San Luis Low Point Improvement Project Environmental Impact Statement/Environmental Impact Report

Appendix R: Statewide Agricultural Production Model

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1.0 Introduction

This technical appendix describes the agricultural economic model used in the analysis of San Luis Low Point Improvement Project (SLLPIP) alternatives. The scenarios evaluated for the feasibility study include Future No Action Alternative (NAA), and three policy alternatives: Central Valley Project (CVP) Reservoir Expansion Alternative; Increased San Luis Reservoir Carryover Storage Alternative; and Shared Reservoir Expansion Alternative. The CalSim modeling technical appendix (Appendix B) provides additional details regarding the development of the alternatives and the water supply delivered to agricultural users under each alternative.

The Statewide Agricultural Production (SWAP) model is used to evaluate the effects of changes in water supply to agriculture in Central Valley regions. As water supply conditions change within a region as a result of the SLLPIP, growers may shift the crop mix, fallow land, and adjust input use in the production of crops. The SWAP model evaluates these effects; results for each alternative are compared to the results of the NAA to quantify changes in agricultural production, irrigated acreage, and gross farm revenues.

2.0 SWAP Model Overview

The SWAP model is a regional agricultural production and economic optimization model that simulates the decisions of farmers across 97 percent of agricultural land in California. It is the most current in a series of California agricultural production models, originally developed by researchers at the University of California at Davis in collaboration with the California Department of Water Resources (DWR) with additional funding provided by the United States Bureau of Reclamation (Reclamation).

The SWAP model has been peer-reviewed (Howitt et al. 2012). The SWAP model, and its predecessor the Central Valley Production Model (CVPM), have been used for numerous policy analyses and impact studies over the past 20 years, including the impacts of the Central Valley Project Improvement Act (Reclamation and United States Fish and Wildlife Service 1999), Upper San Joaquin Basin Storage Investigation (Reclamation 2008), the State Water Project (SWP) drought impact analysis (Howitt et al. 2009a), and the economic implications of Delta conveyance options (Lund et al. 2007).

2.1 SWAP Model Mechanics

The SWAP model data coverage is most detailed in the Central Valley, but it also includes production regions in the Central Coast, South Coast, and desert areas. The model assumes that farmers maximize profit subject to resource, technical, and market constraints. Farmers sell and buy in competitive markets, and no one farmer can affect or control the price of any commodity. The model selects those crops, water supplies, and other inputs that maximize profit subject to constraints on water and land, and subject to economic conditions regarding prices, yields, and costs. 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 four 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 1995).

- Groundwater pumping cost including depth to groundwater.

- California state-wide commodity demand functions.

- Resource constraints on land, labor, water, and other input availability by region.

The SWAP model incorporates project water supplies (SWP and CVP), other local 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. It also fallows land when that appears to be the most cost-effective response to resource conditions.

The SWAP model is used to compare the long-term response of agriculture to potential changes in SWP and CVP irrigation water delivery, other surface or groundwater conditions, or other economic values or restrictions.

Results from Reclamation's and DWR's operations planning model, CalSim II, are used as inputs into SWAP through a standardized data linkage tool. The CalSim II data file for each alternative includes nine water year types of which five were included in the SWAP model inputs. The water year types include: wet; above normal; below normal; dry; and critical conditions. For each scenario and water year type, the CalSim II model provides the SWAP model with CVP and SWP farm-gate irrigation water deliveries for each SWAP model region. For the SLLPIP, the Increased San Luis Reservoir Carryover Storage Alternative is post-processed from the NAA CalSim output file, and as such, the standardized data linkage tool is not applied for this alternative.

2.2 SWAP Model Theory

The SWAP model self-calibrates using a three-step procedure based on PMP (Howitt 1995) 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. The method of 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 a cost function.

Unobserved marginal production conditions are incorporated into the SWAP model through increasing land costs. Additional land brought into production is of lower quality and, as such, requires higher production costs, captured with an exponential “PMP” cost function. 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 reflected in standard crop budgets (known data) are unaffected.

PMP is fundamentally a three-step procedure for model calibration that assumes farmers optimize input use for maximization of profits. In the first step, a linear profit-maximization program is solved. In addition to basic resource availability and non-negativity constraints, a set of calibration constraints is added to restrict land use to observed values. In the second step, the dual (shadow) values from the calibration and resource constraints are used to derive the parameters for the exponential PMP cost function and CES production function. In the third step, the calibrated CES and PMP cost function are combined into a full profit maximization program. The exponential PMP cost function captures the marginal decisions of farmers through the increasing cost of bringing additional land into production (e.g., through decreasing quality). Other input costs (supplies, land, and labor) enter linearly into the objective function in both the first and third step.

The SWAP model, and calibration by PMP, is a complicated process, thus sequential testing is very useful for model validation, diagnosing problems, and debugging the model. At each stage in the SWAP model there is a corresponding model check. In other words, the calibration procedure has particular emphasis on the sequential calibration process and a parallel set of diagnostic tests to check model performance. Diagnostic tests are discussed in Howitt et al. (2012).

2.3 Constant Elasticity of Substitution Production Function

Crop production in the SWAP model is represented by a CES production function for each region and crop. In general, a production function is a mathematical specification used to capture 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 SWAP 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 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 increase efficiency. The CES function used in the SWAP model is non-nested, thus the elasticity of substitution is the same between all inputs.

2.4 Crop Demand Functions

The SWAP model is specified with downward-sloping California state-wide demand functions. The demand curve represents 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.

2.4.1 Demand Shifts

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 consumer tastes and preferences are difficult to predict and will have an indeterminate effect on demand and are consequently not considered in the model.

3.0 SWAP Model Data

The SWAP model requires a wide range of data to simulate the supply and demand for statewide agricultural production. The necessary data are not available from a single source and are instead compiled from various publicly available sources, including state and federal agencies, academic publications, and water district reports. A SWAP model data update was completed between 2009 and 2011 under contract with Reclamation. The model data and code is currently being updated under contract with the California Department of Food and Agriculture. The model update completed in 2011 is known as SWAP version 6 and this version was used for analysis of the SLLPIP alternatives. Importantly, SWAP version 6 is used in the SLLPIP analysis because it includes a National Economic Development (NED) post-processing routine which ensures benefits are consistent with federal guidelines. The NED post-processor was developed in collaboration with Reclamation concurrent with the SWAP version 6 data update.

3.1 SWAP Regions and Crop Definitions

The SWAP model has 27 base regions in the Central Valley. The current SWAP model covers agriculture in the original 21 CVPM regions (the SWAP model regions include 27 areas), 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. Only the 27 regions in the Central Valley are included in the analysis of SLLPIP alternatives.

All SWAP model regions are included in the economic summaries of the SLLPIP alternatives. SWAP model regions are aggregated into the Sacramento Valley (1 - 9), San Joaquin River (10 - 13), and Tulare Lake (14a – 21c) areas for summary of the SLLPIP alternatives. Table 1 summarizes some of the major water users in each of the regions.

