Coast and South Coast. Currently, these regions are not explicitly incorporated in the SWAP model. As such, the results for these regions are extrapolations based on the closest SWAP region. For example, to extrapolate water use per acre to a DWR region we consider the closest SWAP region and calculate water per acre changes from the base year. We take base water from DWR in the region and multiply by the same percentage change and then by acres in the region to get water usage. The same general logic applies to revenue and land use changes. Regions by DWR designation are detailed in figure 2, below.

Figure 2 Map of Coverage of DWR Cal-Ag Regions.

Irrigated crops in each of the twenty-six CVPM regions are classified into thirteen SWAP crop groups: alfalfa, citrus, corn, cotton, field crops, grains, grapes, orchards, pasture, sugar beet, tomato and truck crops. This grouping follows previous SWAP versions (Howitt, Ward et al. 2001; Medellín-Azuara, Howitt et al. 2007). After the model is run these groups are disaggregated into 20 DWR crop groups: grain, rice, cotton, sugar beet, corn, dry bean, safflower, other field crops, alfalfa, pasture, processing tomatoes, fresh tomatoes, cucurbits, onions and garlic, potato, other truck crops, almonds and pistachios, other deciduous crops, subtropical crops and vineyards.

The details of disaggregating SWAP to DWR crop groups in this report are as follows. The model is run with the thirteen initial SWAP crop groupings over twenty-six CVPM regions and results are recorded. Using the base year of 2005 the crop proportions based on acreage are recorded. These acreages and resulting proportions are used to weight the DWR crop groups and disaggregate SWAP results. Specifically, truck crops in SWAP include processing tomatoes, cucurbits, onions and garlic, potato and other truck crops in DWR, field crops in SWAP include dry beans, safflower and other field crops in DWR, and orchard in SWAP includes almonds and pistachios and other deciduous crops in DWR. All other crops have a direct relationship between SWAP and DWR groupings.

2.0.2 SWAP Model Architecture

The following section lays out the technical details of the SWAP model. For a more comprehensive treatment, see the references cited below.

A Constant Elasticity of Substitution (CES) production function is defined and parameterized as in Howitt (2006). The elasticity of substitution between inputs is assumed to vary by crop but not by region. The specification of the generalized CES production function is:

$$Y_{gi} = \tau_{gi}\left[\sum_j \beta_{gij} X_{gij}^{\rho_i}\right]^{\upsilon/\rho_i} \tag{1}$$

Sub-index g corresponds to the CVPM region, i refers to crops and *j* to production factors or inputs. The model in this study has four inputs: land, labor, water and supplies. Y_{gi} represents the output for crop i in region or group *g*. The scale parameter of the CES production function is referred as τ_{gi}, whereas the share parameters for the resources for each crop are represented by β_{gij}. X_{gij} denotes usage of factor j in production of crop i in region *g*. The elasticity of substitution for crop *i*, is defined as σ_i where $\rho_i = {(\sigma-1)}/{\sigma}$. The returns to scale coefficient is given by υ.

The first step in PMP is to obtain marginal values for the calibration constraints to enable the derivation of the cost function parameters in the second step. The linear program with calibration constraints is as follows:

$$Max_{x\geq 0}\prod = \sum_g \sum_i (v_{gi} yld_{gi} - \sum_{\mathrm{j}} \omega_{gij} a_{gij}) x_{gi,land} \tag{2}$$

$$\sum_i a_{gij} x_{gi} \leq b_{gi} \quad \forall \mathrm{g, j} \tag{3}$$

$$x_{gi,land} \leq \tilde{x}_{gi,land} + \varepsilon \quad \forall \text{ g,i} \tag{4}$$

Equation 2 is the objective function (profits) of the linear program. Decision variables are defined as follows: x_{gi} is the total acres planted for region or group g and crop *i*. The marginal revenue per ton of crop *i* in region g is given by v_{gi} and average yields are given by yld_{gj}. Average variable costs, ω_{gji}, are used in the linear objective function 2. The Leontieff coefficients, a_{gji}, are given by the ratio of total factor usage to land.

Equations 3-4 represent the constraint set. Parameter b_{gi} is the regional limit on resource *j*. Constraint four (4) is for the upper bound calibration constraints, $\tilde{x}_{gi,land}$ is the observed value of resources usage and ε is small perturbation that decouples the resource and calibration constraints.

The second step in PMP estimation is to calculate parameters needed by the exponential cost function and the CES production function. The constant elasticity cost function is given by equation 5 below:

$$TC_{gij}(x_{gij}) = \delta_{gi} e^{\gamma_{gi} x_{gi,land}} \quad (5)$$

δgi and γ_{gi} are the intercept and the elasticity parameter for the exponential acreage response function, respectively. These parameters are obtained from an ordinary least squares regression, with restrictions, on the PMP formulation and elasticity of supply for each crop group.

The last step in PMP is to solve a non-linear constrained profit maximization program. The objective function is defined as:

$$Max_{x \geq 0} \prod = \sum_g \sum_i yred_{gi} v_{gi} Y_{gi} - \sum_g \sum_i \delta_{gi} e^{\gamma_{gi} x_{gi,land}} - \sum_g \sum_i \sum_{j, j \neq land} (\omega_{igj} x_{gij}) \quad (6)$$

subject to:

$$Ax \leq b \quad (7)$$

$$xm_{gm} \leq \sum_i met_{gim} x_{gi,water} \quad \forall g,m \quad (8)$$

$$\sum_m xm_{g,m} \leq availwater \cdot b_{water,g} \quad \forall\, g \quad (9)$$

In equation 6, Ygi is defined by the production function in equation (1) above and the derivation of parameters τ_{gi} and β_{gij} of the production function is detailed in Medellin-Azuara (2006). The second term in the equation is the PMP cost function, calibrated in the previous step. Constraint 7 is as in 3 above, except that all resources are included not just those limited by fixed quantities. In equation 6, the parameter $yred_{gi}$ is a scaling factor for yield changed due to climate and technological change.

A new constraint on monthly water use has been included. Variable xm_{gm} in equation (8) is monthly water use in region g in month m. Three underlying assumptions need to be discussed. First, water is assumed to be interchangeable among crops within a region. Second, a farm group (or region) maximizes profits on a yearly basis, equalizing marginal revenue of water to its marginal cost every month. Third, a region or farm group selects the crop mix that maximizes profits within the region. In other words, the shadow value of water will be the same for all months and for all crops i in a region or farm group g. This assumes sufficient levels of water storage and internal water distribution capacity and flexibility.

The last constraint set in equation (9) is for regional water in which $b_{water,g}$ corresponds to that in the right hand side of equation 7 for water. The parameter "availwater" is used later to obtain shadow values of water by constraining water regionally, such that 0<availwater < 1. The constraint set assumes that yearly water is available in a limited amount for every region or group. Less realistically, it also implies that water is not re-traded across groups or regions under the basic calibration assumptions.

3.0 Model Innovations for Year 2050

In this study, modifications and assumptions for projections until 2050 follow Medellin-Azuara et al. (2007). Specifically, we consider land use projections (Landis and Reilly 2002), crop demand projections, and yield changes as a result of technological improvement (Brunke, Sumner et al. 2004).

3.0.1 Changes in Land Use

Urbanization and agricultural land conversion in this study follow estimates from Landis and Reilly (2002) for prime farming land, locally important farms, unique farms and grazing lands. Table 1 shows statewide and regional land use patterns by the year 2050. Most of the land conversion from agriculture occurs south of the Sacramento Valley, where population growth is rapid. A statewide reduction in agricultural land use close to 9 percent is expected by year 2050.

