Appendix Q - Attachment 3

Attachment Q.3 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 6.2 was used for the EIS, which includes an update to land and water use, groundwater sustainable yields, perennial crop plantings, prices, crop yields, and costs relative to the previous version of SWAP. Previous model versions have been used for similar regional-scale impact analyses and feasibility analyses. These include but are not limited to the following. SWAP 6.1 was used for the Reinitiation of Consultation on the Coordinated Long-Term Operation of the Central Valley Project and State Water Project (Reclamation, 2019). SWAP version 6.1 was used to support benefit-cost assessment of agricultural water supply changes from California Waterfix (Sunding, 2015). It was also 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. The earlier 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.

Q.3.1 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 written in GAMS® modeling language.[1] 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 in collaboration with the California Department of Water Resources (DWR). Since Professor Howitt retired, the SWAP model has been developed,

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[1] See GAMS Development Corporation. GAMS is the Generalized Algebraic Modeling System.

updated, and maintained by Professor Howitt and a technical team at ERA Economics LLC. 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).

Q.3.1.1 SWAP Model Version

The SWAP model version 6.2 is based on version 6.1 but with significant updates to data and an improved method to estimate perennial crop acreages under surface water supply uncertainty and SGMA groundwater pumping limits. Version 6.2 is calibrated using 2021 crop acreage, water use, and recent historical averages for crop prices and costs. SWAP input files are linked to GIS, R, and Excel databases from which the calibration data are drawn. Following changes were made to the SWAP version 6.2 model specific to the analysis in this EIS:

- Crop prices can vary within the model due to population-based demand shifts out to 2040 and due to changes in crop output calculated by SWAP using demand elasticities for non-commodity crops. For example, an alternative that provides less water and reduces almond production in the Delta export regions would result in a slight increase in almond prices for other lands continuing to produce almonds.[2]
- Future perennial crop acreages (orchards and vineyards) are estimated using a separate step from that used for annual crops. Perennial crops are a long-term investment and must consider the risk of inadequate water supply over the life of the stand, whereas annual crops can respond year-to-year according to water supply. SWAP 6.2 now makes perennial crop planting and production decisions using expectations of potential future dry-year loss of stand. That is, the model now approximates grower expectations regarding future water supplies for capital investments in perennial crops. This is explained further in Section 3.2.2 of this Attachment.
- Update to regional agricultural land use and crop mix, with GIS-based data management linked to DWR’s Statewide Crop Mapping (California DWR, 2023). The crop acreage is field level, so acreage can be aggregated into larger geographic units such as the standard Central Valley SWAP regions, groundwater sustainability agencies (GSAs), water districts, project service areas, or water budget areas used by groundwater and surface water hydrologic models. SWAP 6.2 regions are defined to include the standard 27 model regions, plus a new region (see bullet below) for a total of 28 model regions in the Central Valley.
- Comprehensive update to crop prices, yields, and production costs, using data from USDA NASS (USDA) and University of California (UCCE) cost of production budgets. This includes updates to establish the price of silage based on its value as an input to milk production for dairy cows in the San Joaquin Valley. All prices and costs are indexed to 2023 price levels.

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[2] To facilitate subsequent regional economic analysis, the changes in value of crop production are decomposed into fixed-price effects and price-change effects. See Appendix Q for an explanation of how fixed-price effects are used in regional impact analysis using the IMPLAN (IMpacts for PLanning and ANalysis) model.

Previous SWAP region 10 is now split into two regions, with revised region 10 focusing on the CVP water service and repayment contractors and region 10X focusing on San Joaquin River Exchange contractors.

CalSim 3 deliveries: The model is run using CalSim estimates of agricultural surface water deliveries. CalSim 3 modeling and assumptions are documented in Appendix F, Modeling. CalSim 3 deliveries in the Sacramento Valley and San Joaquin River Basin are based on water balances in water budget areas that account for actual water delivered to farms and used to meet water demands by crops. In a few regions CalSim delivers more water than SWAP's calibration land use base demands in applied water, so the SWAP model simply uses the amount of water needed for crop production.3

Groundwater pumping is constrained by Sustainable Yields and groundwater allocations defined by Groundwater Sustainability Agencies (GSAs) to implement Groundwater Sustainability Plans (GSPs) under the Sustainable Groundwater Management Act (SGMA). The analysis compares LTO alternatives at 2040 conditions. The sustainability requirements of SGMA are assumed to be in full force, limiting groundwater pumping in nearly all of the San Joaquin Valley not to exceed Sustainable Yield as provided in GSA GSPs and subsequent Annual Updates to the GSP.

