Appendix Q - Attachment 3

Appendix Q3 Statewide Agricultural Production (SWAP) Model Documentation

This appendix documents the Statewide Agricultural Production (SWAP) model used to support the impact analysis in the EIS. The SWAP model version 6.1 was used for the EIS, which is the most recently updated version available. Previous model versions have been used for similar impact analyses. For example, SWAP version 6 was used in Final Environmental Impact Statement of the Coordinated Long-Term Operation of the Central Valley Project and State Water Project (Reclamation 2015). The methodology and assumptions are provided, while more comprehensive SWAP model documentation can be found in the reference list.

Q3.1 SWAP Model Methodology

This section summarizes the SWAP model version, methodology, and coverage. It describes the overall analytical framework and contains descriptions of input data. The project alternatives include several major components that will have significant effects on CVP/SWP operations and the quantity of delivered water to agricultural contractors.

The SWAP model is a regional agricultural production and economic optimization model that simulates the decisions of farmers across 93 percent of agricultural land in California. It is the most current in a series of production models of California agriculture developed by researchers at the University of California at Davis under the direction of Professor Richard Howitt and Duncan MacEwan in collaboration with the California Department of Water Resources (DWR). The SWAP model has been subject to peer-review and technical details can be found in the publication “Calibrating Disaggregate Economic Models of Irrigated Production and Water Management” (Howitt et al. 2012).

Q3.1.1 SWAP Model Version

The SWAP model version 6.1 is the most recent publicly-available model version and was used to estimate the economic value of new water supply in the California Water Commission Water Storage Investment Program Technical Reference Document (CWC 2016) to support the evaluation of Prop 1 applications. It is also being used in several ongoing studies of water projects and operations. This version is calibrated using 2010 crop acreage, 2010 water use, and 2011-2012 crop prices and costs. SWAP model version 6.1 developed for the Prop 1 application was used for the regional economics evaluation in this EIS. Following changes were made to the SWAP version 6.1 model specific to the analysis in this EIS:

1. Using fixes crop prices instead of the endogenous price model: Fixed crop prices were assumed across all regions and all alternatives. The fixed crop prices were escalated and calculated for appropriate population and demand. The scale of change in agricultural deliveries across the EIS alternatives resulted in cropping pattern and production changes outside of the range of the crop demand elasticities. The fixed-price model allows for changes in large changes production without large changes in prices; without fixed prices, the changes in global prices are not affected by changes in production.

2. CalSim II deliveries: The model was run using CalSim estimates agricultural deliveries. CalSim II modeling and assumptions are documented in Appendix F, *Modeling*. Following adjustments were made to CalSim II results specific to the regional economic analysis:
    a. Agricultural water supply deliveries in certain regions were adjusted to correct a CalSim II mis-characterization of decomposition water for rice acreage.
    b. Agricultural deliveries to certain SWAP regions were adjusted to improve the post-processing calculations of CalSim II output with the alternative assumptions.

Q3.1.2 Modeling Objectives

The EIS modeling objectives accomplished with the SWAP model included the evaluation of the following potential impacts:

- Effects on irrigated agricultural acreage
- Effects on total production value
- Effects on groundwater pumping and groundwater pumping costs

Q3.1.3 SWAP Model Methodology

The SWAP model assumes that growers select the crops, water supplies, and other inputs to maximize profit subject to resource constraints, technical production relationships, and market conditions. Growers face competitive markets, where no one grower can influence crop prices. The competitive market is simulated by maximizing the sum of consumer and producer surplus subject to the following characteristics of production, market conditions, and available resources:

- Constant Elasticity of Substitution (CES) production functions for every crop in every region. CES has 4 inputs: land, labor, water, and other supplies. CES production functions allow for limited substitution between inputs which allows the model to estimate both total input use and input use intensity. Parameters are calculated using a combination of prior information and the method of Positive Mathematical Programming (PMP) (Howitt 1995a; Howitt 1995b).
- Marginal land cost functions are estimated using PMP. Additional land brought into production is assumed to be of lower value and thus requires a higher cost to cultivate. The PMP functions capture this cost by using acreage response elasticities which relate change in acreage to changes in expected returns and other information.
- Groundwater pumping cost including depth to groundwater.
- Crop demand functions.
- Resource constraints on land, labor, water, and other input availability by region.
- Agronomic and economic constraints. For example, minimum regional silage production to meet dairy herd feeding requirements.