Table 1. Expected Changes in Land Area (adapted from Landis and Reilly 2002), and CALVIN-SWAP region crop areas (Medellin-Azuara et al. 2008).

	Urbanized Land			Agricultural Land*		
Region	Regional Total Area, Acre (ha)		% Change	CALVIN Regional Total Area, Acre (ha)		% Change
	2020	2050		2005	2050	
Northern California and Sacramento	1,337,465 (540,737)	1,663,876 (660,576)	22.2	3,567,180 (1,443,589)	3,285,691 (1,329,674)	-7.9
San Joaquin Valley and Tulare	646,381 (261,587)	1,044,333 (422,224)	61.4	2,987,800 (1,209,122)	2,700,680 (1,092,928)	-9.6
Southern California	2,550,040 (1,030,981)	3,442,696 (1,391,882)	35.0	933,400 (377,734)	876,328 (354,637)	-6.11
Statewide	4,534,516 (1,833,305)	6,120,905 (2,474,682)	35.0	7,488,380 (3,030,445)	6,762,699 (2,736,771)	-9.7

*Note: For agriculture Northern California includes CVPM regions 1 to 13, San Joaquin Valley and Tulare include regions 14 to 21. Southern California region includes all the Colorado River Basin and the South Coast.

3.0.2 Technological Change

Technological change by year 2050 is represented as increasing crop yields. This is calculated based on extrapolating current trends as detailed in "Future Food Consumption and Production in California Under Alternative Scenarios" (Brunke, Sumner et al. 2004). Current trends are detailed in table 2, below. Growth rates marked with an asterisk (*) are unavailable and, consequently, are set equal to the average log-linear growth rate of 1.2. We assume that the rate of yield increases will level out in the future and we cap the extrapolations and use a slower rate of technical change from 2020-2050. Specifically, we assume a log-linear growth rate of .25 for 2020-2050. Based

on the assumptions above the total rate of growth is extrapolated out and reported in Table 2 below.

Table 2. Technological Change Projection Summary

Technological Change by 2050		
Crop	**Log-Linear Annual Growth Rate**	**2050 Total % Yield Increase**
Alfalfa	1.2*	29.05
Citrus	1.17	28.47
Corn	1.01	25.42
Cotton	1.2*	29.05
Field	1.2*	29.05
Grains	1.2*	29.05
Grapes	0.9	23.37
Orchards	1.57	36.41
Pasture	1.2*	29.05
Rice	1.35	31.98
Sugar Beet	1.2*	29.05
Tomato	1.75	40.14
Truck	1.01	25.42

3.0.3 Shifts in Crop Demands for California

Over time, the demand for California crops, with the exception of global commodities in the Grain, Rice and Corn groups, is expected to increase with increasing population and incomes. As such, demands for crops in 2050 are changed to reflect population growth and income projections. This effect on crop demand is captured through the income elasticity of demand for California crops and population growth. In the absence of alternative information on long-term trends in world crop production, the proportion of California crops exported is assumed to remain constant through 2050.

An important determinant of future demand for many crops is future prices, since California is a price taker for many crop groups. In "Public Funding for Research into Specialty Crops" (2008) Alston and Pardey provide a comprehensive overview of agricultural research spending and the economic importance of specialty crops. Figure 3, below, reproduces figure 6 from Alston and Pardey (2008) detailing the price trends in livestock, field crops, and specialty crops from 1949 through 2004. Over this time average real crop prices have trended down, but the downward trend in specialty crops is much lower than that of field crops and livestock products. In nominal terms, panel a in figure 3 shows that specialty crop prices have increased substantially over the past 30 years.

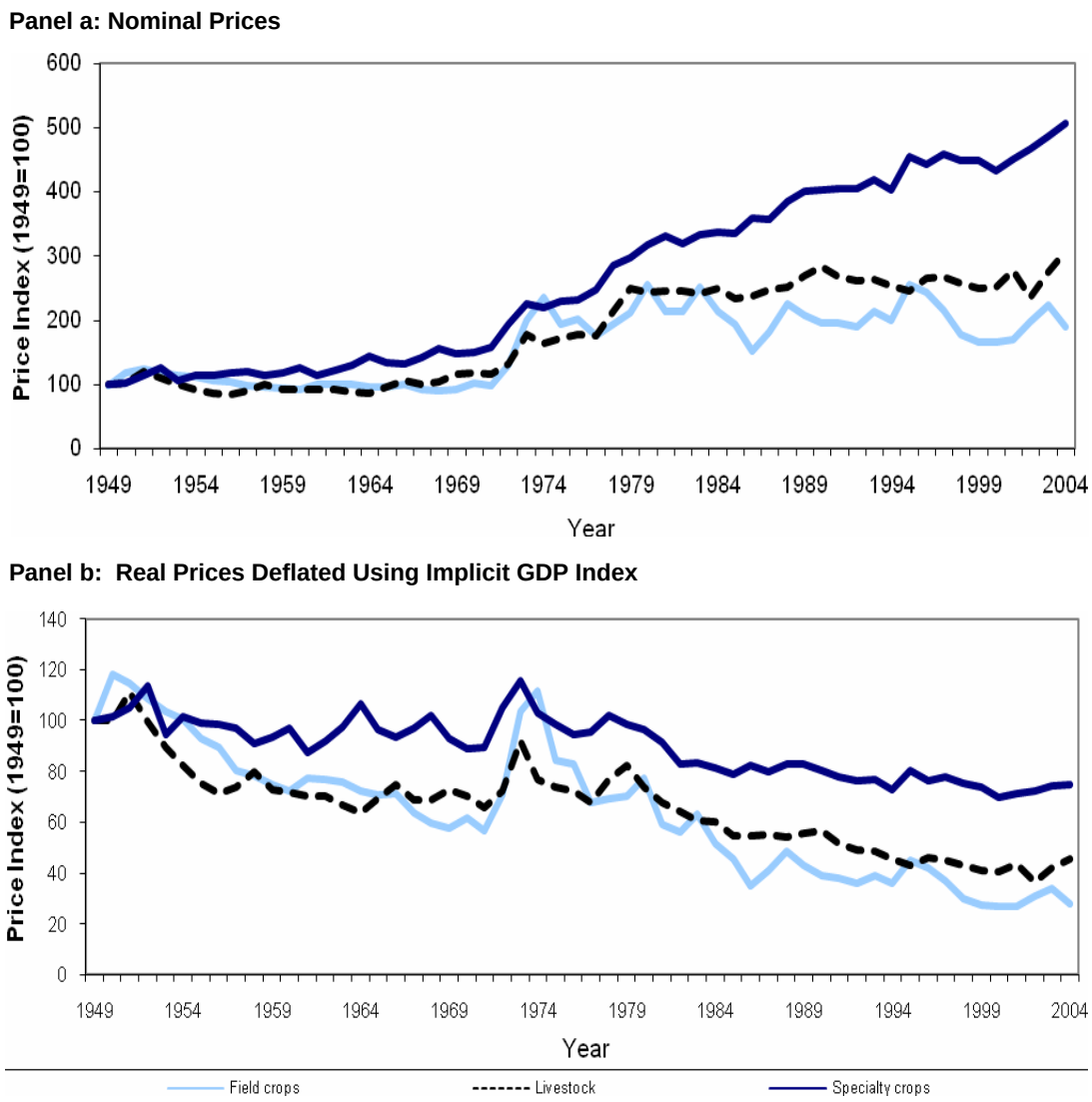

Figure 3: U.S. Prices of Specialty Crops, Field Crops, and Livestock, 1949-2004. Source: Alston and Pardey (2008)