Table 1. SWAP Model Region Summary

Region	Major Surface Water Users
1	CVP Users: Anderson Cottonwood Irrigation District (ID), Clear Creek Community Services District, Bella Vista Water District (WD), and miscellaneous Sacramento River water users.
2	CVP Users: Corning Canal, Kirkwood WD, Tehama, and miscellaneous Sacramento River water users.
3a	CVP Users: Glenn Colusa ID, Provident ID, Princeton-Codora ID, Maxwell ID, and Colusa Basin Drain Municipal Water Company (MWC).
3b	Tehama Colusa Canal Service Area. CVP Users: Orland-Artois WD, and Westside WD.
4	CVP Users: Princeton-Codora-Glenn ID, Colusa Irrigation Company, 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 MWC, miscellaneous Sacramento River water users, Pleasant Grove-Verona WMC, and Placer County Water Agency.
8	Sacramento County south of American River and northern San Joaquin County.
9	Direct diverters within the Delta region. CVP Users: Banta Carbona ID, West Side WD, and Plainview.
10	Delta Mendota service area. CVP Users: Panoche WD, Pacheco WD, Del Puerto WD, Hospital WD, Sunflower WD, San Joaquin River Exchange Contractors.
11	Stanislaus River water rights: Modesto ID, Oakdale ID, and South San Joaquin ID.
12	Turlock ID.
13	Merced ID. CVP Users: Madera ID, Chowchilla WD, and Gravely Ford.
14a	CVP Users: Westlands WD.
14b	Southwest corner of Kings County
15a	Tulare Lake Bed. CVP Users: Fresno Slough WD., James ID, Tranquillity ID, Traction Ranch, Laguna WD, and Reclamation District 1606.
15b	Dudley Ridge WD and Devils Den (Castaic Lake)
16	Eastern Fresno County. CVP Users: Friant-Kern Canal, Fresno ID, Garfield WD, and International WD.
17	CVP Users: Friant-Kern Canal, Hills Valley ID, Tri-Valley WD, and Orange Cove.
18	CVP Users: Friant-Kern Canal, County of Fresno, Lower Tule River ID, Pixley ID, and Tulare ID.
19a	SWP Service Area, including Belridge Water Storage District (WSD), Berrenda Mesa WD.
19b	SWP Service Area, including Semitropic WSD.
20	CVP Users: Friant-Kern Canal. Shafter-Wasco, and South San Joaquin ID.
21a	CVP Users: Cross Valley Canal and Friant-Kern Canal
21b	Arvin Edison WD.
21c	SWP service area: Wheeler Ridge-Maricopa WSD.
23-30	Central Coast, Desert, and Southern California

Note: the list above does not include all water users. It is intended only to indicate the major users or categories of users. All regions in the Central Valley also include private groundwater pumpers.

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. The current 20 crop groups were defined in collaboration with DWR and were last updated in 2011. Crop group definitions and the corresponding proxy crop are shown in Table 2.

Table 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, Miscellaneous Citrus, Olives
Vine	Wine Grapes	Table Grapes, Raisins

3.2 Crop Prices and Yields

The SWAP model is designed to calibrate to the actual conditions growers faced in the calibration year. Growers make current planting decisions based on expectations of prices. The SWAP model does not attempt to model how growers form their price expectations; as an approximation, SWAP uses an average of county-level crop prices. Data for county-level crop prices are obtained from the respective County Agricultural Commissioners' annual crop reports.

3.3 Crop Yields

Crop yields for each crop group in the SWAP model correspond to the proxy crops listed in Table 2 and are based on best management practices. The corresponding costs of production, discussed in Section 3.4, are based on cost studies that also reflect best management practices. Thus, crop yields in SWAP are slightly higher than those estimated by calculating county averages, but are more consistent with the production costs. Crop yield data are compiled from the University of California Cooperative Extension (UCCE) production cost budgets prepared by University of California at Davis (UC Davis) and

Extension Researchers. Yields for each region are based on the most recent proxy crop cost study available in the closest region. For example, if a cost study is not available for a particular crop in the Sacramento Valley, the North San Joaquin Valley study may be used.

3.4 Crop Cost of Production Budgets

Land, labor, and other supply costs of production are obtained from the same UCCE crop budgets used to estimate crop yields. Each UCCE budget uses interest rates for capital recovery and interest on operating capital specific to the year of the study. These range from four percent to over eight percent and, as such, require adjustment to a common base year interest rate. A common rate of six percent is used for all data.

Land costs are derived from the respective UCCE crop budget and include land-related cash overhead plus rent and land capital recovery costs. Where appropriate, interest rates are adjusted as described above.

The labor cost category in the SWAP model includes both machine and non-machine labor. Labor wages per hour differ for machine and non-machine labor and, as such, are reported separately in the UCCE budgets. Both machine and non-machine labor costs include overhead to the farmer of federal and state payroll taxes, workers' compensation, and a small percentage for other benefits which varies by budget. Additionally, a percentage premium (typically around 20 percent) is added to machine labor costs to account for equipment set-up, moving, maintenance, breaks, and field repair. The sum of these components, reported on a per acre basis, is used as input data into the SWAP model.

The supply cost category in the SWAP model includes all inputs not explicitly included in the other three input categories (land, labor, and water), including fertilizers, herbicides, insecticide, fungicide, rodenticide, seed, fuel, and custom costs. Additionally, machinery, establishment costs, buildings, and irrigation system capital recovery costs are included. Each sub-category of supply costs is broken down in detail in the respective crop budget. For example, safflower in the Sacramento Valley requires pre-plant Nitrogen as aqua ammonia at 100 pounds per acre in fertilizer costs. Application of Roundup in February and Treflan in March account for herbicide costs. The sum of these individual components, on a per acre basis, is used as base supply input cost data in the SWAP model.

3.5 Surface and Groundwater

The SWAP model includes five types of surface water: SWP delivery; three categories of CVP delivery; and local surface water delivery or direct diversion. The three categories of CVP deliveries are: water service contract, including Friant Class 1 (CVP1); Friant Class 2 (CL2); and water rights settlement and exchange delivery[1]. Water supply data in the calibration year for SWAP version 6 are derived from various sources, described below. CVP and SWP deliveries for the SLLPIP alternatives are from the CalSim II model, described in Section 2.1.

The volume of deliveries for each water source is estimated using data from DWR, Reclamation, and water district reports. CVP water deliveries were derived from Reclamation operations data. Contract deliveries were obtained from Reclamation; the difference between total and contract deliveries indicates deliveries for water rights settlements. SWP water deliveries are obtained from DWR Bulletin 132 (DWR 2008). Kern County Water Agency provides additional details on SWP deliveries to member agencies by region. Local surface water deliveries were obtained from individual district records and reports, DWR water balance estimates prepared for the California Water Plan Update (DWR 2009), and, where needed, data from the CVPM model. CVPM data were, in turn, provided by the Central Valley Ground-Surface Water Model.

