Sustainable Water Management Strategy for Specialty Crop Expansion in the Sacramento Valley

Task 2 Report:

Regional Water Conveyance Infrastructure and Hydrology

Prepared for

Sacramento Area Council of Governments

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Prepared by
LAND IQ

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LIST OF ACRONYMS

CDFA	California Department of Food and Agriculture
CIMIS	California Irrigation Management Information System
CVHM	Central Valley Hydrologic Model
DWR	Department of Water Resources
ET	Evapotranspiration
ET_o	Reference evapotranspiration
FAO	Food and Agriculture Organization
Kc	Crop Coefficient
PM	Penman-Monteith
RUCS	Rural Urban Connections Strategy
SACOG	Sacramento Area Council of Governments
UC	University of California
UCCE	University of California Cooperative Extension

1 INTRODUCTION

The Sacramento Area Council of Governments (SACOG) is an association of local governments in the six-county Sacramento Region of El Dorado, Placer, Sacramento, Sutter, Yolo, and Yuba counties and the 22 cities therein. SACOG provides planning and funding for the region, and serves as a forum for the study and resolution of regional issues. New agricultural crops and markets coupled with improved irrigation techniques will support new specialty crop acreage in the SACOG area. While new technologies can result in better crop yields and decreased water demands, increases in irrigation efficiency also result in reduced groundwater recharge from irrigation return flows.

1.1 PROJECT BACKGROUND

SACOG has requested and received grant funding from the California Department of Food and Agriculture (CDFA) to evaluate the feasibility of recharging groundwater on specialty crop agricultural lands within the SACOG portion of the Sacramento Valley. The first phase of this feasibility study is to conduct a review of the hydrogeologic setting of the Sacramento Valley portion of the SACOG area to identify the hydrologic and hydrogeologic components important to assessing the feasibility of recharging groundwater on agricultural land. The primary goal of the project is to bring together a broad range of different factors impacting groundwater recharge and infiltration and to identify areas across the region that are most suited for strategic flooding of specialty crop fields; in other words, areas that will most efficiently and effectively facilitate recharge, while minimizing cost to the specialty crop producer. Ultimately, this feasibility information will be incorporated into SACOG's existing Rural Urban Connection Strategy (RUCS) model to provide a tool that can be used to evaluate the potential benefits of recharging groundwater on agricultural land.

1.2 TASK 1 REVIEW AND SUMMARY

The first task of this project was to review existing hydrogeologic information for the Sacramento Valley portion of the SACOG area and prepare a summary conceptual model focused on identifying the key factors relevant to groundwater recharge feasibility. This effort included a high-level review of the Sacramento Valley portion of the SACOG counties, an area of approximately 3,000 square miles, comprising the following components:

1. Review and summary of hydrogeologic characteristics of the region.
2. Review and summary of geological suitability for groundwater recharge.
3. General estimation of agricultural water use.
4. Documentation of groundwater elevations and depths.
5. Recommendations for the hydrogeologic factors to be developed for recharge feasibility assessment.

The regional hydrogeological conceptual model is a simplified representation of the groundwater system including the geology, water quality, extent and flow of groundwater, and was intended to provide a regional conceptualization of the mechanics of recharge in the Sacramento Valley portion of the SACOG area and provide datasets to use in spatial recharge feasibility assessment tools.

1.3 TASK 2 PURPOSE

The purpose of Task 2 is to focus on recent trends and shifts in irrigation conveyance systems and techniques, including conversion of surface irrigation systems to pressurized systems low-flow systems. This evaluation includes the following components:

1. Spatial evaluation of irrigation system types by location
2. General evaluation of changes in irrigation systems in the last 25 years
3. Analysis and summary of applied water by irrigation type and specialty crop
4. Estimation of yields supported by applied water
5. Where possible, determination of water source used for irrigation
6. Where possible, documentation of changes to groundwater recharge that have occurred as a result of conversion to pressurized irrigation techniques

The main objective of this task is to find and compile quantitative and qualitative information on the availability of water recharge from an irrigation water supply and conveyance perspective. This information will be used somewhat to inform Task 3, which includes a recharge-specific hydrological and hydrogeological assessment, and to inform scenario development for the RUCS model.