Demand for California grain, rice, and corn is essentially perfectly elastic. There is no separate demand for these crop groups from California since they are global commodities and California production is a small proportion of national production. As such, California can be seen as a price taker implying that demand is equal to price, and shifts in demand can be directly related to changes in world prices. The only necessary information is long run projections of real prices. Forecasting long run prices for these crops is difficult with current conflicting evidence on the trends in agricultural prices. Over the last few years real prices have increased which is in stark contrast to the historical downward trend. To reconcile these differences for use in our analysis we assume that prices will continue to trend up for several years into the future and will eventually resume the downward trend. Specifically, we assume that prices will increase in accordance with the results of the World Bank in "Double Jeopardy:

Responding to High Fuel and Food Prices" (2008) which projects price increases (in real terms) out to 2015. At 2015 we assume that real prices will resume the historic downward trend. We quantify this effect using data from the Agricultural Issues Center at UC Davis which shows the real prices of Corn, Grain and Rice over the last 100 years. Using this data an exponential time trend regression is fit and used to project prices from 2015-2050. Results are summarized in Table 3, below.

Table 3. Real ($2005) Percent Changes in Price, Base 2005

Crop Group	% Change in Price by 2015 (Total)	% Change in Price 2015-2050 (per year)	% Shift in Demand Intercept (Total)
Rice	60%	-1.45%	-4.05%
Corn	48%	-0.67%	17.00%
Grain	40%	-1.58%	-19.88%

Since all other crop groups can't be considered global commodities the demand shift for all other crop groups is calculated using the following methodology. The United States population is expected to grow into the foreseeable future and this will generate increased food demands. We assume that one percent increases in population will lead to one percent increases in food demand, in essence assuming a "population elasticity" of unity. According to the 2000 Census (http://www.census.gov/population/www/projections/projectionsagesex.html) the population in the United States is projected to increase by approximately 5% every five years until 2030. These projections are based on the 2000 census and include five year interval population projections until 2030. We use US population growth as a proxy for total population generated sources of increased California crop demand. Using the census results we assume 5% growth every five years from present to 2020. From 2020-2050 we reduce the rate of population growth to 2.5%, half of current projections. At these growth rates the US population is expected to increase from approximately 290 million to 415 million by 2050.

In addition to increasing population, real incomes are expected to increase. According to the Bureau of Labor Statistics (http://www.bls.gov/opub/mlr/2007/11/art2full.pdf) average incomes in the United States have increased 6.9% annually between 1982-1992, 5.6% annually between 1992-2002 and are projected to increase 5.4% annually until 2012, nominally. Using this projection and extrapolating out to 2050 we assume incomes increase 5.4% on average annually. With 3.4% average historical inflation this is approximately 2% real annual income growth. Following the method for population expansion, we assume the real income growth rate is halved in 2020 to 1% real annual growth. Extrapolating out, average US annual income is expected to increase from approximately 36 thousand to 90 thousand annually in real terms.

We assume that shifts in demand are solely a result of increasing incomes and population and that California's export share grows in proportion to the domestic market. Income and population increases can be directly mapped to increases in

quantity through respective elasticity estimates. Furthermore, for simplicity in calculations, we assume a perfectly elastic long run supply of each crop. As such, our estimates represent an upper bound on the demand shifts. Crop demands are linear and we are interested in parallel shifts of demand thus it is assumed that the increase in quantity produces a change in price that is constant at every quantity along the demand schedule.

Our calculations follow the methodology of Muth (1964), a seminal paper in equilibrium displacement models. Specifically, we calculate that the percentage shift in the intercept of the demand curve as a result of increasing incomes as: $\alpha = \frac{-\varepsilon_i}{\eta} d\ln(I)$ where α represents the percentage shift along the price axis, ε_i is income elasticity of crop demand, η is the own price elasticity of demand and $d\ln(I)$ is the change in log income over the relevant range (2005-2050 in our analysis). This equation is calculated separately for each crop and the procedure is repeated for changing population. As a proxy for "population elasticity" we assume unity, one percent increase in population leads to a proportional percentage increase in demand. The shifts from income changes and population are combined to determine the overall shift in demand. The details and derivation of this result can be found in Muth (1964), elasticity estimates and data are summarized in Table 4 below. It should be noted that the literature on Income Elasticity estimates is sparse and many, including authors of some studies used here, caution that these estimates often capture other unintended effects. As such, when reliable income elasticity estimates aren't available 0.2 is assumed for low value and 0.5 is assumed for high value crops, these are denoted by asterisks (*). Most of these estimates and references to others used can be found in Green, Howitt and Russo "Estimation of Supply and Demand Elasticities of California Commodities" (2006).

Table 4. Elasticities by SWAP Crop Group

Crop Group	Income Elasticity	Price Elasticity (D)
Alfalfa	0.2*	-0.107
Citrus	0.5*	-1.25
Corn	0.2*	-0.5
Cotton	0.05	-0.95
Field	0.2*	-0.86
Grain	0.2	-0.38
Orchards	0.51	-1.2
Grapes	0.51	-0.28
Sugar beet	0.254	-0.042
Tomato	0.89	-0.25
Truck	0.99	-0.16

Using the Muth results and the elasticity estimates outlined above, the respective demand shifts are calculated. Based on the assumptions detailed above, calculated

demand shifts are presented in table 5 below. Two exceptions are denoted by asterisks (*) in the table below. First, alfalfa is not calculated independently. Since alfalfa demand is largely tied to the expansion of livestock and substitution between grain and alfalfa instead it is pegged to the field crop group which is estimated at 3.34%. Similarly, due to the reduction in sugar beet processing facilities and other exogenous factors we expect the level of California sugar beet production to be zero by 2050. All results are detailed in Table 5, below.

Table 5. Demand Shifts

Crop Group	% Shift in Demand Intercept
Alfalfa*	3.34%
Citrus	3.63%
Corn	5.74%
Cotton	2.14%
Field	3.34%
Grain	7.56%
Orchards	3.83%
Grapes	16.42%
Sugar Beet*	0.00%
Tomato	26.86%
Truck	45.45%

3.0.4 Regional Crop Data in SWAP

An example of a region in SWAP is shown in figure 4, which corresponds to CVPM 19. This region is distinct because it is within a single county (Kern) and has been used as a pilot for ongoing research on salinity south of the San Joaquin Delta (Howitt et al. 2008). Kern is within the service area of the State Water Project. Land use by DWR is at http://www.sjd.water.ca.gov and table 6 shows agricultural land use at CVPM 19.