A key source of irrigation water, and often the costliest, is groundwater pumping. Groundwater pumping capacity estimates are from a 2009 analysis by DWR in consultation with individual districts. Groundwater pumping capacity is intended to represent the maximum that a region can pump in a year given the aquifer characteristics and existing well capacities.

Groundwater pumping costs are broken out into fixed, energy, and operations and maintenance (O&M) components in the SWAP model. Energy and O&M components are variable. Energy costs depend on the price of electricity. The SWAP model version 6 uses the same unit cost of electricity per kilowatt-hour across all regions. Base electricity costs are derived from Pacific Gas and Electric Company (PG&E) rate books and consultation with power officials at the Fresno, California office. Energy cost is 18.9 cents per kilowatt-hour, which is an average of PG&E's AG-1B and AG-4B rates (PG&E Various Years). Overall well efficiency is assumed to be 70 percent.

[1] CVP Settlement water is delivered to districts and individuals in the Sacramento Valley based on their pre-CVP water rights on the Sacramento River, and San Joaquin River Exchange water is pumped from the Delta and delivered to four districts in the San Joaquin Valley in exchange for water rights diversion eliminated when Friant Dam was constructed. These two delivery categories are geographically distinct but for convenience are combined into one water supply category in SWAP.

3.6 Crop Water Requirements

Applied water is the amount of water applied by the irrigation system to an acre of a given crop for production in a typical year. Variation in rainfall and other climate effects will alter this requirement. Additionally, farmers may stress irrigate crops or substitute other inputs in order to reduce applied water. The latter effect is handled endogenously by the SWAP model through the respective CES production functions. Applied water per acre (base) requirements for crops in the SWAP model are derived from DWR estimates. DWR estimates are based on Detailed Analysis Units (DAU). An average of DAUs within a SWAP region is used to generate a SWAP region specific estimate of applied water per acre for SWAP crops.

3.7 Elasticities

SWAP uses a number of economic response parameters, called elasticities, to estimate rates of change in variables. An elasticity is the percent change in a variable, per unit of percent change in another variable or parameter. Acreage response elasticity is one component of supply response. It is the percentage change in acreage of a crop from a one percent change in that crop's price. The SWAP model contains both long run and short run estimates, and the analyst decides which of the elasticities to use. Long run acreage response elasticities are used for this analysis.

3.7.1 SWAP Model Data Sources

The SWAP model version 6 uses a base year of 2005 for calibration. The calibration year is used to calibrate the underlying economic parameters in the model and does not represent current conditions used in the SLLPIP alternatives analysis. The calibration year is simply intended to represent "average" production conditions in the Central Valley. The year 2005 was neither abnormally dry nor wet, and crop markets had been relatively stable. Table 3 summarizes input data and sources used in the SWAP model.

Table 3. SWAP Model Input Data Summary

Input	Source	Notes
Land Use	DWR	Base year 2005
Crop Prices	County Agricultural Commissioners	By proxy crop using 2005—2007 average prices
Crop Yields	UCCE Crop Budgets	By proxy crop for various years (most recent available)
Interest Rates	UCCE Crop Budgets	All interest rates normalized to year 2005 (6.35%)
Land Costs	UCCE Crop Budgets	By proxy crop for various years (most recent available)
Other Supply Costs	UCCE Crop Budgets	By proxy crop for various years (most recent available)

Table 3. SWAP Model Input Data Summary

Input	Source	Notes
Land Use	DWR	Base year 2005
Crop Prices	County Agricultural Commissioners	By proxy crop using 2005—2007 average prices
Crop Yields	UCCE Crop Budgets	By proxy crop for various years (most recent available)
Labor Costs	UCCE Crop Budgets	By proxy crop for various years (most recent available)
Surface Water Costs	Reclamation, DWR, Individual Districts	By SWAP model region
Groundwater Costs	PG&E, Individual Districts	Total cost per acre-foot includes fixed, O&M, and energy cost
Irrigation Water	DWR	Average crop irrigation water requirements in acre-feet per acre
Available Water	CVPM, DWR, Reclamation, Individual Districts	By SWAP model region and water supply source
Elasticities	Green et al. 2006	California estimates

3.8 Linkage to Other Models

The SWAP model has important interactions with other models. In particular, CalSim II, DWR's project operations model for the SWP and the CVP, is used to estimate SWP and CVP supplies which are inputs into SWAP. An existing linkage tool has been developed to translate CalSim II delivery output to a corresponding SWAP input (on-farm applied water) file. Changes in depth to groundwater affect pumping costs and agricultural revenues. Changes in groundwater depth and resulting changes in groundwater pumping costs can be included from other model, such as CVHM or C2VSim, output, if those models are run concurrently for the project.

4.0 Implementing the SWAP Model for the SLLPIP Alternatives

Scenario analysis using the SWAP model can focus on a single point in time or on several future points. With reasonable interpolation, this approach will create a true time sequence to calculate net present value of a stream of costs or benefits. The alternatives for the SLLPIP were evaluated at a single point in time, also called the level of development.

The SWAP model is used to compare responses to changes in irrigation water delivery under the SLLPIP alternatives. Results from the CalSim II model are used as inputs into SWAP through a standardized data linkage tool. This linkage tool is used for the NAA, CVP Reservoir Expansion Alternative, and Shared Reservoir Expansion Alternative. The Increased San Luis Reservoir Carryover Storage Alternative is post-processed from the NAA, and this process is described below. The CalSim II data file for each scenario includes nine water year types, of which five are included in the SWAP model inputs. The water year types include wet, above normal, below normal, dry, and critical conditions. For each scenario and water year type, the CalSim II model provides the SWAP model with CVP and SWP on-farm water deliveries for each SWAP model region.

The Increased San Luis Reservoir Carryover Storage Alternative is post-processed from the CalSim II output for the NAA. Appendix B, the CalSim II modeling appendix, includes additional details about this alternative and how it was estimated from the NAA. CalSim II modelers provided the percent change in agricultural water deliveries relative to the NAA for south of Delta agricultural water service contract deliveries for each water year type. This percent change was then applied to the NAA south of Delta CVP agricultural water service contract deliveries for each of the SWAP model regions, and this is the water supply input file for the Increased San Luis Reservoir Carryover Storage Alternative.

4.1 Level of Development and Water Year Type

The SLLPIP NAA and three alternatives correspond to a 2030 level of development. Each alternative and level of development is evaluated for five water year types, including wet, above normal, below normal, dry, and critical.

4.1.1 Crop Demand Shifts

Crop demands are expected to shift in the future due to increased population, higher real incomes, changes in tastes and preferences, and related factors. The key changes that are included in the analysis of SLLPIP alternatives are population and real income. An increase in real income is expected to increase demand for agricultural products. Similarly, population increases are expected to increase crop demand. Changes in consumer tastes and preferences will have an indeterminate effect on demand and are not included in this analysis.

