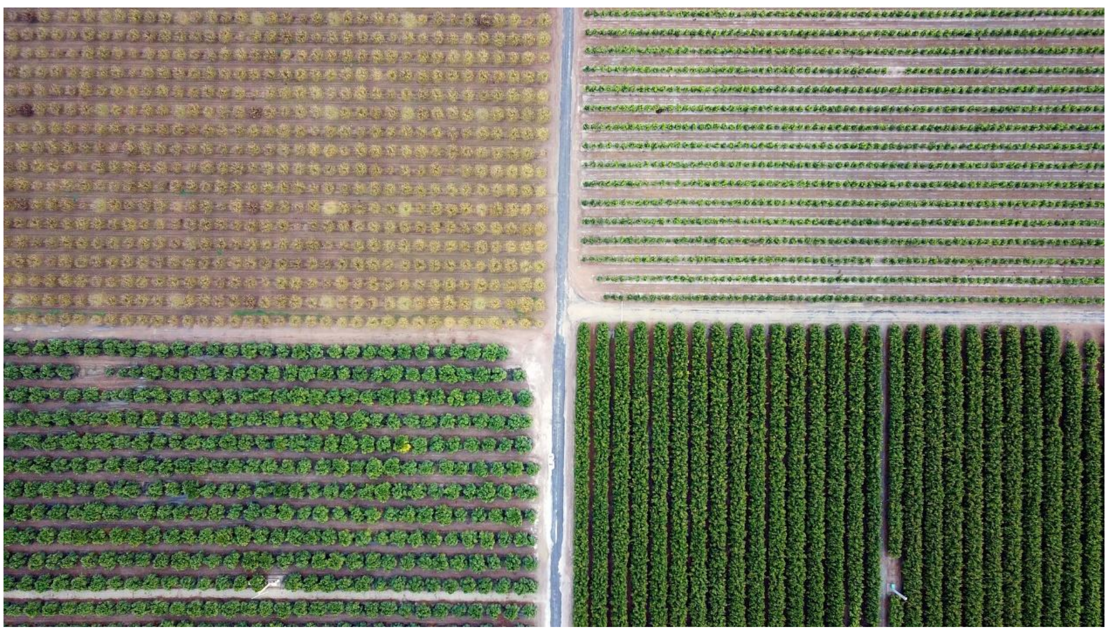
Methodologies for a Scenario-Planning System Applicable to Agriculture Management-based Conservation Programs in California

Prepared for the USDA Natural Resource Conservation Service in fulfillment of Conservation Innovation Grant Award Number 69-3A75-17-287



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INTRODUCTION

This document was prepared for the United States Department of Agriculture (USDA) Natural Resource Conservation Service (NRCS) in fulfillment of Conservation Innovation Grant Award Number 69-3A75-17-287. It describes methodologies developed by The Freshwater Trust (TFT) for the integration of multiple, publicly available data sets and analytical methods, which collectively result in a scenario-planning systems (SPS) for the prioritization and optimization of NRCS practice implementation in California. The methods were developed and applied in the Solano County area, but they can be used throughout California agricultural landscapes. For full details of the project, background, outcomes, and methods application, see the Final Grant Report available through NRCS.

Using available data for the Solano County area, TFT developed the SPS for implementation of select NRCS practices. Three farm management activities were chosen for initial inclusion in the SPS based on their likelihood of adoption, widespread applicability, and potential for water resource benefits. These activities and their applicable NRCS Practice Standard Codes are: irrigation efficiency improvements (441, 442); cover cropping (340); and managed aquifer recharge (MAR). Although NRCS practice standards for agricultural MAR in California are currently under development, these management actions are collectively referred to as NRCS practices (or “conservation practices”) throughout this report. In this context, MAR refers to stormwater retention on—or application of excess surface water flows to— agricultural lands for groundwater recharge. All NRCS practice scenarios are described in greater detail below (see Conservation Practice Scenario Development).

The SPS methodologies were applied to an area referred to by TFT as the Solano Area of Interest (AOI). It encompasses significant agricultural and regulatory boundaries in the region, including Solano County, Dixon and Solano Resource Conservation Districts (RCDs), and all Groundwater Sustainability Agency (GSA) boundaries that will be included in the Solano Subbasin Collaborative Groundwater Sustainability Plan (GSP). As a result, small portions of Sacramento and Yolo Counties are also incorporated into the Solano AOI. In total, this application of the SPS assesses agricultural management on 7,028 fields across 273,161 agronomic acres (Figure 1).

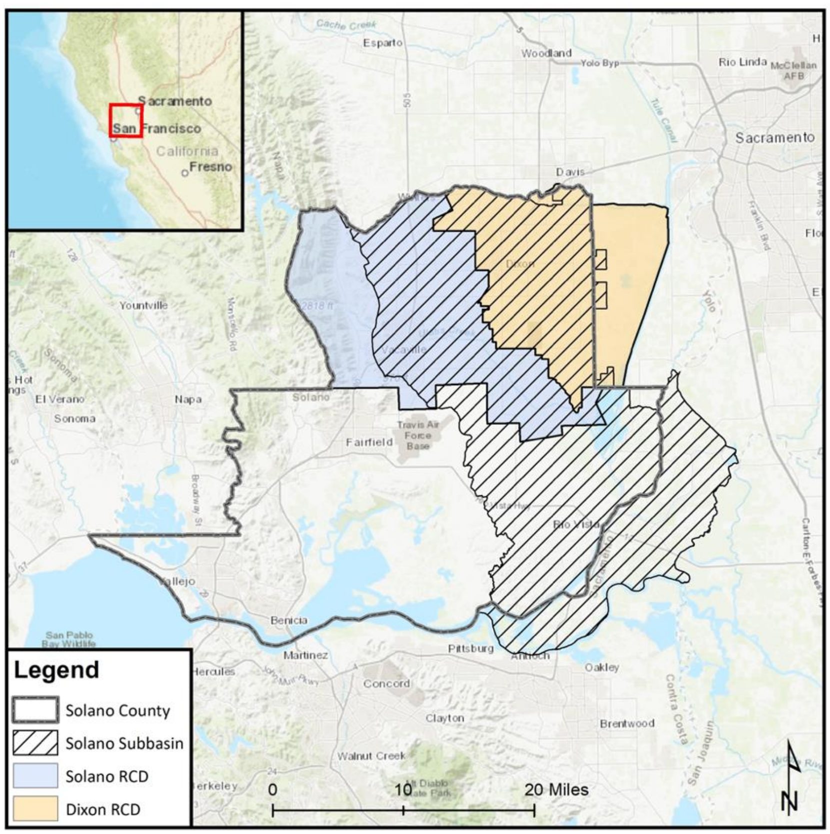

Figure 1. Project area

Among the project outputs were systems to aggregate and validate numerous environmental and farm management data sets. The integration of multiple publicly available models and analytical methods facilitates the quantification of the site-specific economic costs and multiple water resource impacts of NRCS practice implementation across many agricultural fields. All data and models used to facilitate these analyses are described in this document.

OVERVIEW

All data resulting from the application of the SPS to the Solano AOI are provided through a web application developed by TFT. The web application also provides users access to dynamic maps and data tables. Customized plans for optimized implementation of distributed NRCS practices can be created and viewed through the web application, using user-specified areas of interest, water resource benefits of interest, objectives, targets, and budgets.

The analytical steps that collectively comprise the SPS are described below, with examples of results for each step when applied in the Solano AOI. All data displayed in the web application or estimated by the SPS rely on the integration of many independent data sets, models, and methods, each of which has an associated level of uncertainty. Therefore, data displayed in the web application may differ from actual site conditions.

1. Field identification and farm management classification

Using both publicly available spatial data and analysis of aerial imagery, TFT identified all agricultural fields in the Solano AOI and classified the following environmental and management characteristics for each: crop type or types, irrigation method, irrigation water source, majority soil type, average field slope, recharge potential, and hydrogeologic connectivity to a groundwater-dependent ecosystem (GDE) (Figure 2). These data enable modeling of the field-specific feasibility, economic costs, and water resource impacts of NRCS practice implementation.