Table 6. Land use by Crop Group in CVPM 19
(Source DWR Land use surveys)

Crop	Base Acres (2005)
Alfalfa	60,929
Citrus	2,399
Corn	16,469
Cotton	50,995
Field Crops	75,644
Grains	15,675
Grapes	6,199
Orchards	51,890
Pasture	2,455
Rice	15,607
Tomato	2,196
Truck Crops	57,363
Total	**357,819**

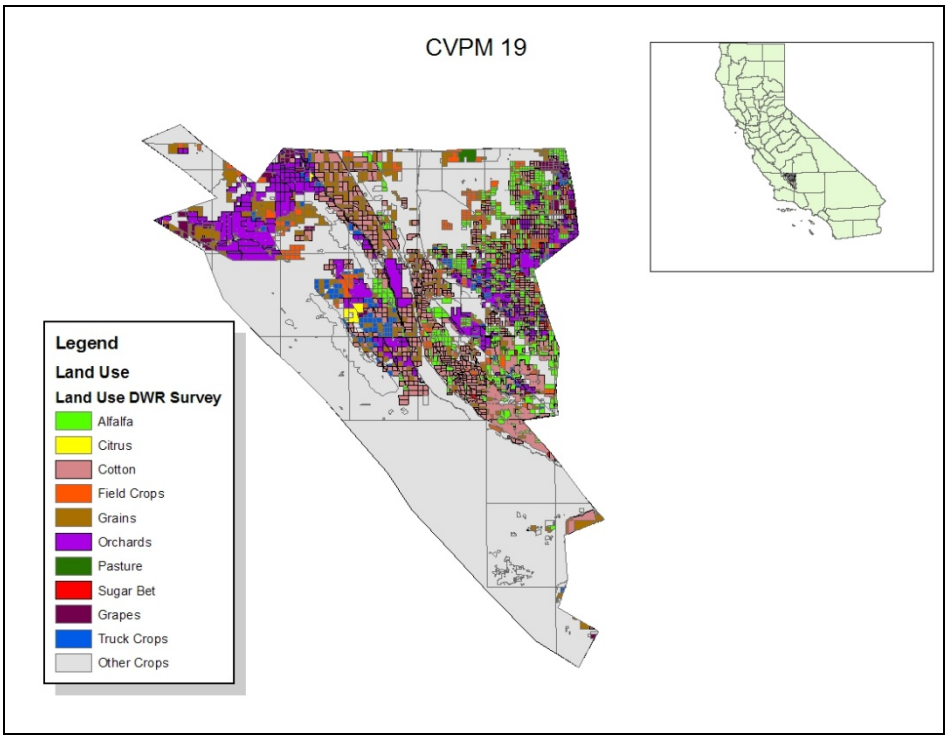

Figure 4. Land Use in CVPM 19. Source: DWR Land Use Surveys.

3.0.5 Policy Simulations

The use of inputs is based on Medellin-Azuara et al. (2007). Inputs to the production function in the model include water, labor, land and supplies. The last group of inputs was normalized to use per acre and comprises farm budgets on fertilizer pesticides and

all other inputs. A constraint on corn silage was imposed on the optimization program to account for the feeding needs of dairy farm operations. The total California dairy herd is assumed to decline slightly from 1.503 million cows in 2005 to 1.25 million in 2050. This reduction in dairy cows in the central valley is based on restrictions that result from current dairy waste disposal technology, costs, and projected regulation (Howitt et al 2008). Corn used for silage tends to displace marginal field crops and cotton.

Analysis of agricultural activity for the year 2050 in SWAP is based on a set of algorithms that incorporate the 2050 adjustments discussed in the model description section. First, the land use from a linear programming program was constrained to the *observed* values of land use from DWR land use surveys and average production input use in the base years. Second, a PMP exponential cost function was calibrated so that, in the base case, input use from a non-linear optimization problem calibrates to observed values. The parameters for the CES production function are derived from the first order profit maximization conditions for each crop and region. Given these parameters, the calibrated non-linear program is used to simulate the economic effects of changes in crop yield parameters and policies.

4.0 Results

This section details the results of the SWAP model runs. Since it is unwieldy to consider results from 26 separate regions results are aggregated, as discussed above, into a total of ten regions. Region specific findings are highlighted and discussed in addition to universal findings. All results are discussed as changes between the base year of 2005 and 2050 and, more importantly; all results are reported in terms of the ten aggregate regions and DWR crop groupings. The details of the aggregation/extrapolation procedure can be found in section 2.0, above.

We detail land use changes, water use changes and revenue and production changes between 2005 and 2050. Results are broken down by categories and overall results can be summarized as follows. There is a total reduction in irrigated acres by 2050 of about 9% statewide. Of the remaining irrigated acres, water use per acre increases by about 1% but statewide total agricultural water use decreases. Production increases statewide by 25% which, combined with changing prices, leads to a 20% increase in farmer revenues. These results are broken down and discussed in more detail in what follows.

4.0.1 Land Use Changes

Changes in land use by region and crop are summarized using 2005 as the base year. These changes are driven by the interaction between three factors: changing resources, changing technology and shifting demand. Changing resources, like land, are captured using the Landis and Reilly (2002) land use change results. Changing technology is quantified using the results of Brunke et al (2004) where changes in yield due to

technology are estimated. Finally, shifts in demand are assumed to come from population changes in the United States and rising real incomes. These effects are quantified using Muth (1964) and combined to determine the aggregate demand shift by crop.

There is an overall land use reduction of 9.7% between 2005 and 2050 under the scenario and assumptions presented in this model. Results show that there is significant variation in crop acreage changes between crops. This is expected as the interaction of driving factors creates comparative advantages for some crops which forces others out of production. The largest reductions in cropping acres are seen in pasture, grain and corn with reductions of 65%, 22%, and 19%, respectively. One surprising result is a minimal increase in the cropped acres of nuts and other deciduous crops. This is a function of technological change and increased efficiency in the industry as will be discussed below. As detailed in the previous section, corn acreage is constrained to a lower bound that is consistent with the feeding needs of the dairy industry and, as such, changes to the dairy industry in the future would have significant implications for corn acres. Total changes in crop acres between 2005 and 2050 across all regions are summarized in table 7 and presented graphically in figure 5, below.

Table 7. Crop Acreage Change (Statewide) 2005 to 2050.

Crop	Acres Base (2005)	Acres 2050	% Change
Grain	484,080	377,403	-22.04
Rice	575,020	572,476	-0.44
Cotton	692,670	627,765	-9.37
Corn	685,780	555,625	-18.98
Dry Bean	69,150	62,249	-9.98
Safflower	50,920	48,514	-4.72
Other Field	516,960	423,035	-18.17
Alfalfa	1,081,680	1,011,746	-6.47
Pasture	822,140	287,513	-65.03
Pr Tom	303,340	319,497	5.33
Fr Tom	46,000	48,956	6.43
Cucurbits	117,550	125,039	6.37
Onion Garlic	71,080	75,739	6.55
Potato	38,910	41,280	6.09
Other Truck	906,150	964,579	6.45
Almds./Pistachios	799,660	806,518	0.86
Other Deciduous	633,790	639,431	0.89
Subtropical	436,050	417,334	-4.29
Vine	867,310	899,238	3.68
Total	**9,198,240**	**8,303,937**	**-9.72**