Increases in demand for crops produced in California may be partially offset by other production regions depending on changing export market conditions. For example, today California is the dominant producer of almonds but this may change if other regions increase production. Thus an increase in almond demand could be partially met by other regions. However, additional demand growth from markets like China may offset this effect. The net effect is indeterminate. In the absence of data or studies demonstrating which effect would dominate, California export share is assumed to remain constant for all crops in the future. This assumption is consistent with peer-reviewed publications for the California Energy Commission (CEC) and the academic journal *Climatic Change,* in addition to the 2009 DWR Water Plan (Howitt et al. 2009a, Howitt et al. 2009b).

Crop demands are linear in the SWAP model and population and real income changes induce a parallel shift in demand. Demand shifts are included for all of the alternative scenarios evaluated for the SLLPIP, including the No Action Alternative. Consequently, comparisons of NAA to each action alternative relates identical future market conditions.

For purposes of the demand shift analysis, a distinction is made between two types of crops grown in California, California specific crops and global commodities. Global commodity crops include grain rice, and corn[2]; all other crop groups are classified as California crops. Global commodity crops are those for which there is no separate demand for California's production. For these crops, California faces a perfectly elastic demand, and is thus a price taker. For California specific crops, California faces a downward sloping demand for a market that is driven by conditions in the United States and international export markets. A routine in the SWAP model calculates the demand shift for the 2030 level of development for the SLLPIP alternatives.

4.1.2 Electricity Costs

Groundwater is typically the most expensive water supply. Real power costs are expected to increase in the future, and groundwater relies heavily on the cost of electricity for pumping. Energy pumping costs are escalated according to future marginal power cost estimates for the year 2030.

A marginal power cost escalator is determined for the year 2030 and applied to the energy cost component of groundwater costs. The cost escalator is the ratio of the expected future power cost in 2030 to the base power cost in 2005, in 2005 dollars per megawatt hour. Expected future power costs are calculated using the DWR Forward Price Projections analysis using wholesale power costs (DWR 2011). This calculates an average power cost for each month as the average of the peak (upper bound) and off-peak (lower bound) rates. An average of the monthly costs generates an average yearly cost. This cost is used to generate the power cost escalator by taking the ratio of the future year average to the current year average. The power cost escalator for 2030 is 1.54.

4.1.3 Groundwater Depth

The SWAP model can be linked to a groundwater model to estimate change in depth to groundwater, both static and dynamic, to estimate the additional lift, and therefore energy cost, for water year types. Dry years can result in groundwater levels dropping by several feet in some regions of the Central Valley, depending on local aquifer conditions. The CVHM or C2VSim models were not run for the SLLPIP alternatives. A review of existing studies using the

[2] Rice demand is very elastic, but not perfectly elastic. For purposes of the demand shifting analysis, it is assumed to be perfectly elastic.

SWAP model linked to CVHM determined that no basis was available to adjust depth to groundwater under the alternative water year types. As such, depth to groundwater is held constant at the baseline levels under all water year types and alternatives.

4.1.4 Other Factors

The SWAP model includes a number of sub-routines that are included in studies on a case-by-case basis. All of these other factors are held constant in the SLLPIP alternatives.

Climate change effects are held constant in the analysis of SLLPIP alternatives. The SWAP model has been linked to crop models, such as LAWS, to estimate the change in crop yield and crop evapotranspiration and, therefore, applied water requirements. Climate change effects on crop growth remain highly uncertain and are consequently held constant in the analysis.

Crop yields have been increasing for most crops due to technological innovations. Innovations like hybrid seeds, better chemicals and fertilizer, improved pest management, and irrigation and mechanical harvesting advances are some examples. The expected future rate of growth in crop yields remains a contentious topic among researchers. Consequently, yield changes due to technological innovations are held constant in the analysis of SLLPIP alternatives. It is important to note that the SWAP model does allow for some minor yield response to changing market conditions. This effect is referred to as endogenous yield changes. The SWAP model includes full CES production functions for each crop and region, which allow for some endogenous yield change in response to changing market conditions, but there is no exogenous technological change included in the analysis.

4.2 NED Benefits Calculations

The basic guidelines for evaluating water development projects at the federal level are specified in the “Principles, Requirements, and Guidelines for Federal Investments in Water Resources” (PR&Gs; CEQ 2014). Under the PR&Gs, the federal objective for water contributions is to maximize the contribution to NED consistent with protection of the environment. In order to adhere to the PR&Gs and determine the contribution to NED, a series of adjustments to the SWAP model and data are necessary. Adjustments fall into two categories, pre- and post-processing. Pre-processing adjustments are made prior to optimization with the SWAP model and include adjustments to SWAP input data and exogenous projections of future costs and demands. Post-processing adjustments are applied to SWAP output and include adjustments to prices and costs. They are adjustments needed in order for the results to comply with PR&Gs and Reclamation guidelines for NED analysis. In particular, guidelines require that certain prices be used for valuing changes in physical inputs and outputs. They do not explicitly affect farmers’ decisions, so they are applied after the SWAP optimization. Post-processing adjustments include interest rates, other supply costs, fallow land costs, normalized crop prices, consumer surplus, water costs, and management charges.

All of the NED adjustments follow the SWAP NED adjustments developed in consultation with Reclamation for the North of Delta Offstream Storage (NODOS) feasibility study. The data have been updated to reflect current conditions (e.g., Current Normalized Prices are updated), but the fundamental method is unchanged. This section provides an overview of the approach.

Pre-processing adjustments include changes to the data that occur before SWAP model optimization. This includes demand shifts, energy pumping costs, interest rate adjustment, and other factors as described earlier in this section. These adjustments are made prior to SWAP optimization and are made regardless of whether the project is being evaluated under NED guidelines.

Post-processing adjustments take place after the SWAP model optimization. These include:

1. The PR&Gs require that the federal discount rate be used for all interest and capital recovery calculations. The current federal discount rate is 3.125 percent. A post-processing adjustment is applied to cost data components to adjust the interest rate to 3.125 percent.

2. Machinery capital recovery costs are removed from the NED analysis under all scenarios. Additional land coming into irrigated production (with the project versus without the project) would be quite small and is therefore unlikely to require additional machinery investment. By the same logic, buildings capital recovery costs are removed from the NED analysis under all scenarios.

3. Land rent and cash overhead and land capital recovery costs are removed from the NED analysis under all scenarios. The NED analysis is adjusted to remove land costs that are included within the SWAP data file because lands being brought into irrigated production are already considered a sunk investment. Sunk investments are irrelevant to determining the economic feasibility of new project investments.

4. Interest on operating capital and capital recovery charges for permanent crop establishment and for irrigation systems are adjusted using interest factors as noted above.

5. An annual maintenance cost of $41.88 per acre (in 2016 dollars) is used for the NED analysis to account for fallow land costs, as required by the PR&Gs.

6. Consumer surplus is the benefit (welfare gain) that consumers realize from being able to purchase crops at less than their maximum

willingness to pay. Since the changes in water supply and crop price are negligible under the SLLPIP alternatives, the change in consumer surplus is negligible and is excluded from the SLLPIP NED benefits calculations.