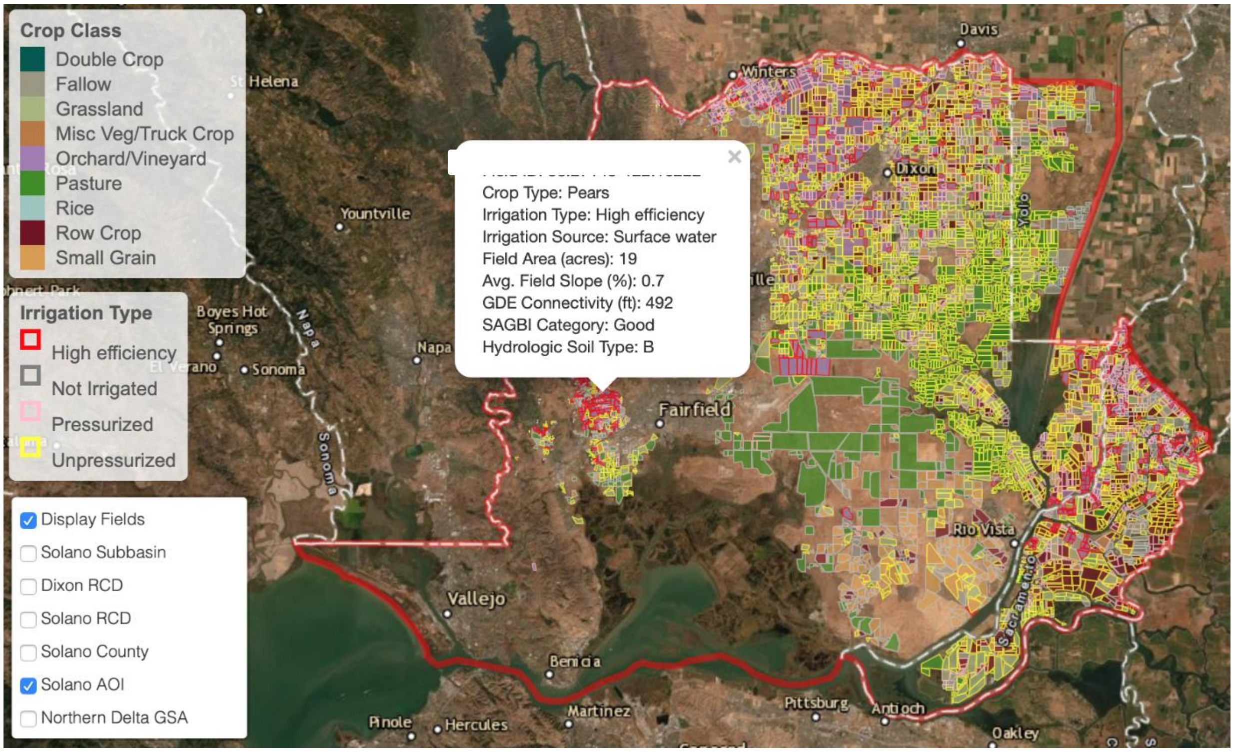

Figure 2. Crop classes and irrigation types for individual fields throughout the Solano AOI, as displayed in the web application. Polygon fill colors represent field crop types, and border colors represent irrigation types. Complete environmental and management data for a randomly selected field are shown in the data “pop-up” box.

2. NRCS practice feasibility assessment

Using the field-specific data, each field is assessed for suitability of implementing variations of the three NRCS practices, alone or in combination. The feasibility of each practice on all fields is displayed in the web application. In Figure 3, for example, the fields within Dixon RCD where cover cropping can likely be implemented are displayed. Cover crop feasibility is indicated by the appearance of a field polygon, regardless of color. The field color indicates a specific model outcome, as described in the next section.

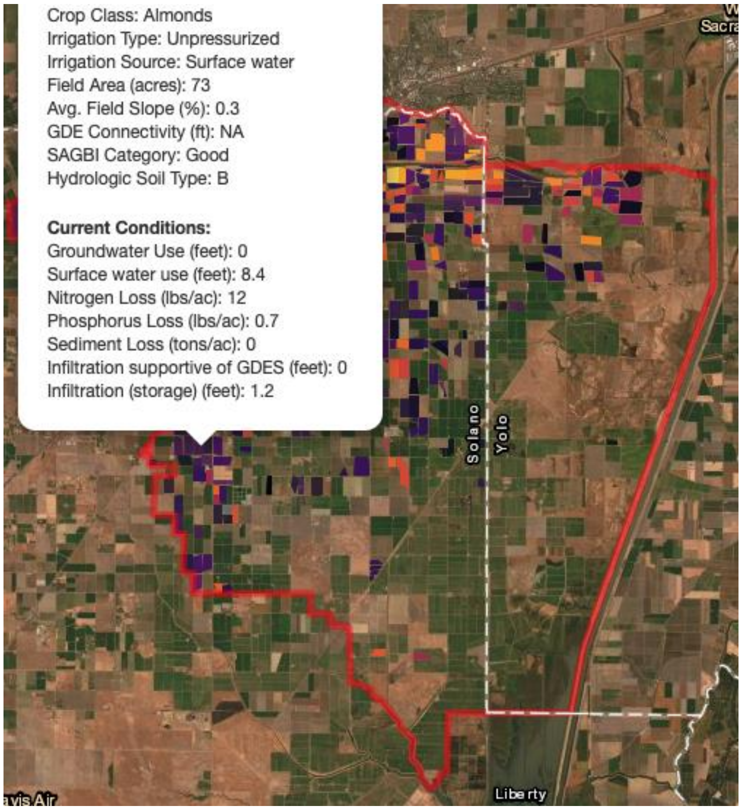

Figure 3. Current conditions within Dixon RCD. In this example view of the web application, the presence of field polygons indicates that cover cropping is likely feasible, and field color represents relative estimated nitrogen loss under current management. The pop-up displays the full suite of modeled values for a randomly-selected field under current management conditions.

3. Field-specific modeling of NRCS practice costs and impacts

Field-specific data are inputs to models used to estimate the 20-year economic costs and average annual water resource impacts of implementing feasible NRCS practices on each field. Modeled impacts include annual change in the following metrics given NRCS practice implementation, either alone or in combination:

- volume of surface water and/or groundwater used for irrigation;
- volume of water that infiltrates beyond the root zone that either supports groundwater-dependent ecosystems (GDE) or likely contributes to groundwater reserves; and
- edge-of-field nitrogen, phosphorus, and sediment losses.

These changes are estimated by simulating both current management conditions *and* management conditions if the feasible NRCS practices are implemented on each field.

Modeled results for selected fields are viewable in a pop-up box in the web application. The pop-up box in Figure 3 shows each metric modeled under current management conditions for the selected field. Cost is not displayed because no practice implementation has occurred under current conditions. Further, in this example, the field color indicates the relative estimated total nitrogen loss under current management conditions on each field where cover cropping is likely applicable.

Figure 4 illustrates expected changes from implementing NRCS practices. In this example, the user is assessing the potential for irrigation upgrades to reduce surface water usage in the Solano RCD. Field polygons indicate sites where irrigation upgrades are likely feasible, and their color represents the resulting reduction in surface water use if this practice is implemented. The pop-up displays the change in all metrics on a specific field given the adoption of the specific irrigation upgrade scenario identified, as well as the estimated 20-year cost of installing and maintaining the irrigation system.