The model chooses the optimal values of land, water, labor, and other input use in addition to input use intensity, as described by the CES production surface, subject to these constraints and definitions. Profit is revenue minus costs where revenue is price times yield per acre times total acres. Costs are standard input costs plus the exponentially increasing land cost (PMP) function. Downward-sloping crop demand curves guarantee, all else constant, that as production increases crop price decreases (and vice-versa). Over time, crop demands may shift out driven by real income growth and population increases. External data and elasticities are used to estimate the magnitude of these shifts.

The SWAP model incorporates CVP/SWP agricultural water supplies, other local surface water supplies, and groundwater. As conditions change within a SWAP region (e.g., the quantity of available project water supply increases or the cost of groundwater pumping increases), the model optimizes production by adjusting the crop mix, water sources and quantities used, and other inputs. Land will be fallowed when it is the most cost-effective response to resource conditions.

The SWAP model is used to compare the long-run response of agriculture to potential changes in CVP/SWP agricultural water delivery, other surface or groundwater conditions, or other economic values or restrictions. Results from the CalSim II model are used as inputs into SWAP through a standardized data linkage tool.

The model self-calibrates using Positive Mathematical Programming (PMP) which has been used in models since the 1980's (Vaux and Howitt 1984) and was formalized in 1995 (Howitt 1995a). PMP allows the modeler to infer the marginal decisions of farmers while only being able to observe limited average production data. PMP captures this information through a nonlinear cost or revenue function introduced to the model.

Q3.1.4 SWAP Model Coverage

The SWAP model has 27 base regions in the Central Valley. The model is also able to include agricultural areas of the Central Coast, the Colorado River region that includes Coachella, Palo Verde and the Imperial Valley and San Diego, Santa Ana and Ventura and the South Coast. Figure Q3-1 shows California agricultural regions evaluated in the EIS. Table Q3-1 details the major water users in each of the regions.

Figure Q3-1. SWAP Model Regions Evaluated in the EIS

Table Q3-1. SWAP Model Region Summary

SWAP Region	Major Surface Water Users
1	CVP Users: Anderson Cottonwood I.D., Clear Creek C.S.D., Bella Vista W.D., and miscellaneous Sacramento River water users.
2	CVP Users: Corning Canal, Kirkwood W.D., Tehama, and miscellaneous Sacramento River water users.
3a	CVP Users: Glenn Colusa I.D., Provident I.D., Princeton-Codora I.D., Maxwell I.D., and Colusa Basin Drain M.W.C.
3b	Tehama Colusa Canal Service Area. CVP Users: Orland-Artois W.D., most of Colusa County, Davis W.D., Dunnigan W.D., Glide W.D., Kanawha W.D., La Grande W.D., and Westside W.D.
4	CVP Users: Princeton-Codora-Glenn I.D., Colusa Irrigation Co., Meridian Farm W.C., Pelger Mutual W.C., Reclamation District 1004, Reclamation District 108, Roberts Ditch I.C., Sartain M.D., Sutter M.W.C., Swinford Tract I.C., Tisdale Irrigation and Drainage Co., and miscellaneous Sacramento River water users.
5	Most Feather River Region riparian and appropriative users.
6	Yolo and Solano Counties. CVP Users: Conaway Ranch and miscellaneous Sacramento River water users.
7	Sacramento County north of American River. CVP Users: Natomas Central M.W.C., miscellaneous Sacramento River water users, Pleasant Grove-Verona W.M.C., and Placer County W.A.
8	Sacramento County south of American River and northern San Joaquin County.
9	Direct diverters within the Delta region. CVP Users: Banta Carbona I.D., West Side W.D., and Plainview.
10	Delta Mendota service area. CVP Users: Panoche W.D., Pacheco W.D., Del Puerto W.D., Hospital W.D., Sunflower W.D., West Stanislaus W.D., Mustang W.D., Orestimba W.D., Patterson W.D., Foothill W.D., San Luis W.D., Broadview, Eagle Field W.D., Mercy Springs W.D., San Joaquin River Exchange Contractors.
11	Stanislaus River water rights: Modesto I.D., Oakdale I.D., and South San Joaquin I.D.
12	Turlock I.D.
13	Merced I.D. CVP Users: Madera I.D., Chowchilla W.D., and Gravely Ford.
14a	CVP Users: Westlands W.D.
14b	Southwest corner of Kings County
15a	Tulare Lake Bed. CVP Users: Fresno Slough W.D., James I.D., Tranquillity I.D., Traction Ranch, Laguna W.D., and Reclamation District 1606.
15b	Dudley Ridge W.D. and Devils Den (Castaic Lake)
16	Eastern Fresno County. CVP Users: Friant-Kern Canal, Fresno I.D., Garfield W.D., and International W.D.
17	CVP Users: Friant-Kern Canal, Hills Valley I.D., Tri-Valley W.D., and Orange Cove.
18	CVP Users: Friant-Kern Canal, County of Fresno, Lower Tule River I.D., Pixley I.D., portion of Rag Gulch W.D., Ducor, County of Tulare, most of Delano-Earlimart I.D., Exeter I.D., Ivanhoe I.D., Lewis Creek W.D., Lindmore I.D., Lindsay-Strathmore I.D., Porterville I.D., Sausalito I.D., Stone Corral I.D., Tea Pot Dome W.D., Terra Bella I.D., and Tulare I.D.
19a	SWP Service Area, including Belridge W.S.D., Berrenda Mesa W.D.
19b	SWP Service Area, including Semitropic W.S.D
20	CVP Users: Friant-Kern Canal. Shafter-Wasco, and South San Joaquin I.D.
21a	CVP Users: Cross Valley Canal and Friant-Kern Canal
21b	Arvin Edison W.D.