7. Surface water costs are excluded from the NED benefits calculation. In a NED benefit-cost analysis of a proposed project, the incremental investment and annual costs of the new water supply are accounted for on the cost side of the ledger, so including them as water costs within the benefits analysis would effectively be double-counting.

8. Reclamation guidelines for preparing NED analysis under the PR&Gs recommend including management costs at no less than six percent of variable costs. A six percent management charge is added to the variable production costs in the SWAP model.

9. The PR&Gs state that U.S. Department of Agriculture (USDA) Current Normalized Prices (CNP) must be used for benefits calculations when available. These prices have been adjusted by USDA to remove any federal subsidies because such subsidies represent an NED cost that must be accounted for in comparing project benefits and costs. For crop groups covered by USDA's CNP estimates, SWAP prices were converted to scaled CNP. For crop groups without available CNP, the SWAP-predicted prices are used. CNP reported in dollars per ton, are as follows: corn $120.36; cotton $1,413.07; dry beans $952.00; grains (wheat) $154.00; rice $312.80; and sugar beets $41.92.

5.0 Description of SLLPIP Results

This section describes the SWAP model results for NAA and the SLLPIP action alternatives. Changes in economic conditions in the Central Valley are summarized in terms of irrigated acreage, gross farm revenues, groundwater use, and groundwater cost. As described previously, the Sacramento Valley, San Joaquin River, and Tulare Lake regions are summarized. Water year types summarized in this section include wet, below normal, and critical conditions.

5.1 No Action Alternative

The NAA represents future market and production conditions for Central Valley agriculture if the SLLPIP is not implemented. The NAA is used to compare the policy alternatives. Table 4 shows the total irrigated acreage and gross value of agricultural production under the NAA. Table 5 shows the total groundwater pumping and cost under the NAA.

On average, in the Central Valley over $28 billion in gross value of production is generated on about 6.8 million irrigated acres. The wet water year conditions lead to the highest value and largest irrigated footprint. The total irrigated area and gross value decreases in below normal and critical conditions as growers shift the crop mix to lower water use crops and fallow land in response to constrained surface water supplies. For example, the Central Valley irrigates 6.87 million acres in wet years and 6.62 million acres in critically dry years and the corresponding gross value of production decreases from $28.2 million to $26.6 million. Growers are able to partially offset reduced surface water supplies by increasing the amount of groundwater pumped. Groundwater pumping increases from 5.98 million acre-feet (AF) to 8.13 million AF between wet and critically dry years.

Table 4. NAA Acreage and Value

Analysis Metric	NAA Value
	Wet Condition
Total Irrigated Acreage (thousand acres)	
Sacramento River	1,522
San Joaquin River	2,212
Tulare Lake	3,139
Total Value of Production (million $)	
Sacramento River	6,572.9
San Joaquin River	8,220.2
Tulare Lake	13,424.2
	Above Normal Condition
Total Irrigated Acreage (thousand acres)	
Sacramento River	1,522
San Joaquin River	2,211
Tulare Lake	3,139
Total Value of Production (million $)	
Sacramento River	5,428.8
San Joaquin River	8,220.1
Tulare Lake	13,423.2
	Below Normal Condition
Total Irrigated Acreage (thousand acres)	
Sacramento River	1,525
San Joaquin River	2,210
Tulare Lake	3,138
Total Value of Production (million $)	
Sacramento River	5,430.1
San Joaquin River	8,219.8
Tulare Lake	13,423.2
	Dry Condition
Total Irrigated Acreage (thousand acres)	
Sacramento River	1,507
San Joaquin River	2,210
Tulare Lake	3,068
Total Value of Production (million $)	

Table 4. NAA Acreage and Value

Analysis Metric	NAA Value
Sacramento River	5,397.3
San Joaquin River	8,225.6
Tulare Lake	13,344.8
	Critical Condition
Total Irrigated Acreage (thousand acres)	
Sacramento River	1,478
San Joaquin River	2,210
Tulare Lake	2,939
Total Value of Production (million $)	
Sacramento River	5,331.1
San Joaquin River	8,246.7
Tulare Lake	13,089.1

Table 5. NAA Groundwater Use and Cost

Analysis Metric	NAA Value
	Wet Condition
Annual Groundwater Pumped (thousand AF [TAF])	
Sacramento River	1,406.2
San Joaquin River	1,474.0
Tulare Lake	3,099.9
Annual Cost of Pumping (million $)	
Sacramento River	83.7
San Joaquin River	126.7
Tulare Lake	436.1
	Above Normal Condition
Annual Groundwater Pumped (TAF)	
Sacramento River	1,399.1
San Joaquin River	1,599.1
Tulare Lake	3,613.2
Annual Cost of Pumping (million $)	
Sacramento River	83.7
San Joaquin River	137.1
Tulare Lake	535.8
	Below Normal Condition
Annual Groundwater Pumped (TAF)	
Sacramento River	1,436.9
San Joaquin River	1,664.0
Tulare Lake	3,761.1
Annual Cost of Pumping (million $)	
Sacramento River	89.3
San Joaquin River	142.4
Tulare Lake	566.1

Table 5. NAA Groundwater Use and Cost

Analysis Metric	NAA Value
	Dry Condition
Annual Groundwater Pumped (TAF)	
Sacramento River	1,447.7
San Joaquin River	1,799.8
Tulare Lake	4,134.0
Annual Cost of Pumping (million $)	
Sacramento River	90.0
San Joaquin River	153.7
Tulare Lake	623.5
	Critical Condition
Annual Groundwater Pumped (TAF)	
Sacramento River	1,574.7
San Joaquin River	2,056.1
Tulare Lake	4,506.7
Annual Cost of Pumping (million $)	
Sacramento River	98.6
San Joaquin River	174.8
Tulare Lake	678.5

5.2 CVP Reservoir Expansion Alternative

The CVP Reservoir Expansion Alternative provides CVP agricultural water service contractors with a larger share of the additional irrigation water. Appendix B describes the water supply conditions underlying this alternative in detail.

Table 6 shows the total irrigated acreage and gross farm revenues under CVP Reservoir Expansion Alternative and the change from the NAA. Table 7 shows the total groundwater use and groundwater cost under the CVP Reservoir Expansion Alternative and the change from the NAA.

Regions that receive CVP supplies show a small increase in irrigated acreage and reduction in groundwater pumping relative to the NAA. The increases in CVP deliveries are relatively modest, less than a few TAF per year, and the corresponding change in irrigated acreage and groundwater use is small. In all water year conditions, the CVP Reservoir Expansion Alternative has a negligible effect on total irrigated acreage and value. Crop production expands by less than 100 acres and crop revenues increase by a few thousand dollars.