2 TASK 2 SUMMARY

Dominant irrigation system types were estimated for each irrigation or water supply district. The majority of districts are predominately using surface/gravity irrigation; however, specialty crops may not reflect this proportion. It is estimated that approximately 20 percent of the land area in the study area has changed from surface irrigation methods to low-flow irrigation methods in the last 25 years.

Estimated applied water for each specialty crop within the SACOG region in 2014 (as identified in Land IQ's 2014 Department of Water Resources (DWR) crop mapping layer) was calculated for each primary irrigation type. Applied water depends on both the crop's water requirement and irrigation efficiency of irrigation systems. Typical yield values for each specialty crop – based on CDFA statewide production statistics and published nitrogen fertilizer recommendations – were compiled for this report; however, there is little research on the impact of increasing applied water. Multiple University of California recharge field studies are ongoing for almonds and pistachios but those results have not been published. Survey information from field agronomists and farmers in the San Joaquin Valley has been collected and developed to estimate recharge water in excess of crop water demand that could be applied at different periods of the year/crop cycle; however, this information is preliminary and will likely be updated and modified as more experience and information accumulates.

Surface water availability was reviewed for irrigation districts within the SACOG region which have specialty crops and where groundwater recharge potential was evaluated in the Task 3 report (Figure 2). Information was obtained through review of Agricultural Water Management Plans. For some districts, only qualitative information on water rights was available.

3 SPATIAL EVALUATION OF IRRIGATION SYSTEM TYPES

Land IQ has developed preliminary spatial information on irrigation system types within the SACOG region for 2014 using several lines of evidence identified in Appendix A. The irrigation type dataset is still being actively improved and has not been finalized, but it represents the best source of spatial information currently available. Irrigation system types were categorized by irrigation classification, then overlaid on the study area and irrigation districts within the study area (Figure 1). Because each irrigation type is categorized per district, the data was used to find the dominant irrigation type for each District. The irrigation types were categorized as follows:

Surface/Gravity:

- Wild Flood
- Flood
- Border Check
- Furrow

Sprinkler:

- Center Pivot
- Hand Move Impact Head Sprinkler
- Permanent Impact Head Sprinkler
- Wheel Line Sprinkler

Low-volume:

- Micro Sprinkler
- Surface Drip
- Sub surface drip
- Drip/Flood
- Micro/Flood

Subsurface:

- Subsurface (not drip) – Delta and Imperial district

Non-irrigated:

- Non-irrigated

50 G / 50 LV:

- 50% of the acreage for given crop in County is on gravity and the other half is on low volume

50 G / 50 S:

- 50% of the acreage for given crop in County is on gravity and the other half is on sprinkler

50 S / 50 LV:

- 50% of the acreage for given crop in County is on sprinkler and the other half is on low volume

33 G / 33 S / 33 LV:

- One third of the acreage for given crop in County is on gravity, one third is on sprinkler, and one third is on low volume

The tabular data for each District can be found in Appendix B. The results show that the majority of the surface/gravity irrigated fields are non-specialty crops while most of the specialty crops are low volume or sprinkler irrigated.

4 EVALUATION OF CHANGES IN IRRIGATION SYSTEMS IN THE LAST 25 YEARS

The primary source of published information on irrigation changes over time in California is from Tindula et al. (2013). Their study estimated change using information from grower surveys conducted in 1972, 1980, 1991, 2001, and 2011 (for 2010 growing season). Survey results indicated that from 1972 until 2010, land irrigated with low volume drip and micro-sprinkler systems increased by 38 percent while land irrigated using surface methods decreased by 37 percent. These changes were driven primarily by increases in the acreage of orchards and vineyards and decreases in the acreages of field crops irrigated using surface methods (Tindula, et al., 2013). The same study concluded that the rate of change from surface to low-volume irrigation methods attributable to new vineyards and orchards had slowed in the last decade of the study (2001-2010), but this was offset by an increase in the use of low-volume irrigation by vegetable growers. For the 2001 through 2010 period low-volume irrigation increased 5 percent and surface irrigation decreased by 7 percent for all crops (Tindula, et al., 2013).