SWAP Region	Major Surface Water Users
21c	SWP service area: Wheeler Ridge-Maricopa W.S.D.
23-30	Central Coast, Desert, and Southern California (not evaluated in the EIS)

CVP = Central Valley Project
I.D. = Irrigation District
M.W.C. = Mutual Water Company
SWAP = Statewide Agricultural Production Model
SWP = State Water Project
W.D. = Water District

Crops are aggregated into 20 crop groups which are the same across all regions. Each crop group represents a number of individual crops, but many are dominated by a single crop. Irrigated acres represent acreage of all crops within the group, production costs and returns are represented by a single proxy crop for each group. Crop group definitions and the corresponding proxy crop are shown in Table Q3-2.

Table Q3-2. SWAP Model Crop Groups

SWAP Definition	Proxy Crop	Other Crops
Almonds and Pistachios	Almonds	Pistachios
Alfalfa	Alfalfa Hay	
Corn	Grain Corn	Corn Silage
Cotton	Pima Cotton	Upland Cotton
Cucurbits	Summer Squash	Melons, Cucumbers, Pumpkins
Dry Beans	Dry Beans	Lima Beans
Fresh Tomatoes	Fresh Tomatoes	
Grain	Wheat	Oats, Sorghum, Barley
Onions and Garlic	Dry Onions	Fresh Onions, Garlic
Other Deciduous	Walnuts	Peaches, Plums, Apples
Other Field	Sudan Grass Hay	Other Silage
Other Truck	Broccoli	Carrots, Peppers, Lettuce, Other Vegetables
Pasture	Irrigated Pasture	
Potatoes	White Potatoes	
Processing Tomatoes	Processing Tomatoes	
Rice	Rice	
Safflower	Safflower	
Sugar Beet	Sugar Beets	
Subtropical	Oranges	Lemons, Misc. Citrus, Olives
Vine	Wine Grapes	Table Grapes, Raisins

SWAP = Statewide Agricultural Production Model
Misc. = miscellaneous

Q3.2 SWAP Model Assumptions

This section is a nontechnical overview of the SWAP model. It is important to note that SWAP, like any model, is a representation of a complex system and requires assumptions and simplifications to be made. All analyses using SWAP are explicit about the assumptions and provide sensitivity analysis where appropriate.

Q3.2.1 Calibration using PMP

The SWAP model self-calibrates using a three-step procedure based on Positive Mathematical Programming (PMP) (Howitt 1995a) and the assumption that farmers behave as profit-maximizing agents. In a traditional optimization model, profit-maximizing farmers would simply allocate all land, up until resource constraints become binding, to the most valuable crop(s). In other words, a traditional model would have a tendency for overspecialization in production activities relative to what is observed empirically. PMP incorporates information on the marginal production conditions that farmers face, allowing the model to exactly replicate a base year of observed input use and output. Marginal conditions may include inter-temporal effects of crop rotation, proximity to processing facilities, management skills, farm-level effects such as risk and input smoothing, and heterogeneity in soil and other physical capital. In the SWAP model, PMP is used to translate these unobservable marginal conditions, in addition to observed average conditions, into an exponential “PMP” cost function. This cost function allows the model to exactly replicate a base year of observed input use and output.