The additional CVP supplies result in a reduction in total groundwater pumping, which is approximately equal to the increase in CVP surface water supplies in most regions. In wet years, total groundwater pumping decreases by 22,800 AF at a cost savings of $4.5 million per year. Under progressively drier conditions the CVP Reservoir Expansion Alternatives provides fewer incremental CVP supplies, and irrigators already rely on groundwater for a larger share of total irrigation supply, thus the groundwater pumping and cost savings attributable to the CVP Reservoir Expansion Alternative decreases. In critically dry years, the CVP Reservoir Expansion Alternative results in no groundwater pumping savings.

The effects of the CVP Reservoir Expansion Alternative are not constant across regions in the Central Valley. For example, in Below Normal, Above Normal, and Wet conditions, the San Joaquin River region receives more CVP water, expands production, and the total value of production increases relative to the NAA. As production increases, the farm-gate price of those crops decreases. In turn, the farm-gate value of production decreases in some Sacramento and Tulare Lake regions.

In general, the incremental effect of the CVP Reservoir Expansion Alternative relative to the NAA is small in most regions. Increased CVP supplies are primarily used to reduce groundwater pumping, which provides a cost-saving benefit to irrigators. This changes the average cost of irrigation water, and growers adjust the underlying crop mix in response. In addition, some regions utilize additional surface supplies to (slightly) expand production slightly under the CVP Reservoir Expansion Alternative. As production increases, the price of the crop falls, all else equal, which can cause farm-gate revenues to fall in other regions.

Table 6. CVP Reservoir Expansion Alternative Acreage and Value

Analysis Metric	CVP Reservoir Expansion Alternative	Change from NAA
	Wet Condition	
Total Irrigated Acreage (thousand acres)		
Sacramento River	1,522	0.00
San Joaquin River	2,212	0.03
Tulare Lake	3,139	0.00
Total Value of Production (million $)		
Sacramento River	5,428.6	0.00
San Joaquin River	8,220.3	0.02
Tulare Lake	13,424.2	0.00
	Above Normal Condition	
Total Irrigated Acreage (thousand acres)		
Sacramento River	1,522	0.000
San Joaquin River	2,211	0.055
Tulare Lake	3,139	-0.010
Total Value of Production (million $)		

Table 6. CVP Reservoir Expansion Alternative Acreage and Value

Analysis Metric	CVP Reservoir Expansion Alternative	Change from NAA
Sacramento River	5,428.8	-0.001
San Joaquin River	8,220.1	0.026
Tulare Lake	13,423.2	-0.015
	Below Normal Condition	
Total Irrigated Acreage (thousand acres)		
Sacramento River	1,525	0.00
San Joaquin River	2,210	0.08
Tulare Lake	3,138	-0.22
Total Value of Production (million $)		
Sacramento River	5,430.1	0.00
San Joaquin River	8,219.8	0.05
Tulare Lake	13,423.1	-0.13
	Dry Condition	
Total Irrigated Acreage (thousand acres)		
Sacramento River	1,507	-0.07
San Joaquin River	2,210	0.00
Tulare Lake	3,069	0.65
Total Value of Production (million $)		
Sacramento River	5,397.2	-0.19
San Joaquin River	8,225.6	-0.01
Tulare Lake	13,345.9	1.14
	Critical Condition	
Total Irrigated Acreage (thousand acres)		
Sacramento River	1,478	0.009
San Joaquin River	2,210	0.000
Tulare Lake	2,939	0.010
Total Value of Production (million $)		
Sacramento River	5,331.2	0.010
San Joaquin River	8,246.7	-0.006
Tulare Lake	13,089.2	0.025

Table 7. CVP Reservoir Expansion Alternative Groundwater Use and Cost

Analysis Metric	CVP Reservoir Expansion Alternative	Change from NAA
	Wet Condition	
Annual Groundwater Pumped (TAF)		
Sacramento River	1,405.0	-1.17
San Joaquin River	1,467.6	-6.40
Tulare Lake	3,084.6	-15.28
Annual Cost of Pumping (million $)		
Sacramento River	83.6	-0.12
San Joaquin River	126.1	-0.54
Tulare Lake	432.3	-3.84
	Above Normal Condition	
Annual Groundwater Pumped (TAF)		
Sacramento River	1,396.8	-2.31
San Joaquin River	1,594.8	-4.34
Tulare Lake	3,599.2	-14.01
Annual Cost of Pumping (million $)		
Sacramento River	83.4	-0.26
San Joaquin River	136.7	-0.36
Tulare Lake	532.6	-3.24
	Below Normal Condition	
Annual Groundwater Pumped (TAF)		
Sacramento River	1,433.2	-3.69
San Joaquin River	1,658.5	-5.45
Tulare Lake	3,756.1	-5.06
Annual Cost of Pumping (million $)		
Sacramento River	88.9	-0.39
San Joaquin River	142.0	-0.46
Tulare Lake	564.3	-1.75
	Dry Condition	
Annual Groundwater Pumped (TAF)		
Sacramento River	1,447.7	0.02
San Joaquin River	1,799.8	-0.05
Tulare Lake	4,133.0	-1.05
Annual Cost of Pumping (million $)		
Sacramento River	90.0	0.00
San Joaquin River	153.7	0.00
Tulare Lake	623.3	-0.16
	Critical Condition	
Annual Groundwater Pumped (TAF)		
Sacramento River	1,575.0	0.22
San Joaquin River	2,056.1	-0.01
Tulare Lake	4,506.6	-0.03

Table 7. CVP Reservoir Expansion Alternative Groundwater Use and Cost

Analysis Metric	CVP Reservoir Expansion Alternative	Change from NAA
Annual Cost of Pumping (million $)		
Sacramento River	98.7	0.02
San Joaquin River	174.8	0.00
Tulare Lake	678.5	0.00

5.3 Increased San Luis Reservoir Carryover Storage Alternative

The Increased San Luis Reservoir Carryover Storage Alternative is post-processed from the NAA, as described under Section 4. Under this alternative, south of Delta CVP water service contractors receive an additional 0.018 to 1.505 percent in surface water supplies, varying by water year type. Appendix B describes the water supply results in more detail.

Table 8 shows the total irrigated acreage and gross farm revenues under the Increased San Luis Reservoir Carryover Storage Alternative and the change from the NAA. Table 9 shows the total groundwater use and groundwater cost under the Increased San Luis Reservoir Carryover Storage Alternative and the change from the NAA.

Regions that receive CVP supplies show a small increase in irrigated acreage and reduction in groundwater pumping relative to the NAA. The increases in CVP deliveries are relatively modest, and in many years are negligible, and the corresponding change in irrigated acreage and groundwater use is small. In all water year conditions, the Increased San Luis Reservoir Carryover Storage Alternative has a negligible effect on total irrigated acreage and value. Crop production expands by less than 100 acres and crop revenues increase by a few thousand dollars.