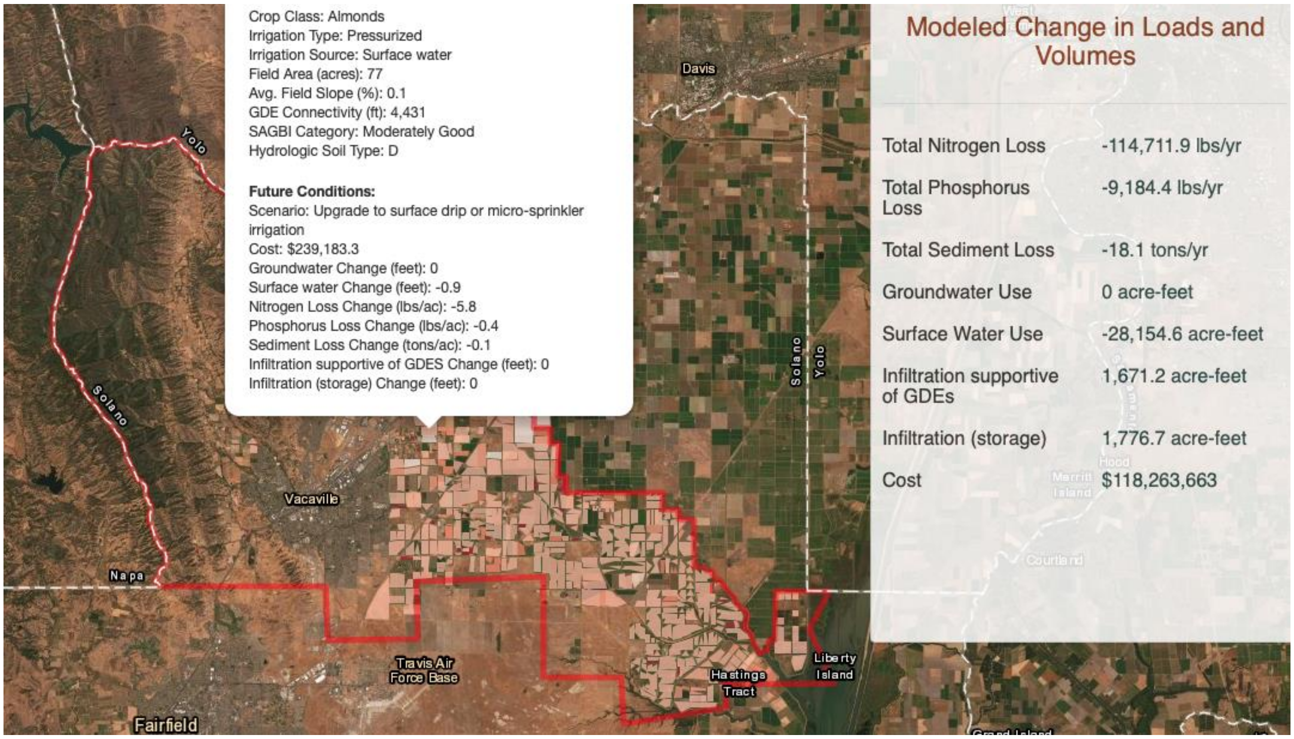

Figure 4. Fields in the Solano RCD where irrigation upgrades are feasible. In this example, the shade of red for each field indicates the relative reduction in surface water usage resulting from an applicable irrigation upgrade scenario. When a field is selected, a pop-up displays the field-specific impacts for all water resource metrics, as well as costs, given the irrigation upgrade. Cumulative costs and outcomes of irrigation upgrades on all fields where they are feasible within Solano RCD is shown in the panel on the right.

4. Basin-wide assessment and prioritization

The field-specific modeled costs and impacts of NRCS practices are used to assess the potential for water resource benefits given implementation at various scales and spatial distributions. Field-specific costs and impact data are used to prioritize practices on specific fields where the greatest benefits can be realized at the lowest cost of implementation.

Continuing with the Solano RCD example above, the shade of red for each field in Figure 4 indicates the relative reduction in surface water usage resulting from an applicable irrigation upgrade scenario, identified through the SPS. This information, which is also provided through the web application in tabular form, can be used to compare costs and benefits among fields and to identify the most cost-effective opportunities for increasing irrigation efficiency on fields that use surface water. The values in the right-side panel are the cumulative costs and impacts of upgrading irrigation on all surface-water-irrigated fields where it is feasible. While not a realistic scenario *per se*, planners can use the values to estimate potential impacts with more attainable recruitment percentages and set achievable targets when designing conservation programs (see *Plan development*).

5. Optimized plan development

Optimization is used to identify site-specific distributions of NRCS practices across a specific area of interest that will collectively achieve specific water resource objectives within specific constraints, including a budget. Optimized landscape-level scenarios can serve as strategic implementation plans.

Figure 5 shows an output of the program planning process in the web application. In this hypothetical example, the user designed a program where $5 million would support NRCS practice implementation in the Dixon RCD over 20 years, with the explicit goal of reducing sediment loss from fields. Based on this water resource objective and budget constraint, a $4.58 million program is identified, where sediment runoff is reduced by 1,322 tons per year through a combination of cover cropping and/or irrigation upgrades on the 45 fields shown on the map. Each identified field and its recommended implementation scenario are also displayed in a table, where projects can be sorted by impacts or costs. The SPS also identified the ancillary benefits of this program, which include annual reduction in use of approximately 814 acre-feet of groundwater and 722 acre-feet of surface water.

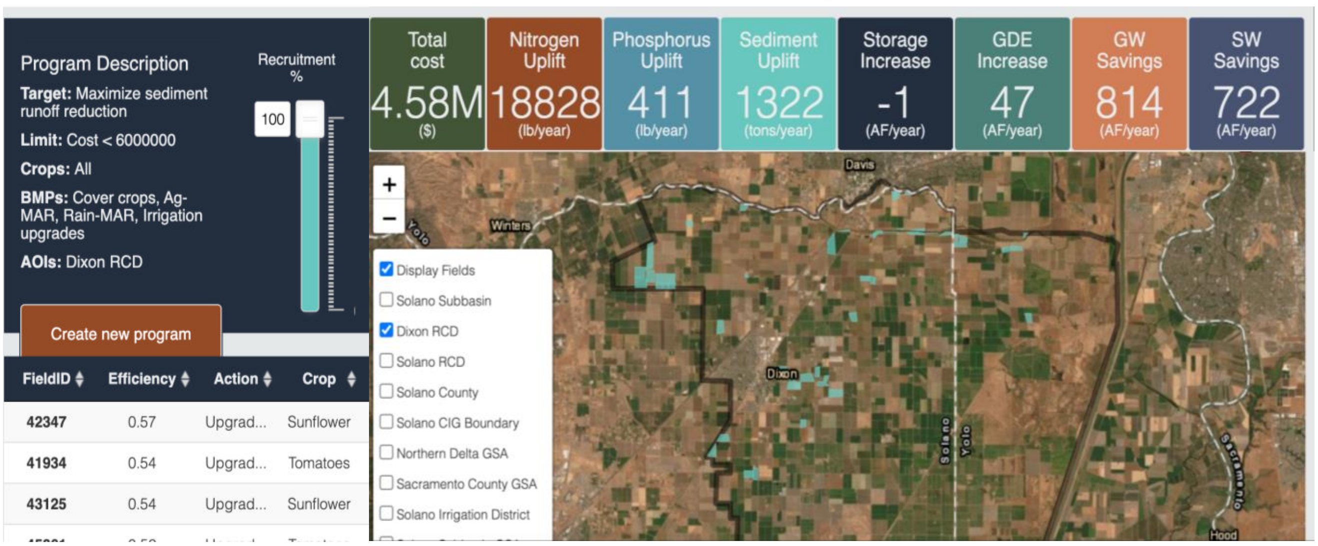

Figure 5. An example of outputs from the program planning feature of the web application, including the fields identified for implementation of specific practices to meet user-specified water resource objectives. Program costs and ancillary water resource impacts of the program are also shown.

The web application allows much more complicated program planning than what is demonstrated in this example. The user can also identify optimized programs that are restricted to specific practices or to fields with specific subsets of crops. They can also set numeric water resources targets (e.g., 10,000 acre-feet of groundwater use reduction) and receive the program cost as an output of the program planning process, rather than specifying a budget up front. The likely success rate of recruiting landowners can be estimated by the user, and the application will display a range of potential optimized outcomes based on simulations of variations in recruitment success. This shows how the program cost will increase and the benefits will decrease if landowners associated with optimal projects cannot be incentivized to adopt practices.

Once an optimized conservation program is developed, outputs of the SPS can be used to: (1) define program trajectory, (2) adaptively manage the program to ensure target achievement, and (3) report program progress and outcomes over time. For example, a planner can set interim milestones and annual recruitment targets based on the likely contribution of practice adoption on individual fields. As program recruitment begins, additional priority practices can be identified if producers initially targeted express no interest in participating. Moreover, using the web application, specific fields can be included in programs or excluded from programs during the planning phase, based on information the user has about likely participation. Cumulative annual impacts of practice adoption can also be calculated using the output data and used to track benefits over time and monitor progress toward a target.

DATA SOURCES, AGGREGATION & PROCESSING

This section describes the datasets used to characterize environmental and management conditions of each *individual* agricultural field. The following datasets are used throughout the SPS to: (1) determine the suitability of the NRCS practices on each field; (2) estimate the resulting site-specific water resource impacts of implementing feasible practices, alone or in combination; and (3) estimating the site-specific 20-year economic costs of NRCS practice implementation.