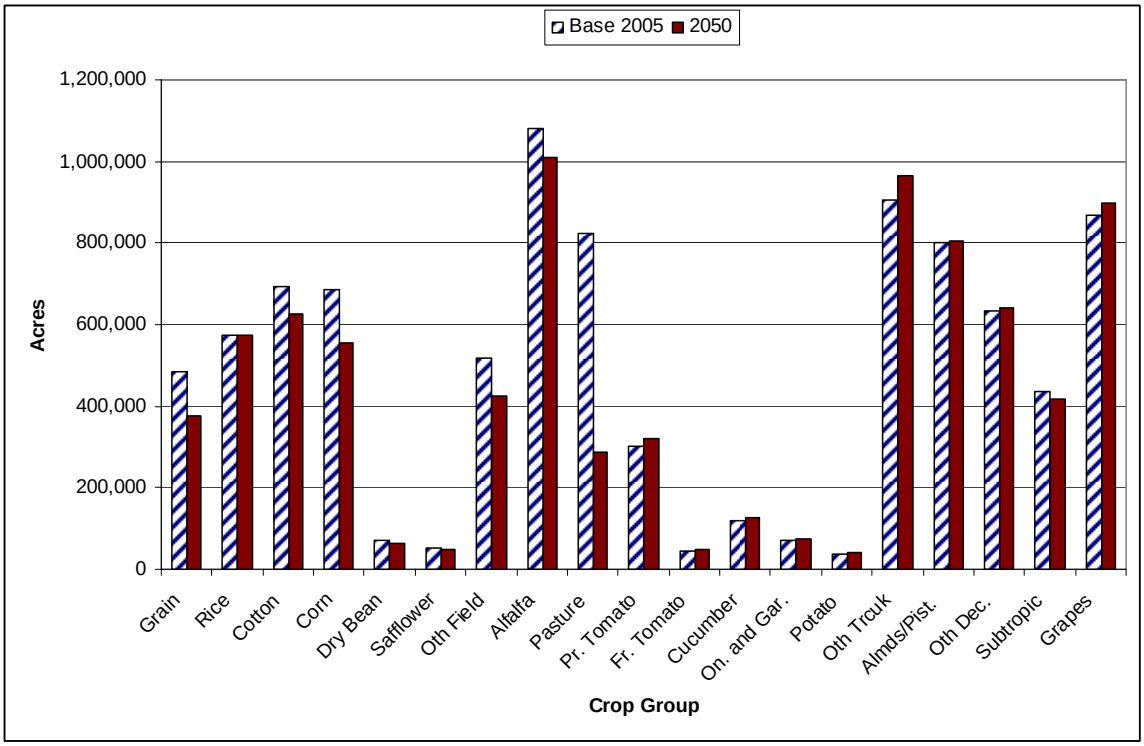

Figure 5. Land Use Changes (Statewide) 2005 – 2050

For further clarity we break down crop acreage changes by region. Results have been aggregated, as detailed in section 1.0, and summarized by ten larger hydrologic regions. These results are summarized in table 8, below. Model simulations indicate that the most affected regions are South Lahontan and North Lahontan with reductions in acres of 33% and 36%, respectively. Again, this is a result of the interaction of crop demand, urban land conversion, technology and inputs. The San Francisco Bay and Central Coast regions see slight increases in cropped acres of 1.2% and 4.8%, respectively. Again, we remind the reader that DWR regions are extrapolations of neighboring SWAP regions.

Table 8. Changes in Acres by Region 2005 to 2050

Region	Acres Base (2005)	Acres 2050	% Change
North Coast	327,530	245,557	-25.0%
San Francisco Bay	90,750	91,832	1.2%
Central Coast	664,120	695,998	4.8%
South Coast	242,460	194,363	-19.8%
Sacramento River	1,920,870	1,707,137	-11.1%
San Joaquin River	2,010,510	1,817,201	-9.6%
Tulare Lake	3,115,000	2,845,048	-8.7%
North Lahontan	128,440	81,819	-36.3%
South Lahontan	65,840	43,816	-33.5%
Colorado River	632,720	581,166	-8.1%
Totals	**9,198,240**	**8,303,937**	**-9.7%**

As a final step we break down crop acreage changes by region and by crop grouping in table 9. This allows us to draw regional inferences about cropping patterns that result by 2050. The most affected crops, in terms of land use change, include pasture, corn and grain. North and South Lahontan show significant reductions in total acres of these crops. This is, in part, a function of using neighboring SWAP regions to extrapolate results. We caution the reader that reductions in pasture and, to a lesser extent, grain in these regions are probably overstated as they reflect comparative advantages in other regions. Thus changes in these regions should be viewed as upper bounds in the plausible scenario we present.

Table 9. Percent Changes in Acres by Region and Crop 2005 to 2050

Crop Group	North Coast	S.F. Bay	Central Coast	South Coast	Sac. River	San Joaquin River	Tulare	North Lahontan	South Lahontan	Colo. River	Total
Grain	-38.09	-38.09	-14.66	-19.48	-38.09	-14.66	-15.57	-38.09	-15.57	-2.88	**-22.04**
Rice	N/A	N/A	N/A	N/A	-0.40	-2.17	N/A	-0.40	N/A	N/A	**-0.44**
Cotton	N/A	N/A	N/A	N/A	-59.81	-5.74	-9.98	N/A	N/A	-1.64	**-9.37**
Corn	-17.56	-17.56	-13.94	-100.0	-17.56	-13.94	-23.91	N/A	-23.91	1.21	**-18.98**
Dry Bean	-0.19	-0.19	-3.01	-42.91	-0.19	-3.01	-38.77	-0.19	N/A	0.53	**-9.98**
Safflower	-0.19	-0.19	-3.01	N/A	-0.19	-3.01	-38.77	N/A	N/A	0.53	**-4.72**
Other Field Crops	-0.19	-0.19	-3.01	-42.91	-0.19	-3.01	-38.77	N/A	-38.77	0.53	**-18.17**
Alfalfa	-7.33	-7.33	-3.46	-90.97	-7.33	-3.46	-8.90	-7.33	-8.90	-1.52	**-6.47**
Pasture	-51.48	-51.48	-95.32	-100.0	-51.48	-95.32	-100.0	-51.48	-100.0	-65.10	**-65.03**
Pr. Tomato	N/A	5.64	5.84	-72.25	5.64	5.84	4.82	N/A	N/A	N/A	**5.33**
Fr. Tomato	N/A	N/A	7.56	-2.30	5.63	7.56	6.89	N/A	N/A	5.61	**6.43**
Cucumber	5.63	5.63	7.56	-2.30	5.63	7.56	6.89	N/A	6.89	5.61	**6.37**
Onion and Garlic	5.63	5.63	7.56	-2.30	5.63	7.56	6.89	5.63	6.89	5.61	**6.55**
Potato	5.63	N/A	7.56	-2.30	N/A	7.56	6.89	N/A	6.89	5.61	**6.09**
Other Truck Crops	5.63	5.63	7.56	-2.30	5.63	7.56	6.89	5.63	6.89	5.61	**6.45**
Almnds/Pistachios	N/A	1.24	0.94	-15.19	1.24	0.94	0.60	N/A	0.60	2.86	**0.86**
Other Deciduous	1.24	1.24	0.94	-15.19	1.24	0.94	0.60	N/A	0.60	2.86	**0.89**
Subtropical Crops	2.14	2.14	0.57	-17.25	2.14	0.57	1.22	N/A	1.22	1.91	**-4.29**
Grapes	4.76	4.76	3.60	-7.89	4.76	3.60	3.29	N/A	3.29	3.92	**3.68**
Total	**-25.03**	**1.19**	**4.80**	**-19.84**	**-11.13**	**-9.61**	**-8.67**	**-36.30**	**-33.45**	**-8.15**	**-9.72**

4.0.2 Water Use Changes

It is important to consider changes in applied water over the time horizon of the study. Farmers maximize profits by making adjustments at the intensive margin (inputs per acre) as well as the extensive margin (changes in crops planted). Changing yields due to technological change, changing crop market demands and the resulting changes in price are all contributing and interrelated factors that influence grower decisions at all margins. Thus water use is affected at two levels, application per acre of planted land and total land that water is applied to. The results and implications of these decisions warrant careful consideration and discussion.

The statewide average water use by crop is shown in table 10, below. The largest reductions in total water use are in pasture, corn and grain with reductions of 66%, 11% and 21%, respectively. These are also the crops that were shown to have the largest reduction in planted acres. Thus a large contribution to reductions in total water use comes from land that was previously in water intensive crops going out of production. Results also indicate that some higher value crops see an increase in total water use. This is in response to increasing demand and the comparative advantage of growing these crops relative to other locations.