Q.3.1.2 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 decomposed into fixed-price effects for use in regional impact modeling and price-change effects

In previous LTO and similar analysis using SWAP, results typically also included effects on groundwater pumping and pumping costs. The current analysis is based on comparisons of alternatives at 2040 conditions in which the sustainability requirements of SGMA are assumed to be in full force. Regions receiving project water affected by changes in deliveries under different alternatives are constrained by the Sustainable Yield in each Subbasin, so little or no changes in groundwater pumping costs result. Some differences in pumping lift and cost could occur due to changes in groundwater recharged by percolation of surface water delivered to crops, but these would be small.

Although not used for LTO analysis, SWAP also provides information useful for benefits analysis or benefit-cost analysis. Estimates can include the change in net return to agricultural production by crop and region. Also, the benefit value (or cost) of a change in water supply can be shown in total, on average per acre-foot (AF) of change in supply, or as a per-AF marginal value before and after the change.

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[3] Primary reasons for this appear to be: mismatches between SWAP's crop acreages based on DWR's Statewide Crop Mapping versus the crop acreages assumed in CalSim's water budget calculations; and water deliveries not directly used to meet crop water needs, such as water delivered for rice decomposition.

Q.3.1.3 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 buy and sell in 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. New land brought into production is assumed to be of lower productivity and/or requires a higher cost to cultivate. The PMP functions capture this cost by using economic optimization conditions and acreage response elasticities which relate change in acreage to changes in expected returns and other information.

- Groundwater pumping cost including depth to groundwater.

- California statewide crop demand functions that govern changes in the market price for crops as their aggregate production changes.

- Resource constraints on land, labor, water, and other input availability by region. For LTO alternatives, changes in available project water delivery will be the most important resource constraint. Groundwater pumping and SGMA implementation is represented in the model to govern whether and to what amount project water users can substitute groundwater for project water shortages.

- 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 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 or 3 models can be used as inputs into SWAP through a standardized data linkage tool. The LTO EIS applies the CalSim 3 model.

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.

Q.3.1.4 SWAP Model Coverage

The SWAP model has 27 base regions in the Central Valley that are evaluated in the EIS. Figure Q.3-1 shows these SWAP regions. Table Q.3-1 details the major water users in each of the regions.

Figure Q.3-1. SWAP Model Regions Evaluated in the EIS

Table Q.3-1. 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, Corning W.D., Kirkwood W.D., Orland Unit water users, and miscellaneous Sacramento River water users.
3a	CVP Users: Glenn Colusa I.D., Provident I.D., Princeton-Codora I.D., Maxwell I.D., Colusa Basin Drain M.W.C., other Sacramento River water users.
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 including: Panoche W.D., Pacheco W.D., Del Puerto W.D., West Stanislaus W.D., Patterson W.D., Banta-Carbona W.D., San Luis W.D., Eagle Field W.D., Mercy Springs W.D., Subregion 10X. Crop acreage and water supply for San Joaquin River Exchange Contractors are handled as a separate subregion within Region 10, due to the different water supply amount, reliability, and cost.
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., Tranquility I.D., Traction Ranch, Laguna W.D., and Reclamation District 1606. Kings River water users.
15b	Dudley Ridge W.D. and Devils Den (Castaic Lake)

SWAP Region	Major Surface Water Users
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. Kings River Users including Alta I.D. and Consolidated I.D.
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., Lost Hills W.D., West Kern W.D.
19b	SWP Service Area, including Semitropic W.S.D
20	CVP Users: Friant-Kern Canal. Shafter-Wasco I.D., and Southern San Joaquin M.U.D.
21a	CVP Users: Cross Valley Canal and Friant-Kern Canal. Also SWP and Kern River users.
21b	CVP User: Arvin Edison W.D.
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;
M.U.D. = Municipal Utility District; SWAP = Statewide Agricultural Production Model; SWP = State Water Project;
W.D. = Water District

SWAP evaluates effects for all regions 1 through 21c, then results are aggregated into larger groups of regions for further economic analysis and display of results in the EIS. SWAP regions 1 through 9 are aggregated as Sacramento Valley and regions 10 through 21c are aggregated as San Joaquin Valley. Note that SWAP region boundaries do not correspond to county lines, and some SWAP regions at the border between Sacramento Valley and San Joaquin Valley, notably region 8, fall partly in each. Part of region 8 falls in Sacramento County and part in San Joaquin County. For purposes of aggregation and display, region 8 is included as part of Sacramento Valley because the effects of Delta operations alternatives in region 8 are more similar to other Sacramento Valley regions than to the more heavily affected Delta export regions in the San Joaquin Valley.