The data described in this section are those that are associated with each individual agricultural field. Other data used in the SPS are not associated with individual fields but are instead associated with a certain crop type, irrigation type, or other field attribute. These data are discussed in the individual model descriptions where they are applicable.

Agricultural Field Boundaries & Acreage

TFT used the 2016 Statewide Crop Mapping dataset[1] released by the California Department of Water Resources (DWR). This data set was originally developed by Land IQ, LLC and subsequently revised, as needed, by DWR Regional Office Land Use staff, using a combination of aerial photography, remote sensing multi-spectral imagery, agronomic analysis, and ground verification.

Areas that appeared to have non-agronomic land uses are excluded from field polygons. Fields typically contain a single crop type and are not intersected by, or inclusive of, any other features, such as houses, irrigation and fertilization structures, barns, roads, canals, etc. Each field's acreage was then calculated using ArcGIS.

Crop Type

The crop or crops grown on each field are classified according to the USDA's 2019 Cropland data layer[2] (CropScape). The majority crop type for each field polygon is used when this dataset shows multiple crops within a field polygon. Intra-annual rotations are classified, but inter-annual rotations are not, as the SPS is intended to be updated annually for planning purposes.

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[1] CDWR (2019). 2016 California Statewide Agricultural Land Use, California Department of Water Resources. https://data.cnra.ca.gov/dataset/statewide-crop-mapping/

[2] USDA National Agricultural Statistics Service Cropland Data Layer. Published crop-specific data layer. Available at https://nassgeodata.gmu.edu/CropScape/ USDA-NASS, Washington, DC.

Irrigation Method

Irrigation type for each unique field was first estimated using 2015 ground-truthed irrigation type data from the DWR Land Use Surveys dataset[3]. Field-level irrigation infrastructure was classified as one of four systems: (1) non-irrigated, (2) unpressurized (i.e., flood or furrow), (3) pressurized (i.e., sprinkler), or (4) high-efficiency (i.e., drip or micro-sprinkler). Publicly available multispectral data from the Landsat 8 satellite throughout 2017 were used to improve classifications.

Crop & Irrigation Data QA/QC

Remotely sensed crop and irrigation data from the sources described above went through a Quality Assurance/Quality Control (QA/QC) procedure and ground-truthing process. First, TFT checked a random subset of these datasets against 2019 satellite imagery and Google Earth "street view" images to look for inconsistencies (i.e., orchards or vineyards identified as row or field crops, evidence of misclassified irrigation systems based on visible infrastructure, summer-time green fields identified as non-irrigated, etc.). Second, TFT performed 'reasonableness' checks between the crop and irrigation types identified on all individual fields to identify unlikely combinations (e.g., "alfalfa" irrigated with high efficiency irrigation, non-irrigated orchards, etc.). Finally, TFT's NRCS and RCD project partners checked the correctness in crop and irrigation type for a random subset of Solano County fields based on their own knowledge of the area. The project partner input, aerial imagery analysis, and Google Earth "street view" imagery was used to rectify data issues identified through the above procedures.

Soils & Field Slope

The majority slope within each field polygon is calculated in ArcGIS using the U.S. Geological Survey 10-meter digital elevation model (DEM)[4], and the majority soil type within each field polygon is determined using the NRCS SSURGO Database[5].

Meteorological Data

The California Irrigation Management Information System (CIMIS)[6] is a program within the California DWR. CIMIS is an integrated network of over 145 weather stations throughout California. Hourly precipitation (in inches) is provided for each weather station location. Daily rainfall for each agricultural field is interpolated using an inverse distance weighted average of data from the three nearest reporting stations to each field for the total precipitation each day. The spatial centroid of each field is used to determine the three nearest stations and the distance to them. Using an inverse weighted average is a well-accepted approach that avoids extreme values that may otherwise be observed by simply taking data from a single nearby station, yet preserves the influence of distance-from-measure overall. The equation is as follows:

[3] https://water.ca.gov/Programs/Water-Use-And-Efficiency/Land-And-Water-Use/Land-Use-Surveys
[4] https://www.usgs.gov/core-science-systems/national-geospatial-program/national-map
[5] https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_053627
[6] https://cimis.water.ca.gov

$$\hat{P} = \sum \frac{\frac{1}{d_i}}{\sum 1/d_i} * p_i$$

P-hat is the estimated precipitation at the location.
d_i is the distance from the location to reporting station ***i***.
p_i is the observed precipitation at station ***i***.

ET_O is the rate of evapotranspiration from a reference surface, usually a hypothetical grass, that is used to calculate estimated crop evapotranspiration (ET_C) as a function of the growth-stage specific crop coefficient (K_C). Daily ET_O (in mm) is provided through Spatial CIMIS, a raster grid of two-kilometer resolution for which ET_O is calculated through interpolation of temperature, humidity, and other data from nearby CIMIS stations using the American Society of Civil Engineers' version of the Penman-Monteith equation (ASCE-PM). Solar radiation data required for the ASCE-PM is acquired by CIMIS through NOAA's Heliosat-II model. The two-kilometer raster that an agricultural field's centroid falls within is the raster used for ET_O for a given field.

Surface Suitability for Recharge

The Soil Agricultural Groundwater Banking Index (SAGBI) dataset[7] is used to assess suitability for NRCS practices aimed at recharging groundwater. A team of researchers at the University of California Davis and the UC Cooperative Extension developed SAGBI, which incorporates soils and topography data to compute a spatially explicit index of the suitability for groundwater recharge. The SAGBI is calculated using five major factors that are critical to successful agricultural groundwater banking: deep percolation, root zone residence time, topography, chemical limitations, and soil surface condition. The SAGBI is derived from parameters like slope classes, soil electric conductivity (EC), and soil hydraulic conductivity (K_{sat}) from the SSURGO Database. A modified SAGBI score (provided by UC Davis) is used in the SPS that accounts for six-foot 'deep tillage', eliminating near-surface confining soil layers.

Source of Irrigation Water

Each field's source of irrigation water is classified as surface water, groundwater, or "mixed" (i.e., the field has the potential to be irrigated by both surface and groundwater). Using the classification methods, the likelihood that a field is irrigated with surface water increases with proximity to a surface water diversion location, based on the State Water Resources Control Board's Electronic Water Rights Information Management System (eWRIMS[8]), or to water conveyance infrastructure (based on the US Fish and Wildlife Service's National Wetlands Inventory[9]). Surface water access is also highly likely for fields located within a water district that supplies surface water from the California State Water Project or other water management project (water district boundary source: California Water District Layer[10]). Similarly, the likelihood of irrigating with groundwater increases with proximity to a groundwater well that is part of

[7] Soil suitability index identifies potential areas for groundwater banking on agricultural lands (2015). *California Agriculture* 69(2):75-84. https://doi.org/10.3733/ca.v069n02p75
[8] https://waterrightsmaps.waterboards.ca.gov/viewer/Resources/Images/eWRIMS/download/POD_data_dictionary.pdf
[9] https://www.fws.gov/wetlands/
[10] https://data.ca.gov/dataset/water-districts

DWR's California Statewide Groundwater Elevation Monitoring (CASGEM) Program (DWR's Periodic Groundwater Levels Dataset[11]). This irrigation source classifications were verified using the DWR California Land Use Surveys dataset[12]. The surveys used to develop irrigation source data were conducted in 2003, 2000, and 2008 for Solano, Sacramento, and Yolo counties, respectively.

Connectivity to Groundwater-Dependent Ecosystems

The hydrogeologic connectivity of each field to a nearby GDE, such as a stream or wetland, is assessed to better understand the likely benefits of water that infiltrates beyond the root zone and into aquifers below each field. A connectivity metric is used to determine the likelihood that this water will travel to and be supportive of a nearby GDE. Two ESRI Arc GIS tools were used to calculate the distance groundwater will flow to reach the closest GDE:

1. The "Flow Direction" tool from the Hydrology Toolset[13] available in ESRI ArcGIS toolkit is used to calculate the direction of groundwater flow. The ESRI ArcGIS "Flow Direction" tool uses a water surface (that provides relative elevation between grid cells) raster to compute flow direction. This tool was used to calculate flow direction based on each cell's steepest downslope neighbor. The result is flow direction raster layer at a 300-meter spatial resolution.
2. The ESRI ArcGIS "Cost Path as Polyline"[14] tool from the Distance Toolset is then input with the flow direction raster layer to calculate the resulting lateral "distance" of the likely path of groundwater from each cell to the nearest GDE. The tool provides the least-cost path from the source (grid with potential MAR) to the closest destination (GDE).