More importantly, consider the total water use by crop (statewide). Results indicate that there is a 8.6% reduction in water used, *for agriculture,* under the plausible scenario presented in this report. However, this does not mean that there is an 8.6% increase in state water available for other uses. As detailed in table 1, there is a significant increase in urbanized land of approximately 600,000 acres and, as detailed in table 7, there is about 1.2 million fewer planted acres in 2050. Assuming that urban acres use approximately the same amount of water as agricultural acres about half of the reduction in water will go to urban users. Finally, while table 10 shows there will be significant reduction in applied water this does not mean that this quantity is available for transfer to other activities. Any reallocation of water must be based on net consumptive use not the applied use. We consider the details of this more below in section 4.0.4, input productivity.

It is also important to consider likely changes in water use per acre of irrigated land. To highlight and discuss this, we break down water use changes at the intensive margin (water use per acre) by crop and region in table 11, below. Results show that changes in water use per acre vary by crop and by region. To highlight the importance of intensive versus extensive margin adjustments, when considering total water use changes, consider pasture and grain (both shown to have reductions in total water use). There are reductions in water use per acre in grain across all regions, in the order of about 3% and increases in water use per acre for pasture, around 4%. Thus the total reduction in water use is driven by extensive margin changes for pasture and intensive margin changes for grain. Again, we caution the reader that pasture and grain results in DWR regions are likely overstated due to extrapolating based on other SWAP regions. Table 12 breaks down changes in water use per acre by taking a weighted average over crops

based on 2005 acres. Overall, there is an average (weighted) 1.16% increase in applied water per acre by 2050. As such, it must be that the entire reduction in total water use is completely driven by agricultural land going out of production and changes in the cropping pattern as farmers have, on average, slightly increased water application per acre on the remaining land to accommodate the increased production per acre, despite the increases in production per unit water that we project will occur over the next 45 years.

Table 10: Total Water Use by Crop (acre-feet)

Crop Group	Base (2005) Water Use	2050 Water Use	% Change
Grain	509,095	401,873.1	-21.06%
Rice	2,866,023	2,836,463	-1.03%
Cotton	2,010,312	1,829,582	-8.99%
Corn	1,900,355	1,686,332	-11.26%
Dry Bean	157,037	147,227.6	-6.25%
Safflower	50,970	48,341.29	-5.16%
Other Field	1,328,124	1,149,697	-13.43%
Alfalfa	4,994,222	4,756,077	-4.77%
Pasture	3,128,806	1,055,984	-66.25%
Pr Tom	740,364	868,081.8	17.25%
Fr Tom	88,686	106,212.2	19.76%
Cucurbits	214,560	255,992.7	19.31%
Onions and Garlic	187,570	226,302.8	20.65%
Potato	74,199	88,447.52	19.20%
Other Truck	1,396,704	1,679,420	20.24%
Almds/Pistachio	2,722,654	2,767,625	1.65%
Other Deciduous	2,067,971	2,072,943	0.24%
Subtropical	1,211,702	1,180,855	-2.55%
Vine	1,469,924	1,608,634	9.44%
Total	**27,119,278**	**24,766,092**	**-8.68%**

Table 11 Water Use Percentage Change at the Intensive Margin (per acre use) 2005 to 2050

Crop Group	North Coast	S.F. Bay	Central Coast	South Coast	Sacramento River	San Joaquin	Tulare Lake	North Lahontan	South Lahontan	Colo. River
Alm/Pist	-4.72	-4.72	2.03	3.14	-4.72	2.03	1.71	-4.72	1.71	2.31
Alfalfa	-1.74	-1.74	0.46	4.10	-1.74	0.46	1.42	-1.74	1.42	3.55
Corn	9.35	9.35	10.45	N/A	9.35	10.45	8.94	9.35	8.94	12.27
Cotton	-6.42	-6.42	-1.83	N/A	-6.42	-1.83	0.46	-6.42	0.46	1.26
Cucurb	6.03	6.03	13.13	14.16	6.03	13.13	14.00	6.03	14.00	14.33
DryBean	2.53	2.53	5.10	7.23	2.53	5.10	6.35	2.53	6.35	6.58
Fr Tom	6.03	6.03	13.13	14.16	6.03	13.13	14.00	6.03	14.00	14.33
Grain	-2.34	-2.34	-4.81	0.52	-2.34	-4.81	-1.37	-2.34	-1.37	-0.03
On Gar	6.03	6.03	13.13	14.16	6.03	13.13	14.00	6.03	14.00	14.33
Oth Dec	-4.72	-4.72	2.03	3.14	-4.72	2.03	1.71	-4.72	1.71	2.31
Oth Fld	2.53	2.53	5.10	7.23	2.53	5.10	6.35	2.53	6.35	6.58
Oth Trk	6.03	6.03	13.13	14.16	6.03	13.13	14.00	6.03	14.00	14.33
Pasture	3.46	3.46	7.90	N/A	3.46	7.90	N/A	3.46	N/A	4.67
Potato	6.03	6.03	13.13	14.16	6.03	13.13	14.00	6.03	14.00	14.33
Pr Tom	6.25	6.25	11.59	15.14	6.25	11.59	15.51	6.25	15.51	N/A
Rice	-0.69	-0.69	2.82	N/A	-0.69	2.82	7.10	-0.69	7.10	N/A
Safflwr	2.53	2.53	5.10	7.23	2.53	5.10	6.35	2.53	6.35	6.58
Subtrop	0.72	0.72	-1.08	4.66	0.72	-1.08	-0.16	0.72	-0.16	3.13
Vine	1.96	1.96	7.18	10.93	1.96	7.18	5.34	1.96	5.34	7.08

Table 12 Weighted* Total Water Use per Acre 2005 - 2050

Crop Group	Use per Acre (2005)	Use per Acre (2050)	% Change
Al/Pist	3.40	3.43	0.79%
Alfalfa	4.62	4.70	1.81%
Corn	2.77	3.04	9.52%
Cotton	2.90	2.91	0.42%
Cucurb	1.83	2.05	12.16%
Dry Bean	2.27	2.37	4.15%
Fr Tom	1.93	2.17	12.53%
Grain	1.05	1.06	1.25%
On Gar	2.64	2.99	13.23%
Oth Dec	3.26	3.24	-0.64%
Oth Fld	2.57	2.72	5.79%
Oth Trk	1.54	1.74	12.96%
Pasture	3.81	3.67	-3.49%
Potato	1.91	2.14	12.36%
Pr Tom	2.44	2.72	11.32%
Rice	4.98	4.95	-0.59%
Safflwr	1.00	1.00	-0.45%
Subtrop	2.78	2.83	1.82%
Vine	1.69	1.79	5.55%
Weighted Average	**2.95**	**2.98**	**1.16%**

* Weighted by crop acres in base year 2005. i.e. proportion of acres*use per acre

4.0.3 Revenue and Production Changes

The results show that there is an overall reduction in cropped acres and a corresponding overall reduction in water use even though farmers increase water use per acre. An interesting finding is that total farmer revenues are expected to increase by about 20%. This indicates that technological advances and changes in prices and cropping patterns are able to more than offset the lost revenues from reducing farmed acres. The crops with the largest gains in total revenue are vine crops and tomatoes, largely driven by the increasing demand and price. Crops that see the largest reductions in revenue include pasture and grain. Total changes in revenue are summarized by crop in table 13, below.