Although not specific to the study area, these results provide an estimate of the likely changes in irrigation systems for the study area. The Tindula et al. (2013) results, when adjusted to a 25-year period and accounting for the lower rate of change in the 2001 to 2010 period, suggest that approximately 20 percent of the land area in the study area has changed from surface irrigation methods to low-flow irrigation methods in the last 25 years.

5 APPLIED WATER BY SPECIALTY CROP AND IRRIGATION TYPE

Land IQ previously completed this spatial estimate of agricultural water use for each groundwater basin within the SACOG area as documented in Appendix A of the Task 1 report. Estimated applied water for each specialty crop within the SACOG region in 2014 (as identified in Land IQ's 2014 crop mapping layer) was calculated for each irrigation type identified in Table 1. The estimated applied water varies by location due to climate differences; thus, Table 1 shows only example estimated values based on weather data from Davis, CA.

Irrigation type efficiency is used to estimate applied water from consumptive use. The four primary irrigation types in the SACOG region are shown in Table 1 along with their associated efficiency. The dominant irrigation type for each crop as indicated in a statewide 2010 survey completed by Tindula, et al. (2013) is also indicated in Table 1. Recently, more detailed spatial information on irrigation type for fields in the SACOG region as described previously, has been developed by Land IQ (Appendix A) and could be used along the 2014 DWR crop layer and local CIMIS weather station data to spatially estimate applied water by field.

Table 1. Estimated Applied Water by Irrigation Type for SACOG Region Specialty Crops

Specialty Crop	Dominant Irrigation Type[1]	Estimated Applied Water (inches)[2]			
		Drip/Micro 90% efficient	Sprinkler 75% efficient	Subsurface 95% efficient	Surface 60% efficient
Almonds	Micro	59.8	71.8	56.7	89.7
Apples	Micro	53.7	64.5	50.9	80.6
Beans (Dry)	Flood	20.2	24.2	19.1	30.3
Bush Berries	Sprinkler	53.3	64.0	50.5	80.0
Carrots	Sprinkler	16.9	20.2	16.0	25.3
Cherries	Drip/Micro	53.7	64.5	50.9	80.6
Citrus	Flood	47.9	57.5	45.4	71.9
Dates	Drip/Micro	63.9	76.7	60.6	95.9
Flowers, Nursery and Christmas Tree Farms	Micro	77.4	92.9	73.3	116.1
Grapes	Micro	39.6	47.5	37.5	59.4
Kiwis	Micro	47.2	56.6	44.7	70.8
Lettuce/Leafy Greens	Sprinkler	13.2	15.8	12.5	19.8
Melons, Squash and Cucumbers	Sprinkler	26.8	32.2	25.4	40.3
Olives	Micro	60.6	72.7	57.4	90.8
Onions and Garlic	Sprinkler	30.0	36.0	28.4	45.0
Peaches/Nectarines	Micro	49.0	58.9	46.5	73.6
Pears	Micro	53.7	64.5	50.9	80.6
Peppers	Sprinkler/Drip	32.6	39.1	30.9	48.9
Pistachios	Drip/Micro	53.9	64.7	51.1	80.9
Plums, Prunes and Apricots	Drip/Micro	51.9	62.3	49.2	77.8
Pomegranates	Drip/Micro	53.7	64.5	50.9	80.6
Potatoes and Sweet Potatoes	Sprinkler	34.2	41.1	32.4	51.3
Strawberries	Drip/Micro	35.4	42.4	33.5	53.1
Tomatoes	Furrow	34.7	41.7	32.9	52.1
Walnuts	Drip/Micro	55.6	66.7	52.7	83.4

Notes:
[1] Survey of Irrigation Methods in California in 2010 (Tindula et al., 2013).
[2] Applied water varies by location, values shown were calculated using ET_o from Davis, CA weather station

6 ESTIMATION OF YIELDS SUPPORTED BY APPLIED WATER

There has been little research done on crop suitability to recharge water since this is not a common practice among growers. Extended saturated or near saturated conditions in the root zone can damage crops. RMC (2015) estimated that saturated conditions may be less of an issue

with cold floodwater which carries more oxygen during cooler winter months. The majority of the research that has been completed on crop tolerance to flooding has focused on heavy soil types where recharge is not suitable (RMC, 2015). The primary source of field data available is from a 2012 recharge study in Fresno County (Bachand et al., 2012). During this study, wine grapes irrigated with on-farm flood flow were observed to have no damage in either the 2010 or 2011 crops. Pistachios and alfalfa were also irrigated similarly and no significant yield reduction was found.