Water infiltrating below fields that does not travel to any GDE is characterized as contributing to groundwater reserves (or "storage"). Based on the methods described above, this will likely be the case for fields over groundwater cones of depression or where the groundwater flows to a local depression. This method does not consider the time it takes for groundwater to reach the nearest GDE.

Groundwater elevations are acquired from the DWR Periodic Groundwater Levels data set[15]. GDEs were classified according to the "Natural Communities Commonly Associated with Groundwater", a spatial data set developed by DWR, the California Department of Fish and Wildlife, and The Nature Conservancy[16].

CONSERVATION PRACTICE SCENARIO DEVELOPMENT

While the SPS methodologies facilitate the addition of more practices, three NRCS practices were included in the initial development of the SPS. For each of these three practices, TFT developed three scenarios for model simulation, for a total of nine scenarios, each with applicability to fields based on the field's environmental and management classification data.

Multiple practices can be feasible on each field. For instance, both MAR and cover cropping can be feasible on applicable fields. When multiple practices are feasible on a field, they will be simulated in each SPS

[11] https://data.ca.gov/dataset/periodic-groundwater-level-measurements
[12] https://water.ca.gov/Programs/Water-Use-And-Efficiency/Land-And-Water-Use/Land-Use-Surveys
[13] https://pro.arcgis.com/en/pro-app/tool-reference/spatial-analyst/an-overview-of-the-hydrology-tools.htm
[14] https://desktop.arcgis.com/en/arcmap/latest/tools/spatial-analyst-toolbox/cost-path-as-polyline.htm
[15] https://data.cnra.ca.gov/dataset/periodic-groundwater-level-measurements
[16] https://data.cnra.ca.gov/dataset/natural-communities-commonly-associated-with-groundwater

model both as if they are implemented individually and as if they are implemented together. This provides the costs and water resource impacts for the full range of options on that field, for use in program planning.

Irrigation Efficiency Improvements

Irrigation efficiency improvements, as defined for the SPS, are upgrades to a farm's irrigation infrastructure that reduce water used to grow crops. Irrigation efficiency is a measure of the water directly used by crops compared to the water lost to evaporation, wind, infiltration, runoff, or during conveyance to the field. Irrigation systems with higher efficiencies have less of these losses. "Unpressurized" systems, such as flood or furrow irrigation, are least efficient and, therefore, are where irrigation efficiency improvements are most applicable. Efficiency improvements would include converting to "pressurized" or "high efficiency" systems. Pressurized systems (as defined in the SPS) include impact sprinklers, wheel lines, center pivots, and similar sprinkler systems. While "pressurized" systems are more efficient than flood irrigation, they are not as efficient as "high efficiency" systems, such as drip or micro-sprinkler systems, that deliver water directly to the base or roots of plants. Thus, irrigation efficiency improvements are also applicable on fields with "pressurized" systems because less water can be used through conversion to "high efficiency" irrigation. In summary, irrigation efficiency improvement can take three forms: (1) from flood to pressurized system; (2) from flood to high efficiency system; or (3) from pressurized to high efficiency system.

The crop and irrigation systems classified for each field are the primary determinants of whether a specific upgrade scenario is feasible. For example, fields that are classified as already having high efficiency systems will not be selected in the SPS for irrigation upgrades; however, upgrades to pressurized and/or high-efficiency systems will potentially be feasible on fields that are flood irrigated. Further, irrigation efficiency improvements are feasible only when the crop is compatible with a more efficient system. For example, rice, although typically flood irrigated, is not compatible with higher efficiency systems, and, therefore, rice fields are not eligible for irrigation upgrades in the SPS. A Solano County-specific crop and irrigation system compatibility matrix, developed with TFT's NRCS and RCD partners, is used to assess feasibility for irrigation upgrades on each field.

Finally, while irrigation efficiency improvements reduce surface and groundwater use, they also potentially result in less sediment and nutrient runoff and less infiltration of water to aquifers. In the SPS, irrigation efficiency improvements are simulated across all models, to not only estimate the resulting change in surface and/or groundwater demand, but to also estimate the change in infiltration and runoff. Thus, impacts across multiple water resource metrics are estimated and these tradeoffs can be considered.

Managed Aquifer Recharge

The SPS includes two forms of managed aquifer recharge: "Ag-MAR" and "Rain-MAR". TFT uses the term Rain-MAR to refer to stormwater retention on agricultural fields and to differentiate it from Ag-MAR, which is the application of excess surface water flows to fields. Rain-MAR manages the precipitation that falls directly on agricultural fields for recharge, whereas Ag-MAR conveys precipitation or snowmelt that originates elsewhere in the watershed to agricultural fields for recharge. Rain-MAR and two variations of Ag-MAR collectively comprise the three MAR scenarios.

Crop type, irrigation source, and the SAGBI rating for each field determine its suitability for each scenario. In the SPS, MAR is not feasible unless the SAGBI rating indicates that the field location has “Good” or “Excellent” suitability for recharge. Further, MAR is not considered feasible on fields with crops that have low tolerance of soil saturation or management that would be impeded by wet field conditions in late winter.

TFT simulates Ag-MAR as the application of excess surface water flows to fields at an assumed seasonal rate of either 1 foot or 2 feet, referred to as the “low” and “high” scenarios, respectively. These application volumes were developed by TFT and informed by experiments, including those by Dahlke *et al.* (2017[17], 2018[18]), where four- and six-foot application scenarios were used to test upper bounds for alfalfa crop damage, and by modeling exercises such as Niswonger *et al.* (2017)[19], where 2.46 feet (0.75 meters) per acres was the assumed availability of winter irrigation water in the Carson Valley Basin (Nevada).[20] The 1 foot and 2 feet application rates chosen for the “low” and “high” modeled Ag-MAR scenarios account for:

(1) the potential risk aversion of producers to apply significant volumes of water to fields in winter that may impact spring operations; and

(2) the likely constraints to application volume based on surface water availability and demands on the infrastructure needed to convey it to fields where MAR is potentially implemented across a targeted region.

Annually installed berms, which will retain applied water and stormwater on fields for infiltration, are included in cost models and management simulations for estimating changes in infiltration. Ag-MAR includes both winter berming to eliminate runoff and application of excess surface flows, while Rain-MAR is simulated with only winter berming to retain stormwater. Because Ag-MAR will by default retain stormwater via berming, Rain-MAR and Ag-MAR are not simulated together for the same field (although they can be applicable on the same field and simulated separately).

Feasibility for the “low” or “high” Ag-MAR scenarios is based on the crop type classified for each field, where specific crops are potentially more sensitive to damage or management disruption and are only eligible for the more conservative “low” scenario. Finally, because Ag-MAR requires the conveyance of excess surface water flows from streams, rivers, or other networks to the field, it is feasible only for fields that are classified as having an irrigation water source of surface water or “mixed”. Feasibility of implementing Rain-MAR is determined by a field’s crop and SAGBI rating, and it is feasible on fields using either surface water or groundwater.

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[17] Dahlke, H. E., Brown, A. G., Orloff, S., Putnam, D., & O’Geen, T. (2017). *Groundwater with Minimal Crop Damage*. (March 2018).
[18] Dahlke, H. E., Brown, A. G., Orloff, S., Putnam, D., & O ’Geen, T. (2018). Managed winter flooding of alfalfa recharges groundwater with minimal crop damage. *California Agriculture*.
[19] Niswonger, R. G., Morway, E. D., Triana, E., and Huntington, J. L. (2017), Managed aquifer recharge through off-season irrigation in agricultural regions, *Water Resources. Research.*, 53.