Table 13 Revenue (in $2005)

Crop Group	Base Revenue (2005)	Revenue 2050	% Change
Grain	$411,566,373	$344,303,285	-16.34%
Rice	$723,028,240	$925,297,691	27.98%
Cotton	$796,098,144	$818,068,755	2.76%
Corn	$386,497,424	$469,680,647	21.52%
DryBean	$62,253,313	$76,631,527	23.10%
Safflwr	$189,101,617	$166,023,671	-12.20%
Oth Fld	$432,669,803	$489,972,621	13.24%
Alfalfa	$994,914,372	$1,135,209,637	14.10%
Pasture	$350,993,811	$150,907,043	-57.01%
Pr Tom	$661,636,038	$1,212,080,545	83.19%
Fr Tom	$227,947,436	$227,947,436	0.00%
Cucurb	$569,563,053	$569,563,053	0.00%
On Gar	$376,602,958	$376,602,958	0.00%
Potato	$195,970,012	$195,970,012	0.00%
Oth Trk	$4,691,411,030	$4,691,411,030	0.00%
Al Pist	$3,790,069,689	$4,540,997,673	19.81%
Oth Dec	$3,004,173,707	$3,599,836,190	19.83%
Subtrop	$2,626,652,362	$3,078,809,373	17.21%
Vine	$6,051,832,337	$8,949,147,640	47.88%
Total	**$26,542,981,720**	**$32,018,460,787**	**20.63%**

Revenues were also extrapolated to all the regions specified by DWR. Large increases in revenue are shown in the coastal regions in wine grapes. The largest reductions in revenue are seen in pasture, with the Sacramento River region being the least affected with 32% reductions in pasture revenue. Overall revenue reductions are shown in North Lahontan, South Lahontan, Colorado River, North Coast and the South Coast regions. These losses are relatively small ranging from 2% to 20%. Revenues are shown to increase overall in the remaining six regions, some by as much as 40% or more. The overall percentage change in revenue by crop and region is summarized in table 14, below.

Table 14 Percentage Change in Revenues 2005 to 2050

Crop Group	North Coast	S.F. Bay	Central Coast	South Coast	Sacramento River	San Joaquin	Tulare Lake	North Lahontan	South Lahontan	Colo. River
Grain	-38.79	-38.79	-14.85	-11.21	-38.79	-14.85	-10.99	-38.79	-10.99	5.54
Rice	N/A	N/A	N/A	N/A	28.03	25.56	N/A	28.03	N/A	N/A
Cotton	N/A	N/A	N/A	N/A	-54.56	6.84	1.99	N/A	N/A	11.03
Corn	28.57	28.57	33.18	-100.00	28.57	33.18	16.54	N/A	16.54	-100.00
DryBean	33.85	33.85	31.28	-24.78	33.85	31.28	-15.61	33.85	N/A	35.60
Safflwr	-5.51	-5.51	-9.82	N/A	-5.51	-9.82	-42.72	N/A	N/A	-4.81
Oth Fld	33.85	33.85	31.28	-24.78	33.85	31.28	-15.61	N/A	-15.61	35.60
Alfalfa	11.67	11.67	17.81	-89.01	11.67	17.81	11.85	11.67	11.85	20.48
Pasture	-32.29	-32.29	-93.78	-100.00	-32.29	-93.78	-100.00	-32.29	-100.00	-100.00
Pr Tom	N/A	83.41	85.07	-100.00	83.41	85.07	82.01	N/A	N/A	N/A
Fr Tom	N/A	N/A	0.00	0.00	0.00	0.00	0.00	N/A	N/A	0.00
Cucurb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	N/A	0.00	0.00
Onin/Gar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Potato	0.00	N/A	0.00	0.00	N/A	0.00	0.00	N/A	0.00	0.00
Oth Trk	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Almd/Pist	N/A	20.20	19.88	-1.61	20.20	19.88	19.58	N/A	19.58	22.21
Oth Dec	20.20	20.20	19.88	-1.61	20.20	19.88	19.58	N/A	19.58	22.21
Subtrop	26.24	26.24	17.30	-0.02	26.24	17.30	22.79	N/A	22.79	24.94
Vine	54.86	54.86	49.29	30.86	54.86	49.29	45.42	N/A	45.42	45.34
Wtd. Avg.	**-3.22**	**42.47**	**7.20**	**-8.56**	**13.08**	**16.57**	**13.83**	**-17.88**	**-23.25**	**-1.83**

Results of the model runs show that total production (in tons) across all crops statewide increases by a weighted average of 25% by 2050. Since the production functions in the SWAP model are calibrated based on SWAP data we are unable to disaggregate and report results by DWR crop grouping. As such, results are reported by SWAP crop grouping. The details of the crop groupings can be found in section 2.0.

Table 15, below, summarizes total production (in tons) by SWAP crop grouping between 2005 and 2050. Results show that pasture and rice have the largest reductions in production of 73% and 10%, respectively. Orchard, citrus and grapes show the largest increases in statewide total production. This is expected as these crops are high value and the increasing prices, demand and technology allow farmers to capture these profits. An important observation is that total irrigated acres are reduced and total productivity is increased, driven largely by technological innovations.

Table 15 Statewide Production (in Tons)

SWAP Crop Group	Production Base (2005)	Production 2050	% Change
Alfalfa	7,205,357	8,765,437	21.65%
Citrus	5,736,829	7,015,605	22.29%
Corn	3,833,420	4,081,845	6.48%
Cotton	464,089	465,885	0.39%
Field	4,332,047	4,872,246	12.47%
Grain	1,344,257	1,427,571	6.20%
Grape	5,679,381	7,337,139	29.19%
Orchard	2,432,940	3,348,122	37.62%
Pasture	2,776,513	745,134	-73.16%
Rice	1,478,215	1,320,184	-10.69%
Tomato	13,065,574	19,703,259	50.80%
Truck Crops	14,739,425	19,783,609	34.22%
Total	**63,088,048**	**78,866,038**	**25.01%**

For further clarity the percentage changes in production by region are summarized in table 16, below. The weighted average is calculated based on 2005 acres and results are by SWAP crop group. Results show that, on average, (weighted) South Lahontan region shows decreases in total production of 23%. All other regions show percentage increases in total production, some as high as 20%. The largest reductions are in Pasture across basically all regions. Higher value crops show increases in production that vary by region.

Table 16 Percent Change in Crop Production (2005 to 2050) by Region

SWAP Crop Group	North Coast	S. F. Bay	Central Coast	South Coast	Sacramento River	San Joaquin River	Tulare Lake	North Lahontan	South Lahontan	Colorado River
Alfalfa	19.1	19.1	24.9	-88.2	19.1	24.9	18.4	19.1	18.4	28.8
Citrus	31.4	31.4	29.2	3.8	31.4	29.2	30.2	31.4	30.2	31.2
Corn	7.4	7.4	13.1	-100.0	7.4	13.1	0.2	7.4	0.2	30.7
Cotton	-56.4	-56.4	4.2	N/A	-56.4	4.2	-0.2	-56.4	-0.2	8.5
Field	30.1	30.1	27.1	-27.0	30.1	27.1	-18.5	30.1	-18.5	31.5
Grains	-18.4	-18.4	9.6	4.0	-18.4	9.6	10.0	-18.4	10.0	25.2
Grapes	31.0	31.0	29.8	16.4	31.0	29.8	28.8	31.0	28.8	29.3
Orchards	38.1	38.1	37.9	15.9	38.1	37.9	37.6	38.1	37.6	40.3
Pasture	-36.3	-36.3	-94.1	-100.0	-36.3	-94.1	-100.0	-36.3	-100.0	-54.0
Rice	31.9	31.9	30.5	N/A	31.9	30.5	-56.2	31.9	-56.2	N/A
Tomato	50.4	50.4	51.5	-60.3	50.4	51.5	50.7	50.4	50.7	N/A
Truck	35.0	35.0	37.2	24.5	35.0	37.2	36.5	35.0	36.5	34.1
Weighted Average	**15.01**	**15.01**	**16.72**	**-23.10**	**15.01**	**16.72**	**5.19**	**15.01**	**5.19**	**19.96**

4.0.4 Land and Water Productivity

Comparing tables 7, 10, 13 and 15 we see interesting trends of a 9.7% reduction in land use, a 8.9% reduction in water use coupled with a 25% increase in the quantity produced and a 20% increase in revenue. These seemingly contradictory results can be explained by the change in productivity per unit land and water, and the price of effect of increased production. Given the downward trend in some commodity crop demands and the normal price effect for high-value crops, the ratio between increases in production and revenue are expected.