The SWAP model assumes additional land brought into production faces an increasing marginal cost of production. The most fertile land is cultivated first; additional land brought into production is of lower “quality” because of poorer soil quality, drainage or other water quality issues, or other factors that cause it to be more costly to farm. This is captured through an exponential land cost function (PMP cost function) for each crop and region. The exponential function is advantageous because it is always positive and strictly increasing, consistent with the hypothesis of increasing land costs. The PMP cost function is both region and crop specific, reflecting differences in production across crops and heterogeneity across regions. Functions are calibrated using information from acreage response elasticities and shadow values of calibration and resource constraints. The information is incorporated in such a way that the average cost data (known data) are unaffected.

Q3.2.2 Constant Elasticity of Substitution Production Function

Crop production in the SWAP model is represented by a Constant Elasticity of Substitution (CES) production function for each region and crop with positive acres. In general, a production function captures the relationship between inputs and output. For example, land, labor, water, and other inputs are combined to produce output of any crop. CES production functions in the SAWP model are specific to each region, thus regional input use is combined to determine regional production for each crop. The calibration routine in SWAP guarantees that both input use and output exactly match a base year of observed data.

The SWAP model considers four aggregate inputs to production for each crop and region: land, labor, water, and supplies. All units are converted into monetary terms, e.g. dollars of labor per acre instead of worker hours. Land is simply the number of acres of a crop in any region. Land costs represent basic land investment, cash overhead, and (when applicable) land rent. Labor costs represent both machinery labor and manual labor. Other supplies are a broad category that captures a range of inputs including fertilizer, pesticides, chemicals, custom, capital recovery, and interest on operating capital. Water costs and use per acre vary by crop and region.

The generalized CES production function allows for limited substitution among inputs (Beattie and Taylor 1985). This is consistent with observed farmer production practices (farmers are able to substitute among inputs in order to achieve the same level of production). For example, farmers may substitute labor for chemicals by reducing herbicide application and increasing manual weed control. Or, farmers can substitute labor for water by managing an existing irrigation system more intensively in order to reduce water use.

Q3.2.3 Crop Demand Functions

The SWAP model is specified with downward-sloping, California-specific crop demand functions. The demand curve represents consumer's willingness-to-pay for a given level of crop production. All else constant, as production of a crop increases the price of that crop is expected to fall. The extent of the price decrease depends on the elasticity of demand or, equivalently, the price flexibility. The latter refers to the percentage change in crop price due to a percent change in production. The SWAP model is specified with linear demand functions.

The nature of the demand function for specific commodities can change over time due to tastes and preferences, population growth, changes in income, and other factors. The SWAP model incorporates linear shifts in the demand functions over time due to growth in population and changes in real income per capita. Changes in the demand elasticity itself, resulting from changing tastes and preferences, are not considered in the model.

Q3.2.4 Water Supply and Groundwater Pumping

Total available water for agriculture is specified on a regional basis in the SWAP model. Each region has six sources of supply, although not all sources are available in every region:

- CVP (including Friant-Kern Class I)
- CVP Settlement and Exchange
- Friant Kern Class 2
- SWP
- Local surface water
- Groundwater

SWP and CVP deliveries are estimated from DWR and Reclamation. Local surface water supplies are based on DWR estimates, reports of individual water suppliers, and, where necessary, drawn from earlier studies.

Costs for surface water supplies are compiled from information published by individual water supply agencies. There is no central data source for water prices in California. Agencies that prepared CVP water conservation plans or agricultural water management plans in most cases included water prices and related fees charged to growers. Other agencies publish and/or announce rates on an annual basis. Water prices used in SWAP are intended to be representative for each region, but vary in their level of detail.

Groundwater availability is specified by region-specific maximum pumping estimates. These are determined by consulting the individual districts records and information compiled by DWR. DWR analysts provided estimates of the actual pumping in the base year and the existing pumping capacity by region. The model determines the optimal level of groundwater pumping for each region, up to the capacity limit specified. In some studies using SWAP or CVPM, the model has been used interactively with a groundwater model to evaluate short-term and long-term effects on aquifer conditions and pumping lifts.

Pumping costs vary by region depending on depth to groundwater and power rates. The SWAP model includes a routine to calculate the total costs of groundwater. The total cost of groundwater is the sum of fixed, operation and maintenance, and energy costs. Energy costs are based on a blend of agricultural power rates provided by PG&E.

Q3.3 References

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