Additional University of California (UC) recharge field studies are ongoing for almonds and pistachios but those results have not been published yet (Dahlke, 2017). O'Geen et al. (2015) reported saturation tolerance for several perennial crops as estimated in surveys completed by UC ANR Cooperative Extension (UCCE) commodity experts. These experts indicated that saturation tolerance is generally higher before budbreak than after and that the most tolerant crops were thought to be grapes and pears, with plums/prunes, walnuts, and almonds also having some tolerance before budbreak. For annual crops, it is assumed that recharge would only occur during the crop's fallow period as they have little to no tolerance to flooding. A summary of the information from these surveys along with other literature sources is provided in Table 2. Typical yield values for each specialty crop based on CDFA statewide production statistics are shown for reference since yield reduction information in response to recharge is not currently available.

In the absence of completed academic research on the quantities of recharge water that crops can tolerate, Mountjoy (2017) collected survey information from field agronomists and farmers in the San Joaquin Valley who have experience with applying recharge water. Table 3 shows the median values from this survey information of estimated recharge water in excess of crop water demand that could be applied at different periods of the year/crop cycle. These values were based on experience with recharge on well drained soils (SAGBI index value of 4 or 5) and typical climate and growing conditions within the San Joaquin Valley. These values are being continually updated each year as more field measurements are collected.