Crops are aggregated into 19 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. The proxy crop is selected to be representative of gross and net returns and water use for the group. Whenever possible, the proxy crop must have a UCCE budget produced or updated within the last ten years. As a result, the proxy crop may not represent the largest acreage within the group. Crop group definitions and the corresponding proxy crop are shown in Table Q.3-2. The table also lists some of the other crops included in each group.

Table Q.3-2. SWAP Model Crop Groups

SWAP Definition	Proxy Crop	Other Crops
Alfalfa	Alfalfa Hay	Other hay
Almonds	Almonds	N/A
Corn	Grain Corn	N/A
Cotton	Pima Cotton	Upland cotton
Grain	Wheat	Oats, barley
Other Field	Sunflowers	Dry beans, safflower
Other Orchard	Peaches	Plums, nectarines, apricots, apples, olives
Pasture	Irrigated Pasture	N/A
Other Truck	Eggplant	Cucurbits, peppers, onions, other vegetables
Pistachios	Pistachios	N/A
Processing Tomatoes	Processing Tomatoes	Fresh tomatoes
Rice	Medium Grain Rice	Other rice varieties
Safflower	Safflower	N/A
Silage	Corn Silage	Other grain silage
Subtropical	Oranges	Lemons, other citrus
Table Grapes	Table Grapes	Raisins
Sweet Potatoes	Sweet Potatoes	Potatoes
Walnuts	Walnuts	N/A
Wine Grapes	Wine Grapes	N/A

Q.3.2 SWAP Model Features

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. The model is continually being updated to apply the best available data and economic methods to improve model calibration and its policy predictions. For example, SWAP 6.2 applied for the LTO EIS includes substantial improvements in data and modeling of perennial crops (see Section Q3.1). All analyses using SWAP are explicit about the assumptions and provide sensitivity analysis where appropriate.

Q.3.2.1 Calibration using PMP

The SWAP model self-calibrates using a 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 combines directly observed information on production conditions (costs, prices, acreage, resource availability) with economic principles about how changes in those conditions affect profit-maximizing decisions on crop selection and input use. This additional economic information, referred to as marginal conditions, allows the model to exactly replicate a base period of observed input use and output. Marginal conditions allow the model to reflect the heterogeneity in production and market conditions that are not readily observable over a large scale. These 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 this version of the SWAP model, the PMP approach calculates an additional cost function component that is calibrated to incorporate these unobserved marginal conditions. The resulting PMP model thus includes both observed average conditions and unobserved marginal conditions, allowing the model to exactly replicate a base period of observed input use and output.

The SWAP model's PMP cost function is structured so that, for each crop in each region, additional land brought into production faces an increasing marginal cost of production. As mentioned above, reasons for the increasing marginal cost can include varying land quality, market conditions, and risk. As an example, for a particular crop in a production region (or on a farm), the best land for that crop is cultivated first; any additional land brought into production is less suitable for that crop because of poorer soil quality, drainage or other water quality issues, or other factors that cause it to be more costly to farm. The PMP cost function is both region and crop specific, reflecting differences in production across crops and heterogeneity within and across regions. The PMP cost 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.

Q.3.2.2 Selection of Perennial Crop Acreage Under Uncertainty

SWAP 6.1 and earlier versions of the model were structured as annual time-step decision models. All crops were subject to change in acreage and input decisions as water supply, other resources, prices, or costs changed within the model. Production costs of perennial crops (orchards and vineyards) included the substantial investment cost incurred at planting and stand establishment, with those costs amortized over the economically productive life of the stand (typically 25 years or longer). In other words, perennial crops were treated similar to other crops such as processing tomatoes, rice, or wheat. Appropriate analysis using the SWAP model was either explicitly characterized as a long-term response to changing conditions (i.e., over a long enough period of time to let all crops adjust without substantial stranding of perennial crop investment costs), or the rate of change in perennial crop acreage was constrained to the typical, average turnover rate per year based on the economic life. For example, given a 25-year economic stand life and a uniform age distribution, on average up to one-twenty-fifth of the acreage of, say, almonds might be replaced in a given year. So, a SWAP analysis evaluating the effect of a policy change after 10 years would restrict any reduction in perennial crop acreage to an amount related to the underlying economic stand removal rate.