Cover Cropping

Annually using cover crops in the fall and winter can reduce the runoff of sediment and nutrients from fields into surface waters during storm events. The roots of cover cropping also open compacted soils to potentially allow more water to infiltrate and recharge groundwater instead of running off fields. Cover crops also provide numerous additional farm, soil, and ecosystem benefits not currently quantified through the SPS, including: sequestering atmospheric carbon; increasing soil nutrients and organic material; and providing habitat for pollinator species. The SPS quantifies the potential groundwater quantity and surface water quality benefits of three typical cover cropping scenarios in California, where feasible. The water demand of the cover crop is also estimated. While they do not typically require additional irrigation because they are grown in the cooler, rainy season, this is not always the case (especially in drier years). The SPS provides this potential irrigation demand for the user to evaluate cover crops' potential for both positive and negative impact to ground or surface water quantity.

Each of the three cover crop scenarios used in the SPS will have different water quality and quantity impacts on various fields. The three cover cropping scenarios (and their feasibility criteria) are:

1. "Cover crop active" is applicable in orchards and vineyards. This scenario is simulated in models as a clover cover crop, planted in fall and incorporated into the soil in mid-June.
2. "Cover crop full winter" is applicable in annually planted row crops. It is simulated as a ryegrass planted upon harvest of the main crop until a month before planting the following year.
3. "Cover crop small grain" is also applicable in annually planted row crop settings, but it is modeled as winter wheat.

Each of these is defined more specifically for simulating the practice in the irrigation, infiltration, runoff, and economic models. For instance, the following management practices are associated with the "cover crop active" scenario on orchards and vineyards, in addition to typical management of the primary crop:

- annually seeding a legume-dominant cover crop mix between rows each fall after harvest;
- irrigating once upon sowing and then subsequently irrigating enough to keep the plants alive (based on weather data; implies irrigation system can water between rows);
- spring mowing to maintain the crop is performed three times, followed by chemical termination approximately one month prior to leaf out; and
- plow down of the cover crop is assumed to occur in the first five years of orchard development to build the soil nutrient levels.

The simulation of current conditions scenarios or other scenarios without cover cropping includes no fall seeding, winter irrigation, or other activities to maintain or terminate cover crops. The specifics of modeling scenarios were developed through consultation with TFT's NRCS and RCD project partners, as well as through interviews with Solano County orchard managers who use winter cover crops.

While winter cover cropping and MAR practices have been adopted in Solano County on some fields, they are rare, and TFT is not able attain reliable data on the current use of cover cropping or MAR on specific farms. Therefore, it is assumed they do not occur on any farm.

FIELD-SPECIFIC ECONOMIC & WATER RESOURCE IMPACT MODELS

These modeling methods are used to estimate the field-specific economic costs and water resource impacts of the conservation practice scenarios. For each field, costs and impacts are estimated through this suite of models under both current management conditions and under management conditions for all feasible conservation practice scenarios, alone and in combination. The criteria for model selection for the SPS included the model's ability to: (1) estimate costs or impacts at the individual agricultural field level (rather than a coarser spatial unit) and (2) simulate differences in management scenarios on each field, particularly the changes in management that would be associated with the adoption of the conservation practices included in the SPS.

Irrigation Model

The SPS employs the Consumptive Use Program Plus (CUP+ version 6.1), developed by DWR.[21, 22] CUP+ was developed to "help growers and water agencies determine reference evapotranspiration (ET_O), crop coefficient (Kc) values, and evapotranspiration of applied water (ET_{aw}), which provides an estimate of the net irrigation water needed to produce a crop." The SPS uses the underlying methods of CUP+ for modeling of site-specific, daily water use on many fields across a landscape under multiple scenarios. Irrigation efficiency values are applied to the ET_{aw} values derived from this model, based on the existing irrigation system on each field, to estimate the total water used for irrigation during the timeframes specified for modeling.

TFT modeled water use for irrigation for each field across each of the five California water year types, as defined by the DWR *Water Year Hydrologic Classification Indices*.[23] Daily precipitation and ET_O data from CIMIS were used for recent representative years (October 1 prior year to September 30 of the listed year): wet (2017), above normal (2005), below normal (2016), dry (2013), and critical (2015). The resulting modeled values are field-specific, total annual irrigation volumes, averaged across these five years.

For cover cropping scenarios, the irrigation model estimates daily ET_c and ET_{aw} of both the primary crop and the cover crop. MAR scenarios do not impact irrigation volumes, and change in "water use" is considered negligible because it leverages excess surface water flows. Irrigation efficiency improvements are reflected in varying irrigation application efficiency (IAE) factors between scenarios, which are applied to field-specific ET_{aw} based on the identified or simulated irrigation system. While IAE estimates vary greatly between fields, irrigation systems, management decisions, and many other factors, in the SPS, IAE are based solely on the identified class of irrigation system. The ranges of the specific efficiencies for the systems within these classes are well-documented[24], and are used along with local expertise to make assumptions of application efficiency based on the classification of a field's irrigation system.

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[21] Orang, M.N, Snyder, R.L., and J.S. Matyac. 2005. CUP (Consumptive Use Program) Model. DWR and UC Davis. California Water Plan Update 2005.
[22] Orang, M.N, Matyac, J.S., and R. L. Snyder. 2011. CUP+ (Daily Soil Water Balance Program). ICID 21st International Congress on Irrigation and Drainage. 15-23 October 2011. Tehran, Iran.
[23] See http://cdec.water.ca.gov/reportapp/javareports?name=WSIHIST
[24] Evans, R. G. (n.d.). Irrigation Technologies. Sidney, MT. Retrieved from https://www.ars.usda.gov/ARSUserFiles/30320500/IrrigationInfo/general irrigation systems-mondak.pdf
Martin, D. L., & Gilley, J. R. (1993). Irrigation Water Requirements. Part 623 National Engineering Handbook, (September 1993).
Neibling, H. (1994). Irrigation Systems for Idaho Agriculture. University of Idaho, College of Agriculture.

Irrigation volume is characterized in the SPS as groundwater use or surface water use depending on the source of irrigation water classified for each field. Irrigation volumes for "mixed" source fields are split evenly between groundwater and surface water use.

Infiltration Model

The infiltration model used in the SPS applies a water balance (or water budget) equation at the field level to estimate the changes in water distribution given the implementation of one or more NRCS practices. The water balance approach is a flexible method that allows various component water sources and sinks to be defined for a unit of analysis, and manipulated to estimate how the NRCS practice(s) impact the distribution of source water among sinks.

The model uses daily, field-specific volumes of water sources to estimate their daily, field-specific distribution among various sinks. Sources include precipitation and irrigation, including additional water retained or applied when MAR practices are simulated. Daily precipitation volumes are from CIMIS weather data, and irrigation volumes are outputs of the irrigation model described above. Sinks include crop evapotranspiration, runoff flows, and infiltration to aquifers. TFT's infiltration model assumes that a fraction of the source water that remains after allotment to crop demand and runoff will percolate past the root zone to shallow groundwater stores and potentially deeper aquifers.

Crop water demand is determined by daily ET_c values from the irrigation model. Runoff is determined by the runoff curve number, as described in the National Engineering Handbook (NEH), Part 630 (Hydrology).[25] A runoff curve is a function that defines the volume of water that will runoff an agricultural field given a volume of source water. Runoff curves are selected based on the fields hydrologic soil group, land use (cropping and tillage practices), and "hydrologic condition". Hydrologic condition qualitatively describes the infiltration potential of a field as "good", "fair", or "poor". It is a function of land cover, field slope, crop residue, and grazing intensity. An additional adjustment to the curve number is made based on precipitation or irrigation events in the last five days to account for the increased likelihood of soils either being saturated or dried out.

The simulation of irrigation efficiency improvements decreases daily water sources, as defined by outputs of the irrigation model. The simulation of Ag-MAR and Rain-MAR increases daily water sources, depending on application and rain events, respectively. Ag-MAR simulations include the application of water every two weeks throughout January and February, in fractional applications of 6 or 12 inches per event, until a defined scenario's target volume is reached. For Rain-MAR simulations, it is assumed that the runoff water modeled under current conditions is being retained for infiltration. Because of the annual variability in surface water available for MAR, it is assumed MAR can only be implemented on any given field in two of every three years, on average, during the 20-year modeling timeframe. Therefore, the modeled infiltration is divided by 0.67 (2/3) to estimate the average annual infiltration benefit. The two-in-three MAR schedule comes from an analysis of DWR's water year classification data[26] for the Sacramento River Basin. By looking at rolling 20-year periods from 1901 to 2017, TFT identified the number of years in each 20-year period that

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Rogers, D. H., Lamm, F. R., Alam, M., Trooien, T. P., Clark, G. A., Barnes, P. L., & Mankin, K. (1997). Efficiencies and Water Losses. of Irrigation Systems. Retrieved from https://www.bookstore.ksre.ksu.edu/pubs/MF2243.pdf

[25] See chapters 7 - 10: https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/manage/hydrology/?cid=stelprdb1043063

[26] See: http://cdec.water.ca.gov/reportapp/javareports?name=WSIHIST

were classified as Below Normal, Above Normal, or Wet (excluded Dry and Critical). On average, there were 13.38 years per 20-year period (67%) which fell into the categories defined above.