Table 2. Specialty Crop Yield and Saturation Tolerance

Crop	Yield with Optimum Applied Water	Source	Rootstock	Tolerance to Saturation Before Budbreak	Tolerance to Saturation After Budbreak	Source	Recommended N Fertilizer Rate[5] (lbs N/acre/yr)	Source
Perennial Crops								
Almonds	2181 lbs/acre	CDFA[1]	Peach; peach x almond hybrid	up to 48 hrs	up to 48 hrs	O'Geen et al., 2015 [2]	95-380	CDFA-FREP
			Plum; peach x plum hybrid	1 - 2 weeks	up to 48 hrs	O'Geen et al., 2015 [2]		
Apples	7.9 tons/acre	CDFA	M.1, M.3, M.7	Moderately tolerant to flooded soil conditions		Schaffer et al., 1992 [3]	80	CDFA-FREP
			M.111, MM.106, M.9, M.26	Some sensitivity to flooded soil conditions; varies by study		Schaffer et al., 1992 [3]		
Apricots	5.5 tons/acre	CDFA	no literature found	Most sensitive of *Prunus* species to flooded soil conditions		Schaffer et al., 1992 [3]	0-40	UCANR
Bush Berries	197 cwt/acre	CDFA	--	Unknown		--	0.25 lbs N/plant/yr	UC
Cherries	2.53 tons/acre	CDFA	--	up to 48 hrs	no tolerance	O'Geen et al., 2015 [2]	60	O'Geen et al., 2015
Citrus	orange-608 cartons/acre	CDFA	--	no tolerance	no tolerance	O'Geen et al., 2015 [2]	100	O'Geen et al., 2015
Dates	3.6 cwt/acre	CDFA	Unknown	Unknown	Unknown	--	50-245	UC
Kiwis	6.88 tons/acre	CDFA	Unknown	Unknown	Unknown	--	150	UC
Olives	3.2 tons/acre	CDFA	--	Unknown	Unknown	O'Geen et al., 2015 [2]	40-100	CDFA-FREP
Peach/Nectarines	peach - 15 tons/acre nectarine - 8.9 tons/acre	CDFA	no literature found	Extremely sensitive to flooded soil conditions		Schaffer et al., 1992 [3]	60 - 150	CDFA-FREP
Pears	17.2 tons/acre	CDFA	*P. betulaefolia*	> 2 weeks	> 2 weeks	O'Geen et al., 2015 [2]	120-150	CDFA-FREP
			P. communis	> 2 weeks	2 weeks	O'Geen et al., 2015 [2]		
			Cydonia oblonga	2 or more weeks	1 - 2 weeks	O'Geen et al., 2015 [2]		
Pistachios	2648 lbs/acre	CDFA	--	Unknown - no damage observed during recharge study		Bachand et al., 2014	40-240	CDFA-FREP
Plums/prunes	plums - 5.7 tons/acre prunes - 2.2 tons/acre	CDFA	Peach	up to 48 hrs	up to 48 hrs	O'Geen et al., 2015 [2]	65-150	CDFA-FREP
			Plum; peach x plum hybrid	1 - 2 weeks	up to 48 hrs	O'Geen et al., 2015 [2]		
Pomegranate	fresh market 6-10 MT/ha juice 25-35 MT/ha	UCANR[4]	--	Unknown	Unknown	--	100	O'Geen et al., 2015
Walnuts	1.81 tons/acre	CDFA	--	1 - 2 weeks	up to 48 hrs	O'Geen et al., 2015 [2]	86-214	CDFA-FREP
Wine Grapes	6.83 tons/acre	CDFA	--	> 2 weeks	1 week	O'Geen et al., 2015 [2]	0 - 40	CDFA-FREP
Annual Crops								
Beans (Dry)	2116 lbs/acre	CDFA	--	N/A - recharge would occur during fallow period		--	0 - 125	CDFA-FREP
Carrots	315 cwt/acre	CDFA	--	N/A - recharge would occur during fallow period		--	150	CDFA-FREP
Flowers, Nursery and Christmas Tree Farms	varies	--	--	Unknown	Unknown	--	Unknown	--
Lettuce/Leafy Greens	230-405 cwt/acre	CDFA	--	N/A - recharge would occur during fallow period		--	100-180	CDFA-FREP
Melons, Squash, and Cucumbers	melons- 200-610 cwt/acre squash- 191 cwt/acre cucumber-201 cwt/acre	CDFA	--	N/A - recharge would occur during fallow period		--	80 - 160	UC
Onions and Garlic	garlic - 169 cwt/acre onion - 400-600 cwt/acre	CDFA	--	N/A - recharge would occur during fallow period		--	100-200	CDFA-FREP
Peppers	415	CDFA	--	N/A - recharge would occur during fallow period		--	200	UC
Potatoes and Sweet Potatoes	potatoes- 402 cwt/acre sweet potato-325 cwt/acre	CDFA	--	N/A - recharge would occur during fallow period		--	160-240	CDFA-FREP

Crop	Yield with Optimum Applied Water	Source	Rootstock	Tolerance to Saturation Before Budbreak	Tolerance to Saturation After Budbreak	Source	Recommended N Fertilizer Rate[5] (lbs N/acre/yr)	Source
Strawberries	650 cwt/acre	CDFA	--	N/A - recharge would occur during fallow period		--	158	UC
Tomatoes	processing - 44.8 tons/acre	CDFA	--	N/A - recharge would occur during fallow period		--	150 - 175	CDFA-FREP

Notes:
[1] Average of statewide mean yield from 2006 - 2015 - https://www.cdfa.ca.gov/statistics/PDFs/2016Report.pdf
[2] Tolerance to saturated conditions based on expert opinion and has not been supported by controlled experimentation
[3] Literature review of results from several studies
[4] http://ucanr.edu/sites/Pomegranates/files/164437.pdf
[5] N recommendations vary based on yield goals and perennial crop age

Table 3. Estimated Recharge Water Application Rates in excess of Crop Water Demand for Select Specialty Crops

Specialty Crop	Estimated Recharge Water Application in Excess of Crop Water Demand (acre-inches)[1]		
	Nov. – Mar.	Dec. – Feb.	Jan. – Dec.
Almonds	30.64	24.47	45.45
Wine Grapes	61.11	38.38	71.86
Pistachios	32.50	20.00	38.50
Walnuts	71.00	53.00	87.00