The methods and assumptions for perennial crop response to water supply changes in SWAP 6.1 and earlier versions were simplifications of a complex investment decision process that growers would actually face. These earlier versions of the model were also limited by the available data for the plant date of the orchard or vineyard. The assumptions were viewed as acceptable in earlier analyses of water policy changes for three reasons:

- Perennial crop net returns have been great enough relative to some of the annual crop returns that meaningful reductions in acreage due to water supply changes had only a small effect on perennial acreage. Any effects on irrigated acreage fell predominantly on annual crops with lower net returns.

- Annual crops remained a large enough portion of total regional acreage that water supply reductions could be largely managed by annual crop reductions. Over the past 15 years the perennial crop acreage in California has significantly increased with a consequent reduction of the proportion of annual crops. For example, the acreage of bearing almonds doubled to1.33 million acres from 2007 to 2021. This rapid expansion increased the perennial dry year water requirements and simultaneously reduced the lower net return annual crop acreage.

- Prior to the ongoing implementation of SGMA, growers or water suppliers in many parts of the Central Valley could pump groundwater to make up for at least some of any policy-driven change in surface water supply. Going forward groundwater will be limited to the Sustainable Yield in each Subbasin and GSA.

As of 2024, these conditions no longer hold for many regions in the San Joaquin Valley. Changes in the amount and reliability of surface water supply, as is being evaluated in this EIS, would affect some regions that are dominated by perennial crops and SGMA will be fully in place by 2040 to limit groundwater pumping to the Sustainable Yield, effectively limiting the ability to substitute surface water for groundwater in many years.

Q3.2.2.1 Perennial Crop Decisions: Approach, Data, and Assumptions

A perennial crop's substantial investment cost is incurred in expectation of a stream of net returns lasting twenty years or more. If growers face an increased risk that water supply will not be sufficient to maintain the stand at some point during the stand's expected life, they are less likely to incur that initial investment cost. In other words, the increased risk of premature removal of the stand due to water shortage acts as an additional cost of planting a perennial crop, making it less attractive relative to an annual crop.

The perennial crop investment decision with uncertain future water supply is fundamentally dynamic and stochastic. For example, growers make up-front decisions to plant not knowing the timing and severity of water shortage over the life of the stand. Importantly, the cost of a water shortage (lost future net return and capital investment due to premature removal of the stand) depends on when it occurs during the stand life. If the shortage occurs early in the stand life, the cost is very large, whereas if it occurs within the last few years of the stand life the cost is much smaller, the best decision growers could hypothetically make would occur if they knew the exact pattern of water supply out into the future – the so-called perfect foresight decision. But instead, growers need to make perennial investment decisions based on expectations, not perfect foresight.

SWAP 6.2 makes use of a perennial crop risk management model (PRMM) that is a dynamic, stochastic optimization model written in GAMS® code. It develops an optimal water supply expectations rule based on the pattern of costs and returns over the perennial crop stand life and on the frequency distribution of water supplies that could occur in any one period. The model optimizes the selection of a crop mix consisting of a representative perennial crop and a representative annual crop over a multi-period production horizon in which the pattern of water supplies is uncertain. The PRMM is not formally part of SWAP 6.2 and does not automatically run as a subcomponent of SWAP, but rather must be run separately using specific water supply amounts and frequencies relevant to the analysis (in this case the EIS evaluation of alternatives).

Almonds are selected as the representative perennial crop with establishment costs, operating costs, and returns as defined in the UCCE production budgets.[4] 3-year age classes are used to capture the variability in costs and returns of an almond stand over its economic life. The distribution of CalSim 3 surface water deliveries are used to develop a random sequence of deliveries for each SWAP region. The dynamic stochastic model selects the mix of annual and perennial crops to maximize the sum of the discounted net returns over the water supply uncertainty. This provides the mix of annual crops and investment in perennial crops that would be expected by a rational grower with expectations, but not perfect foresight, of future water supply deliveries. The framework is applied to each LTO alternative.