The simulation of cover cropping scenarios impact infiltration in two ways; each reflects differences in source water volumes and the distribution among discharges resulting from cover crop use:

(1) The daily crop water demand (ET_c) and resulting irrigation volume outputs from the irrigation model will differ as a result of the presence of cover crops. The crop water demand is met first through precipitation and remaining demand is met through irrigation. Therefore, irrigation as a source will typically increase with cover crops and evapotranspiration will typically be a greater component of discharge compared to runoff and infiltration.

(2) The runoff curve number will potentially change as a result of the "hydrologic condition" differing between the current condition and 'with cover crop' scenarios. Under current conditions, the hydrological condition of "poor", "fair", or "good" is generated for each field based its current conditions (e.g., slope and crop type), but when cover cropping is simulated, hydrologic condition is set to "good" regardless of existing determinants.

The first difference between scenarios reflects the potential for cover crops to reduce infiltration through increased crop water demand, especially if winter precipitation is low. Conversely, the second difference between scenarios reflects the widely accepted effect cover crops have to potentially increase infiltration capacity, but it allows this effect to be quantified independently for each field. It also allows the existing infiltration capacity to be high without cover crops if indicated by the current conditions.

As with irrigation, infiltration is modeled across each of the five California water year classifications. The resulting modeled values are field-specific, total annual infiltration volumes, averaged across these five years. Infiltration volumes on each field are characterized as "storage" or "supporting GDEs" based on the GDE connectivity value at their location.

Nutrient & Sediment Runoff Model

The field-specific, edge-of-field nutrient and sediment runoff analyses in the SPS employ the Nutrient Tracking Tool (NTT). NTT was developed by the Texas Institute for Applied Environmental Research at Tarleton State University with funding and technical support from USDA's Office of Environmental Markets. In NTT, key inputs for each individual field are formatted for simulating management scenarios.

The scientific basis for NTT is the APEX (Agricultural Policy/Extender; (Gassman et al., 2010)[27] (Version 0806) model, which has been widely used and extensively tested for modeling the environmental impacts of agricultural conservation practices on farmland (Tuppad et al., 2010)[28]. APEX uses mostly physically-based modeling routines, and validation efforts for both APEX and NTT has been conducted across many parts of the United States, including California (Saleh, Gallego, & Osei, 2015)[29].

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[27] Gassman, P. W., Williams, J. R., Wang, X., Saleh, A., Osei, E., Hauck, L. M., Izaurralde, R. C., Flowers, J. D. (2010). The Agricultural Policy/Environmental eXtender (APEX) model: An emerging tool for landscape and watershed environmental analyses. Transactions of the ASABE.

[28] Tuppad, P., Santhi, C., Wang, X., Williams, J. R., Srinivasan, R., & Gowda, P. H. (2010). Simulation of conservation practices using the APEX model. *Applied Engineering in Agriculture*

[29] Saleh, A., Gallego, O., & Osei, E. (2015). Evaluating nutrient tracking tool and simulated conservation practices. *Journal of Soil and Water Conservation*. https://doi.org/10.2489/jswc.70.5.115A

NTT outputs used in this analysis include average annual edge-of-field total nitrogen, total phosphorus, and sediment losses based on 35 years of simulated weather data (PRISM; (Daly & Bryant, 2013)[30], which includes 2-km resolution daily rainfall and minimum and maximum temperature through 2018[31].

To estimate the difference in annual runoff metrics between current conditions and NRCS practice scenarios, the field-specific management inputs are altered in NTT simulations. Table 2 shows an example of the differences in management inputs between current conditions and the “cover crop annual” scenario. Note that only the management specifications that differ between these scenarios are shown here. Many other management inputs that are specific to the crop or irrigation type for each field will not change between these scenarios because they are not altered by adoption of the specific practice being simulated.

For example, in both scenarios, NTT models the orchard or vineyard operations with planting occurring in the first year, fertilizer applied annually in spring, irrigation over the summer, and harvest annually in the fall. All orchards and vineyards are assumed to be untilled, and for all NTT scenarios, TFT uses the auto-irrigation practice, which applies water based on crop demand. The “cover crop annual” simulation uses a clover cover crop.

[30] http://www.prism.oregonstate.edu/

[31] Weather data used in this portion of the analysis differs from that used in the irrigation and infiltration analysis portions, in that the runoff modeling is based on simulated weather, while the others use measured weather data from the California Irrigation Management Information System (CIMIS).

Table 2. Examples of management inputs that differ between two scenarios simulated in NTT. Here, the differences between the "current conditions" scenario and "cover crop annual" scenario is shown for relevant crop types.

Crop	Simulation Input	Current Conditions	"Cover Crop Annual"
Almonds	Nitrogen Fertilizer (lbs/ac)	250	218
	Cover crop planting	n/a	Date: Oct. 20 Density: 1224 seeds/m^2
	Cover crop termination	n/a	Date: Feb. 18
Walnuts	Nitrogen Fertilizer (lbs/ac)	200	168
	Cover crop planting	n/a	Date: Oct. 20 Density: 1224 seeds/m^2
	Cover crop termination	n/a	Date: Mar. 18
Grapes	Nitrogen Fertilizer (lbs/ac)	30	0
	Cover crop planting	n/a	Date: Oct. 20 Density: 1224 seeds/m^2
	Cover crop termination	n/a	Date: Apr. 18
Pistachios	Nitrogen Fertilizer (lbs/ac)	160	132
	Cover crop planting	n/a	Date: Oct. 20 Density: 1224 seeds/m^2
	Cover crop termination	n/a	Date: Mar. 18
Olives	Nitrogen Fertilizer (lbs/ac)	160	132
	Cover crop planting	n/a	Date: Oct. 20 Density: 1224 seeds/m^2
	Cover crop termination	n/a	Date: Mar. 18

Economic Model

The SPS economic model estimates the cost of NRCS practice implementation over 20 years. Each practice is divided into cost components, which are aggregated and scaled individually for simulation of management on each field. The field-specific model outputs include average annual costs, as well as the total present value for a 20-year implementation time frame. This model reflects a partial budgeting approach[32] to quantify the *changes* in a producer's costs given the implementation of NRCS practices; therefore, under current conditions costs equal $0, while the economic model generates outputs for the implementation scenarios only.

[32] See https://www.extension.iastate.edu/agdm/wholefarm/pdf/c1-50.pdf

Costs are calculated for each field by selecting the appropriate costs for a given scenario, and applying them based on a field's characteristics. Practices are assumed to be additive in cost. NRCS practice implementation costs consider the estimated costs of all necessary equipment, materials, and labor needed to implement a particular NRCS practice scenario. The costs of these components are informed by costs estimated by NRCS for California Practice Scenarios[33], Crop Enterprise Budgets from the University of California Davis, and USDA survey data. Technical reports, peer-reviewed literature, and professional opinion were also used extensively in developing the final values. All values were transformed into a per acre (variable) or per field (fixed) value. Cost estimates are compiled and adjusted to a spatial unit, and common dollar year.

Comparing one-time capital-intensive practices (such as irrigation efficiency improvements) to reoccurring labor-intensive practices (such as cover cropping and MAR) requires proper considerations for the timing of incurred costs. To handle this, costs are presented as a 20-year present value, with an assumed 3% discount rate, to reflect the long-term cost in today's dollar. Some cost and benefit values vary over the 20-year timeframe (including some costs that apply only to the first year), while others have the same annual value over time.

Below are examples of the cost components used to estimate the 20-year cost of the "cover crop annual" scenario. Each individual component is applied on a specific schedule over 20 years to each field where this scenario is feasible, on either a per-site or per-acre basis.