The additional CVP supplies result in a reduction in total groundwater pumping, which is approximately equal to the increase in CVP surface water supplies in most regions. In wet years, total groundwater pumping decreases by 5,900 AF at a cost savings of $1.1 million per year. Under progressively drier conditions the Increased San Luis Reservoir Carryover Storage Alternative provides fewer incremental CVP supplies, and irrigators already rely on groundwater for a larger share of total irrigation supply, thus the groundwater pumping and cost savings attributable to the Increased San Luis Reservoir Carryover Storage Alternative decreases. In critically dry years, the Increased San Luis Reservoir Carryover Storage Alternative provides no additional CVP supplies relative to the NAA, and there is no change in groundwater pumping.

The effects of the Increased San Luis Reservoir Carryover Storage Alternative are not constant across regions in the Central Valley. In Below Normal, Above

Normal, and Wet conditions, all of the additional CVP water is used to substitute for groundwater pumping. There is no increase in the farm-gate value of production in these years. Under dry years, there is a modest increase in irrigated acreage in the Tulare Lake region. In turn, production increases and the price of the crops for which production increases falls, causing a decrease in farm-gate revenues in other region. The critical water year conditions do not provide any additional surface supplies.

In general, the incremental effect of the Increased San Luis Reservoir Carryover Storage Alternative relative to the NAA is small in most regions. The alternative provides no additional surface water under critical water year conditions. For years in which it is available, increased CVP supplies are primarily used to reduce groundwater pumping, which provides a cost-saving benefit to irrigators. This changes the average cost of irrigation water, and growers adjust the underlying crop mix in response. In addition, some regions utilize additional surface supplies to (slightly) expand production slightly under the Increased San Luis Reservoir Carryover Storage Alternative. As production increases, the price of the crop falls, all else equal, which can cause farm-gate revenues to fall in other regions.

Table 8. Increased San Luis Reservoir Carryover Storage Alternative Acreage and Value

Analysis Metric	Increased San Luis Reservoir Carryover Storage Alternative	Change from NAA
	Wet Condition	
Total Irrigated Acreage (thousand acres)		
Sacramento River	1,522	0.00
San Joaquin River	2,212	0.00
Tulare Lake	3,139	0.00
Total Value of Production (million $)		
Sacramento River	5,428.6	0.00
San Joaquin River	8,220.2	0.00
Tulare Lake	13,424.2	0.00
	Above Normal Condition	
Total Irrigated Acreage (thousand acres)		
Sacramento River	1,522	0.00
San Joaquin River	2,211	0.00
Tulare Lake	3,139	0.00
Total Value of Production (million $)		
Sacramento River	5,428.8	0.00
San Joaquin River	8,220.1	0.00
Tulare Lake	13,423.2	0.00

Analysis Metric	Increased San Luis Reservoir Carryover Storage Alternative	Change from NAA
	Below Normal Condition	
Total Irrigated Acreage (thousand acres)		
Sacramento River	1,525	0.00
San Joaquin River	2,210	0.00
Tulare Lake	3,138	0.00
Total Value of Production (million $)		
Sacramento River	5,430.1	0.00
San Joaquin River	8,219.8	0.00
Tulare Lake	13,423.2	0.00
	Dry Condition	
Total Irrigated Acreage (thousand acres)		
Sacramento River	1,507	-0.001
San Joaquin River	2,210	-0.002
Tulare Lake	3,070	2.260
Total Value of Production (million $)		
Sacramento River	5,397.3	-0.008
San Joaquin River	8,225.6	-0.044
Tulare Lake	13,348.8	4.012
	Critical Condition	
Total Irrigated Acreage (thousand acres)		
Sacramento River	1,478	0.000
San Joaquin River	2,210	0.000
Tulare Lake	2,939	0.000
Total Value of Production (million $)		
Sacramento River	5,331.1	0.000
San Joaquin River	8,246.7	0.000
Tulare Lake	13,089.1	0.000

Table 9. Increased San Luis Reservoir Carryover Storage Alternative Groundwater Use and Cost

Analysis Metric	Increased San Luis Reservoir Carryover Storage Alternative	Change from NAA
	Wet Condition	
Annual Groundwater Pumped (TAF)		
Sacramento River	1,406.2	0.000
San Joaquin River	1,472.4	-1.592
Tulare Lake	3,095.5	-4.355
Annual Cost of Pumping (million $)		
Sacramento River	83.7	0.000
San Joaquin River	126.5	-0.133
Tulare Lake	435.1	-1.057

Analysis Metric	Increased San Luis Reservoir Carryover Storage Alternative	Change from NAA
	Above Normal Condition	
Annual Groundwater Pumped (TAF)		
Sacramento River	1,399.1	0.000
San Joaquin River	1,597.9	-1.212
Tulare Lake	3,609.9	-3.318
Annual Cost of Pumping (million $)		
Sacramento River	83.7	0.000
San Joaquin River	137.0	-0.101
Tulare Lake	535.0	-0.801
	Below Normal Condition	
Annual Groundwater Pumped (TAF)		
Sacramento River	1,436.9	0.000
San Joaquin River	1,663.9	-0.038
Tulare Lake	3,761.0	-0.114
Annual Cost of Pumping (million $)		
Sacramento River	89.3	0.000
San Joaquin River	142.4	-0.003
Tulare Lake	566.0	-0.027
	Dry Condition	
Annual Groundwater Pumped (TAF)		
Sacramento River	1,447.7	-0.002
San Joaquin River	1,797.6	-2.167
Tulare Lake	4,132.7	-1.306
Annual Cost of Pumping (million $)		
Sacramento River	90.0	0.000
San Joaquin River	153.5	-0.181
Tulare Lake	623.3	-0.182
	Critical Condition	
Annual Groundwater Pumped (TAF)		
Sacramento River	1,574.7	0.000
San Joaquin River	2,056.1	0.000
Tulare Lake	4,506.7	0.000
Annual Cost of Pumping (million $)		
Sacramento River	98.6	0.000
San Joaquin River	174.8	0.000
Tulare Lake	678.5	0.000

5.4 Shared Reservoir Expansion Alternative

The Shared Reservoir Expansion Alternative provides additional surface supplies to both SWP and CVP contractors. Appendix B describes the water supply conditions underlying this alternative in detail.

Table 10 shows the total irrigated acreage and gross farm revenues under the Shared Reservoir Expansion Alternative and the change from the future NAA. Table 11 shows the total groundwater use and groundwater cost under Shared Reservoir Expansion Alternative and the change from NAA.

Regions that receive CVP or SWP irrigation water supplies show a small increase in irrigated acreage and reduction in groundwater pumping relative to NAA. Similar to the CVP Reservoir Expansion alternative, the increases in CVP and SWP deliveries are relatively modest, less than a few TAF per year, and the corresponding change in irrigated acreage and groundwater use is small. In all water year conditions, the Shared Reservoir Expansion Alternative has a negligible effect on total irrigated acreage and value. Crop production expands or contracts by fewer than 200 acres under any water year type. Crop revenues increase by less than $200,000 annually.