Q3.2.2.2 Perennial Crop Risk Management Model

The PRMM sequentially solves for the optimal selection of annual crops, perennial crop planting, and perennial crop removal at each period, subject to equations of motion defining the acreage of perennial crops within each age class and the movement of perennial acreage by age class as the time horizon progresses. At each period, the model simulates a grower that knows the current state of crop acreage and the current year water supply. Future year water supply is either known (perfect foresight) or set by expectations related to the parameters of the water supply distribution. This process is repeated for each of the random water year sequences drawn from the distribution, resulting in a Monte Carlo analysis that compares the outcome (present value of expected net returns, PVNR) of each expectation target to the ideal possible outcome (perfect foresight).

For each random water supply sequence, the difference in PVNR between perfect foresight and the expectations target was tabulated. This process was repeated for each region and alternative over a range of expectations targets. The best performing expectations target (smallest average deviation from perfect foresight), at least for the dozens of cases evaluated, included the dry-year average delivery and percentile-based deliveries ranging from the 20th to 35th percentile (i.e., deliveries equal to or greater than 20 to 35 percent of the projected annual deliveries). In every case evaluated, the dry-year average was within or near this percentile range and was either the best-performing or near-best.

Given these results, the dry-year average[5] was chosen as the best target expectations rule for setting long-term perennial crop investment decisions. It performed reasonably well compared to perfect foresight – always less than 10 percent and often within 4 percent of the average PVNR

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[4] The analysis can be adapted to other multi-year crops, including short-lived stands such as alfalfa or longer-lived orchards such as pistachios.

[5] In the context of this application that splits a multi-decade time horizon into 3-year periods, a dry condition is interpreted as any three-year period that averages the water supply condition of a single dry year.

for the perfect foresight decision. It is also a commonly used parameter for policy-level evaluation of water operations alternatives, and a readily understood metric by most water managers and users.

Q3.2.2.3 Use of Results in SWAP 6.2

Based on this analysis of optimal perennial crop investment under uncertainty, the SWAP model used dry-year average water supply to estimate perennial crop acreages under 2040 conditions for each EIS alternative. The dry-year average varied by alternative, and the resulting perennial crop mix estimated for the dry-year condition was used as a constraint (an upper bound) for purposes of running the average and dry condition SWAP analysis for the full crop mix at 2040. That is, the level of investment in perennial crops under future conditions is constrained to approximate the optimal decisions that growers would make when facing stochastic future surface water supplies and increasingly constrained groundwater. This approach enables us to approximate optimal stochastic dynamic perennial planting decisions that respond to alternative water supply conditions but are fully incorporated in the optimal cropping pattern.

The result of the PRMM is to limit future perennial crops relative to past and current conditions with largely unconstrained groundwater pumping. Growers would also expand annual crop acreage in years with sufficient surface water supply relative to current conditions. To account for this, the difference in water use between the future conditions perennial crop plantings (estimated by using the optimal water supply expectations rule derived from PRMM analysis) and current conditions is calculated. This additional water is used to increase annual crop acreage. This application of the PRMM with SWAP applies a proportional expansion in annual crops. Future iterations of the tool may be expanded to consider the relative expansion in different types of annual crops based on market conditions and net returns.

SWAP 6.2 remains a yearly time-step model, but the PRMM allows it to represent long-term perennial crop investment decisions related to expected water supply. Similar to previous SWAP versions, the effects of water supply variability on crop production can be illustrated by running SWAP with different water year conditions such as wet, dry, or critical water years. For the analysis in this EIS, results are estimated for both below normal (used as a proxy for overall average) and dry conditions, defined according to the yearly Sacramento River Index values associated with the water deliveries from the CalSim 3 operations model.

Q.3.2.3 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 operations, 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.

Q.3.2.4 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.

Q.3.2.5 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. CalSim 3 provides SWP, CVP, and local deliveries under each of the EIS alternatives.

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 Subbasin-specific Sustainable Yields and GSA-specific allocations (in areas where GSAs have defined allocations). These are determined by reviewing GSPs, GSP updates, GSP technical appendices, and GSA meeting minutes and policies. The Sustainable Yield for each region was updated for the SWAP 6.2 model. The model determines the optimal level of groundwater pumping for each region, up to the defined Sustainable Yield. 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 and were updated to reflect current, 2023 power costs.

Q.3.3 References

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