- *Seed*. Seed costs reflect the average material costs of cover crop seed. Given the innumerable combinations of seeds and ratios, an average cost is representative of the widest range of scenarios. Seeding is assumed to occur annually, therefore this is a reoccurring cost over the defined timeframe.
- *Soil preparation/seeding*. Soil preparation and seeding costs are operations cost which include the machine and labor costs. Seeding is assumed to occur annually, therefore this is a reoccurring cost over the defined timeframe.
- *Irrigation*. Irrigation costs cover the cost to irrigate seeds shortly after planting and then minimally to keep cover crops alive in winter. This estimate includes the acquisition, set-up, and operation of a temporary irrigation system. This is a reoccurring cost over the defined timeframe.
- *Mowing.* Mowing costs are operations costs that include the machine and labor costs for three mowing events per year to keep plant height and biomass controlled. Mowing is assumed to occur annually, therefore this is a reoccurring cost over the defined timeframe.
- *Pest management*. Pest management costs are primarily to address a potential increase in gophers. Estimates are an average cost of a trapping mechanisms and rodent baiting. This cost is assumed to occur over the defined timeframe, but realistically might be higher in some years and lower in others depending on frequency of infestation.
- *Termination.* Termination costs are all-inclusive costs which are assumed to include material, application, and labor. Chemical termination of the cover crop prior to incorporation is assumed to occur annually.

[33] See: NRCS. (n.d.). USDA Natural Resources Conservation Service California Practice Scenarios. Retrieved from https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/programs/financial/?cid=nrcseprd1328227

- *Plow-down.* Plow-down costs are operations costs which are assumed to include the machine and labor costs. Plow down of the cover crop is assumed to occur in the first five years of orchard development to build the soil nutrient levels.

A more specific example of the cost model is provided here for the Ag-MAR scenarios. TFT used scenarios developed by the NRCS for the State of California related to the construction of temporary ponds and seasonal flooding on agricultural fields[34], specifically Practice 644 *Wetland Wildlife Habitat Management*. While the primary goal of these actions is described as habitat creation, they functionally operate as MAR projects would on agricultural fields, and, therefore, the costs are appropriate for estimating the costs of MAR.

The annual field preparation for MAR consists of building temporary berms and is represented by Scenario #22 (*Temporary Habitat Ponds*) of Practice 644. This scenario describes creating checks on rice fields to hold water seasonally. The annual equipment and labor cost estimate according to NRCS is $241.53 per acre. Tractor implements are used to construct temporary berms between 6 and 12 inches tall.

The operation of MAR is represented by Scenario #6 of Practice 644, *Seasonal Flooding*. This NRCS scenario estimates annual equipment and labor cost at $133.57 for water application and the management of flood water at certain depths, specifically "water depths of 6 [inches] with an average depth of 3 [inches]". Thus, for the MAR-low scenario, which requires 1 foot of water, TFT applies this value twice ($267.14 per acre annually). Additional costs are added to account for the potential permitting and/or water rights issues that need to be addressed for MAR implementation.

Finally, based on variable surface water availability, it is assumed that MAR can only be implemented two of three years, on average, over the 20-year timeframe for which costs are estimated. TFT employs an average annual cost by assigning 67% of the cost estimates to each year in the 20-year costs schedule.

SCENARIO-PLANNING EXAMPLES

The outcome of the models and processes described above is a data set of water resource impacts and costs resulting from the implementation of feasible NRCS practices on all fields within an area of interest. This dataset can be used to identify NRCS practices on specific fields that have the greatest outcomes for specific water resource objectives. For example, through ranking projects based on their modeled outcomes, the fields where specific NRCS practice implementation results in the greatest reduction in groundwater use can be identified. Further, the fields where this outcome is achieved most cost-effectively can be identified by ranking based on impacts per dollar.

"Conservation programs" result when the modeled data are used to identify a group of the highest impact or most cost-effective NRCS practices on specific fields based on a set of criteria. Narrowing the cost and impact data set (e.g., to fields within a specific AOI, with specific crops, or where specific NRCS practices are feasible) facilitates the design of programs that meet more specific constraints or objectives. Three examples of programs designed for the Solano AOI are provided below. They can be designed through the

[34] See: NRCS. (n.d.). USDA Natural Resources Conservation Service California Practice Scenarios. Retrieved from https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/programs/financial/?cid=nrcseprd1328227; Practice 644, Scenario 6 & 22.

web application and viewed in full detail, including a map and table of the specific projects identified in each program, as well as their individual impacts and costs.

Program 1: *Identify projects for Solano County orchards and vineyards that maximize infiltration that supports GDEs, with planned spending of $5,000,000 over 20 years.*

- PROGRAM CRITERIA
  - Objective: Maximize increase in infiltration where it will likely support GDEs
  - Target: $5 million maximum spending (over 20 years)
  - Area of interest: Solano County
  - NRCS practices: All (unconstrained)
  - Crops: Orchard and vineyard crops (almonds, walnuts, grapes, etc.)
- PROGRAM IDENTIFIED:
  - Fields included: 35 fields, where MAR and/or cover cropping were identified as optimal practices
  - Budget: $5 million (over 20 years)
  - Water resource impacts:
    - Impact of interest: Increase annual infiltration that supports GDEs by 1,350 acre-feet
    - Example ancillary impacts: Reduce annual nitrogen runoff by 5,079 pounds; reduce annual sediment runoff by 118 tons; increase annual surface water use by 284 acre-feet; reduce annual groundwater use by 163 acre-feet.

Program 2: *Identify the lowest cost irrigation upgrade and/or cover crop projects in the Dixon RCD that collectively reduce nitrogen runoff by at least 10,000 pounds per year.*

Note that in this example, the program is constrained to specific NRCS practices, but not constrained to fields growing a specific crop type. Also, a specific water resource target is specified rather than a budget; thus, the program design process will reveal the lowest cost to achieve this target.

- PROGRAM CRITERIA
  - Objective: Minimize cost
  - Target: Reduce annual nitrogen runoff by 10,000 pounds
  - Area of interest: Dixon RCD
  - NRCS practices: Irrigation efficiency improvements and cover cropping
  - Crops: All (unconstrained)
- PROGRAM IDENTIFIED:
  - Fields included: 12 fields, where irrigation upgrades and cover cropping were identified, implemented alone or together on specific fields
  - Budget: $1.15 million (over 20 years)
  - Water resource impacts:
    - Impact of interest: Decrease annual nitrogen runoff by 10,000 pounds
    - Example ancillary impacts: Reduce annual phosphorus runoff by 156 pounds; reduce annual surface water use by 4 acre-feet; increase annual groundwater use by 178 acre-feet; increase annual infiltration that supports GDEs by 23 acre-feet.

Program 3: *Identify the lowest cost projects that collectively reduce annual groundwater use by 5,200 acre-feet in the Solano Subbasin.*

The costs and impacts reported above for Programs 1 and 2 assume that 100 percent of the fields identified can be recruited into the program. The web application allows the user to set more realistic assumptions about recruitment success rate and design programs accordingly. This is facilitated by simulation of program design at various recruitment rates from 0 to 100 percent, representing reduced willingness of producers to be incentivized or participate. At lower recruitment rate simulations, random samples of fields are drawn and optimal programs are created from these subsets of fields. As recruitment success decreases, it will be less likely that the highest impact or most cost-effective projects can be included in programs, and program costs and number of required projects will increase as less optimal projects are used to meet program targets or objectives.

- PROGRAM CRITERIA
  - Objective: Minimize cost
  - Target: Reduce annual groundwater use by 5,200 acre-feet
  - Area of interest: Solano Subbasin
  - NRCS practices: All (unconstrained)
  - Crops: All (unconstrained)
- PROGRAM IDENTIFIED (**100 percent recruitment success rate assumed**):
  - Fields included: *87 fields*, where irrigation upgrades were identified
  - Budget: *$13.99 million* (over 20 years)
  - Water resource impact of interest: Decrease annual groundwater use by 5,200 acre-feet
- PROGRAM IDENTIFIED (**40 percent recruitment success rate assumed**):
  - Fields included: *100 fields*, where irrigation upgrades were identified
  - Budget: *$16.5 million* (over 20 years)
  - Water resource impact of interest: Decrease annual groundwater use by 5,200 acre-feet

Note that the impact of the program on groundwater use did not change with assumed recruitment success because this was the primary target set for program design.