Table 17 Land and Water Productivity Changes 2005-2050

Land	Yield/acre		% change
SWAP Crop Group	Base 2005	2050	
Alfalfa	6.66	11.40	71.08%
Citrus	13.16	17.93	36.28%
Corn	5.59	8.92	59.54%
Cotton	0.67	0.79	18.10%
Field	6.33	8.45	33.53%
Grain	2.78	3.98	43.21%
Grapes	6.55	8.47	29.36%
Orchard & Nuts	1.70	2.37	39.38%
Pasture	3.38	1.95	-42.18%
Rice	2.57	2.33	-9.38%
Tomatoes	43.07	61.02	41.67%
Truck crops	12.49	20.32	62.64%

Water	Yield/AcFt		
SWAP Crop Group	Base 2005	2050	% change
Alfalfa	4.62	6.18	25.33%
Citrus	2.78	3.02	7.92%
Corn	2.77	3.68	24.79%
Cotton	2.90	3.11	6.60%
Field	2.24	2.33	3.82%
Grain	1.05	1.12	6.06%
Grapes	1.69	1.86	8.74%
Orchard & Nuts	3.34	3.42	2.28%
Pasture	3.81	2.77	-37.53%
Rice	4.98	5.01	0.42%
Tomatoes	0.29	0.33	11.12%
Truck crops	2.22	3.20	30.84%

Table 17 shows that the changes in productivity per acre vary widely between crops. With the exception of rice and pasture, all crops show very significant productivity increases. There are significant differences between land and water productivity, for example alfalfa has a 71% increase in productivity per unit land but 25% increase in production per unit water. This suggests that, given the relative cost of water in the production of alfalfa, land productivity has taken precedence over water productivity.

Similarly, truck crops show a much higher increase in productivity per unit land of 62.6% and a water productivity gain of 30 %, less than half the land productivity gain. Given the relatively low proportion of truck crop production costs that water represents, and the potential for multiple cropping with truck crops, these results are not surprising. In summary, the land and water productivity results highlight the difficulties of generalizing water productivity on a per acre basis, or over all irrigated crops.

Finally, while table 10 shows there will be a significant 8.7% reduction in applied water this does not mean that this quantity is available for transfer to other activities. First, any reallocation of water must be based on net consumptive use not the applied use. We have not calculated the net consumptive use in table 17. Second, urbanization in the Central Valley from 2005 to 2050 is projected to require the conversion of an approximate additional 600,000 acres of irrigated land. New urban development in the central and southern valley will, on average, require 1.14 million acre feet of water for urban use. We note that this is about 50% of the reduction of applied water in agriculture. Thus the net water available for increased environmental or agricultural use will be substantially less than the reduction in applied water use shown in table 10.

4.1 Model Limitations and Extensions

The model results for 2050 should be viewed as a plausible scenario that results from the most probable assumptions. Given the very long time horizon required in this study, the results should not be considered a projection or forecast, but as a probable outcome of the interaction of several uncertain driving forces. California agriculture has always been driven by the interactions between technology, resources, and market demands, and future production can be viewed as a balance between the rates of change in these three variables. Accordingly, we have attempted to make the assumptions, the mathematics, and the parameter values used in this study as transparent as possible to enable the reader to assess the basis for the results.

Limitations of the basic production model have been discussed in Medellin-Azuara (2007) and elsewhere (Howitt et al. 2001). SWAP is in the process of major updates to address most of these limitations. An important caveat is that estimated changes in future yields calculated in other studies vary widely, depending on the set of assumptions. These assumptions include the effects of CO_2 fertilization, location and crop variety. Another limitation is that some SWAP crop categories are aggregated and yields may vary within each category. Furthermore, DWR crop groupings are simply SWAP categories disaggregated, thus there is the potential for improved accuracy with finer crop groupings. A future goal is to have SWAP calibrated to DWR crop groupings and regions which will eliminate the need for disaggregating and extrapolating.

Given the very long time horizon used in these crop calculations, the omission of the effects of global climate change on the water supply and evapotranspiration probably induces an optimistic bias to the results. Initial work on the effects of a dry

climate change scenario on California irrigated production can be found in Howitt et al (2008). Using a similar model to the one in this working paper, significant changes to California cropping patterns and water scarcity value are shown to be caused by dry climate change projections.

Extensions and other improvements to the model include modeling agricultural production in regions other than the Central Valley and Southern California such as coastal and northern areas of California. Future versions of the model will also include more disaggregated estimations of changes in yields and shifts in future demands that incorporate results from research in progress. Production cost information is also continuously updated in the SWAP database. Inputs, in addition to fertilizer and other supplies, are being added. The addition of more inputs in the production function will allow for a more accurate representation of the response of farmers into the future.

Finally, we caution that the calculation of a scenario so far in the future is highly sensitive to small changes in the rates of change of the critical parameters, and that results for a shorter 15- 20 year time horizon would be more persuasive.

5.0 Conclusions

This report has considered the likely cropping pattern changes to California agriculture between 2005 and 2050. We have quantified these results using SWAP, a PMP optimization model of California agriculture. Several innovations and improvements have been added to the model and this has significantly improved realism of the results. These improvements include calibrating to geo-referenced data, introducing demand shifts, introducing technological change and including corn silage restrictions. It is important to note that results generated hinge on the assumptions of the model and every attempt has been made to clearly convey them.

The results show that the calibrated SWAP model represents profit maximizing farmer reactions at all three margins. First, extensive margin adjustments are shown by changes in the total and proportional areas allocated to each crop. Second, intensive margin adjustments are reflected by the change in input use per acre. Third, there are changes in market prices received by farmers that result from the change in total output produced. With the interaction of the driving factors we would expect the comparative advantage of different crops to change over time.

Results indicate that there will be an overall reduction of 9.7 % in land devoted to agricultural use in California by 2050. This is a function of increased urbanization and technological change that increases yields per acre thereby allowing farmers to produce more on less land. Additionally, the interaction of market forces contribute to the resulting changes in cropped acres. Agricultural water use is shown to decrease by 8.7% by 2050, largely in response to reductions in pasture and other water intensive crop acres. However, water use per acre is shown to increase by about 1% as remaining land

is cropped more intensely. Total statewide production is shown to increase by just over 25% which contributes to an increase in farm revenue of about 20%. This counter-intuitive result stems from technological change and demand growth. Both the revenue and resource effects are shown to vary by region.

The overall conclusion from the model results is that changes in irrigated crop production and water use are predominantly the result of the interaction and rate of change of three factors: Resource availability, the growth of production technology, and the continued growth of market demand for California's specialty crops.

The model results, for the set of parameters that we find most plausible, show that California irrigated agriculture can grow in terms of production and revenues, while simultaneously accommodating urban growth and a moderate reduction in total irrigated land and applied water.

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