The additional CVP and SWP supplies result in a reduction in total groundwater pumping, which is approximately equal to the increase in surface water supplies in most regions. In wet years, total groundwater pumping decreases by 11 TAF at a cost savings of $2.1 million per year. Under progressively drier conditions the Shared Reservoir Expansion Alternative provides fewer incremental CVP and SWP supplies, and irrigators already rely on groundwater for a larger share of total irrigation supply, thus the groundwater pumping and cost savings attributable to the Shared Reservoir Expansion Alternative decreases. In dry and critically dry years, the Shared Reservoir Expansion Alternative results in no groundwater pumping savings.

The effects of the Shared Reservoir Expansion Alternative are not constant across regions in the Central Valley. In Above Normal conditions, the Tulare Lake region receives CVP and SWP supplies, expands production, and the total value of production increases relative to the NAA. As production increases, the farm-gate price of those crops decreases. In turn, the farm-gate value of production decreases in some Sacramento and San Joaquin River regions.

In general, the incremental effect of the Shared Reservoir Expansion Alternative relative to the NAA is small in most regions. Increased CVP and SWP supplies are primarily used to reduce groundwater pumping, which provides a cost-saving benefit to irrigators. This changes the average cost of irrigation water, and growers adjust the underlying crop mix in response. In addition, some regions utilize additional surface supplies to (slightly) expand production under the Shared Reservoir Expansion Alternative. As production increases, the price of the crop falls, all else equal, which can cause farm-gate revenues to fall in other regions.

Table 10. Shared Reservoir Expansion Alternative Acreage and Value

Analysis Metric	Shared Reservoir Expansion Alternative	Change from NAA
	Wet Condition	
Total Irrigated Acreage (thousand acres)		
Sacramento River	1,522	0.00
San Joaquin River	2,212	0.01
Tulare Lake	3,139	0.00
Total Value of Production (million $)		
Sacramento River	5,428.6	0.00
San Joaquin River	8,220.2	0.01
Tulare Lake	13,424.2	0.00
	Above Normal Condition	
Total Irrigated Acreage (thousand acres)		
Sacramento River	1,522	0.00
San Joaquin River	2,211	0.03
Tulare Lake	3,139	0.06
Total Value of Production (million $)		
Sacramento River	5,428.8	-0.01
San Joaquin River	8,220.0	-0.01
Tulare Lake	13,423.3	0.11
	Below Normal Condition	
Total Irrigated Acreage (thousand acres)		
Sacramento River	1,525	0.00
San Joaquin River	2,210	0.05
Tulare Lake	3,138	-0.20
Total Value of Production (million $)		
Sacramento River	5,430.1	0.00
San Joaquin River	8,219.8	0.03
Tulare Lake	13,423.1	-0.08
	Dry Condition	
Total Irrigated Acreage (thousand acres)		
Sacramento River	1,507	-0.08
San Joaquin River	2,210	0.00
Tulare Lake	3,068	0.11
Total Value of Production (million $)		
Sacramento River	5,397.1	-0.20
San Joaquin River	8,225.6	0.03
Tulare Lake	13,345.1	0.36
	Critical Condition	
Total Irrigated Acreage (thousand acres)		
Sacramento River	1,478	0.04
San Joaquin River	2,210	0.00
Tulare Lake	2,939	0.02
Total Value of Production (million $)		
Sacramento River	5,331.2	0.09
San Joaquin River	8,246.8	0.06
Tulare Lake	13,088.9	-0.20

Table 11. Shared Reservoir Expansion Alternative Groundwater Use and Cost

Analysis Metric	Shared Reservoir Expansion Alternative	Change from NAA
	Wet Condition	
Annual Groundwater Pumped (TAF)		
Sacramento River	1,405.6	-0.57
San Joaquin River	1,471.1	-2.88
Tulare Lake	3,092.3	-7.65
Annual Cost of Pumping (million $)		
Sacramento River	83.7	-0.06
San Joaquin River	126.4	-0.24
Tulare Lake	434.3	-1.86
	Above Normal Condition	
Annual Groundwater Pumped (TAF)		
Sacramento River	1,397.7	-1.44
San Joaquin River	1,597.1	-2.04
Tulare Lake	3,604.2	-8.96
Annual Cost of Pumping (million $)		
Sacramento River	83.5	-0.15
San Joaquin River	136.9	-0.17
Tulare Lake	533.9	-1.92
	Below Normal Condition	
Annual Groundwater Pumped (TAF)		
Sacramento River	1,434.7	-2.17
San Joaquin River	1,660.5	-3.43
Tulare Lake	3,760.4	-0.73
Annual Cost of Pumping (million $)		
Sacramento River	89.1	-0.23
San Joaquin River	142.1	-0.29
Tulare Lake	565.4	-0.64
	Dry Condition	
Annual Groundwater Pumped (TAF)		
Sacramento River	1,447.7	0.03
San Joaquin River	1,799.8	-0.05
Tulare Lake	4,134.6	0.60
Annual Cost of Pumping (million $)		
Sacramento River	90.0	0.00
San Joaquin River	153.7	0.00
Tulare Lake	623.5	0.01
	Critical Condition	
Annual Groundwater Pumped (TAF)		
Sacramento River	1,574.7	0.01
San Joaquin River	2,056.0	-0.05
Tulare Lake	4,506.9	0.22

Analysis Metric	Shared Reservoir Expansion Alternative	Change from NAA
Annual Cost of Pumping (million $)		
Sacramento River	98.6	0.00
San Joaquin River	174.8	0.00
Tulare Lake	678.6	0.0

6.0 SWAP Model Limitations

The SWAP model is an optimization model that makes the best (i.e., most profitable) adjustments to water supply and other changes. Constraints can be imposed to simulate restrictions on how much adjustment is possible or how fast the adjustment can realistically occur. Nevertheless, an optimization model can tend to over-adjust and minimize costs associated with detrimental changes or, similarly, maximize benefits associated with positive changes.

SWAP does not explicitly account for the dynamic nature of agricultural production; it provides a point-in-time comparison between two conditions. This is consistent with the way most economic and environmental impact analysis is conducted, but it can obscure sometimes important adjustment costs.

SWAP also does not explicitly incorporate risk or risk preferences (e.g., risk aversion) into its objective function. Risk and variability are handled in two ways. First, the calibration procedure for SWAP is designed to reproduce observed crop mix, so to the extent that crop mix incorporates risk spreading and risk aversion, the starting, calibrated SWAP base condition will also. Second, variability in water delivery, prices, yields, or other parameters can be evaluated by running the model over a sequence of conditions or over a set of conditions that characterize a distribution, such as a set of water year types.

Groundwater is an alternative source to augment SWP and CVP delivery in many subregions. The cost and availability of groundwater therefore has an important effect on how SWAP responds to changes in delivery. However, SWAP is not a groundwater model and does not include any direct way to adjust pumping lifts and unit pumping cost in response to long-run changes in pumping quantities.

Similar to other DWR water models including LCPSIM, SWAP currently does not differentiate between water delivered under the Table A, Article 21, or Article 56 provisions of the SWP water contracts, treating the supplies as equally valuable for crop production.

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