[1] Median values from survey of agronomists/farmers in San Joaquin Valley with experience applying excess water for recharge. Values are specific to growing and weather conditions in San Joaquin Valley (Mountjoy, 2017)

7 WATER SUPPLY FOR IRRIGATION

Water supply varies by irrigation district depending on water rights and location. Surface water availability is the most important factor for evaluating feasibility of groundwater recharge. In districts without surface water availability, there is no water source to apply recharge water from. Due to the large number of districts in the SACOG region and budgetary and timeline restraints, water supply information was only researched for districts containing specialty crops and where hydrogeologic recharge potential was evaluated (Figures 2 and 3) as discussed in the Task 1 and Task 3 reports. Some fields in the SACOG region were not located within the boundaries of an irrigation district and are thus likely supplied by groundwater. Available Agricultural Water Management Plans (AWMPs) were consulted for districts within the focus area and reviewed to identify the sources and amounts or irrigation water. This information is shown in Table 4. For several districts specific surface water volume was not provided in the AWMPs, but in these cases, there was typically some qualitative estimate of availability based on surface water rights. Older water rights, especially pre-1914, indicate good surface water availability. Some districts supply only municipal water or are entirely on groundwater. Most of the reclamation districts, whose primary purpose is flood control, do not supply water. If more specific information is needed, follow up with the individual districts is recommended.

Table 4. Irrigation and Reclamation District Surface Water Availability within Focus Area

Agency Name	Total Agency Acres	Agency Acres within SACOG Region	Estimated Surface Water Availability (AFY)
Reclamation Districts			
Reclamation District No 1001	28,720,748	28,720,748	0
Reclamation District No 784	1,927,950	1,927,950	0
Reclamation District No 10	6,043,607	6,033,813	0
Reclamation District No 777	8,532,417	8,532,380	0
Reclamation District No 1660	2,182,763	2,172,143	0
Reclamation District No 730	246,170	246,170	0
Reclamation District No 1000	4,462,342	4,462,342	0
Reclamation District No 2054	1,515,225	1,512,303	0
Reclamation District No 1500	45,218,748	45,014,633	0
Reclamation District No 2056	976,142	976,142	0
Reclamation District No 823	414,427	414,427	0
Reclamation District No 108	10,570,822	4,412,509	142,250 - Sac. River 1917 permit
Reclamation District No 2035	3,093,585	3,093,585	19,824
Reclamation District No 787	774,613	774,613	0
Reclamation District No 783	357,210	357,210	0
Reclamation District 1004	23,226	675	76,465
Reclamation District No 2068	365,829	7,205	70,941
Irrigation Districts			
YCFC & WCD	814,086,659	813,798,921	80,387
Galt Irrigation District	32,448,079	32,397,442	gw primary source
South Sutter Water District	96,949,548	96,949,548	74,877
Wheatland Water District	2,252,302	2,252,302	23,092
Tudor Mutual Water Company	504,313	504,313	pre-1914 water rights

Agency Name	Total Agency Acres	Agency Acres within SACOG Region	Estimated Surface Water Availability (AFY)
Omochumne-Hartnell/ SCWA Overlap Service	1,117,898	1,117,898	––
Western Placer Irrigation District	581,564	581,564	no data; 0 CVP water
Omochumne-Hartnell Water District	10,050,214	10,050,214	100
Sacramento County Water Agency (SCWA)	24,672,404	24,672,404	76,000
Camp Far West Irrigation District	331,453	331,453	Bear River access
Dunnigan Water District	2,673,797	2,664,341	11,600
Feather Water District	3,673,403	3,673,403	20,000
California American Water Company	4,505,955	4,505,955	11,831
Dry Creek Mutual Water Company	865,257	865,257	13,682
Sutter Community Service District	158,667	158,667	municipal
Butte Water District	19,034,753	8,049,572	133,000
South Yuba Water District	2,643,621	2,643,621	25,487
Brophy Water District	6,157,708	6,157,708	43,470
Plumas Mutual Water Company	675,649	675,649	pre-1914 water rights
Colusa County Water District	2,061,081	62,417	54,000
Elk Grove Water Service Retail/ SCWA WSA	352,139	352,139	––
Linda County Water District	58,133	58,133	0 - municipal
North San Joaquin Water Conservation District	13,466,053	149,875	limited Mokelumne River access
Rio Linda/ Elverta Water District	443,086	443,086	municipal
Sutter Extension Water Districts	23,972,257	23,972,257	111,000
Natomas Central MWC	7,093,336	7,093,336	61,123
Tisdale Irrigation and Drainage Company	108,684	108,684	no data
Clay Water District	593,567	593,567	0
Hallwood Irrigation Company	4,691,475	4,691,475	78,000
Oswald WD	52,622	52,622	Feather River access
Sutter Community SD / Sutter Ext. WD	260	260	––
Nevada Irrigation District	290,053,777	72,411,174	239,000
Elk Grove Water District	15,017	15,017	2,935
Ramirez Water District	427,931	378,235	25101
Cordua Irrigation District	2,717,142	2,717,142	60,000
Meridian Farms Water Company	2,250,475	2,241,823	35,000
Browns Valley Irrigation District	21,913,105	21,876,960	47,574
Pleasant Grove Verona Municipal WD	1,396,795	1,396,795	municipal
Garden Highway Mutual Water Company	362,307	362,307	Feather River access
YCFC&W / UC Davis	337,547	332,542	––
Deseret Farms	21,801	21,801	no data
Newhall Land & Farming Company	118,216	118,216	no data
SMUD Rancho Seco	4,973	4,973	1,600
California Water Service	42,038	2,993	0
Sutter Mutual Water Company	24,767,558	24,767,558	182,025
River Garden Farms Company	458,073	458,073	poor recharge suitability
Butte Slough Irrigation Company	375,784	375,784	poor recharge suitability
Pelger Mutual Water Company	96,036	96,036	poor recharge suitability
Hershey Land Company	7,575	7,575	poor recharge suitability
Biggs - West Gridley Water District	384,725	12,160	161,000
Placer County Water Agency	105,057,303	104,814,465	290,667
San Juan Water District	398,556	398,556	poor recharge suitability
Citrus Heights Water District	8,235	8,235	poor recharge suitability

Agency Name	Total Agency Acres	Agency Acres within SACOG Region	Estimated Surface Water Availability (AFY)
Carmichael Water District	5,448	5,448	poor recharge suitability
Browns Valley ID/Cordua ID	2,920	2,920	no specialty crops
Fair Oaks Water District	6,162	6,162	no specialty crops
UC Davis	7,043	769	no specialty crops

Notes:
–– Service overlap, see individual agency providers for surface water availability

8 CHANGES IN GROUNDWATER RECHARGE

Based on state-wide irrigation survey data (Tindula et al., 2013), approximately 20 percent of the irrigated lands in the study area have been converted from surface irrigation methods to low flow irrigation methods over the last 25 years. Studies, including a study by the Irrigation Training and Research Center (ITRC) at the California Polytechnic State University, have documented that crop evapotranspiration increases with low flow irrigation methods and groundwater recharge is reduced to minor amounts (ITRC, 2008). Opportunities for recharge of winter or early-season recharge using surface water supplies may also be reduced due to the lack of surface water infrastructure after the switch to low-flow methods at the farm level. When the change from surface to low-flow irrigation is accompanied by a change from surface water to groundwater, impacts to groundwater levels are exacerbated by the reduction in recharge and the increase in groundwater pumping (ITRC, 2008).

Based on this information, groundwater recharge has likely decreased to near zero over the last 25 years for the 20 percent of irrigated lands in the study area where irrigation method has been converted from surface to low-flow. Where the change in irrigation practices has been accompanied by increased groundwater pumping, as frequently occurs to facilitate the operation of low-flow systems, groundwater levels are likely to have decreased significantly, except possibly in areas where groundwater recharge has been intentionally supplemented, or the additional groundwater pumping captures stream flow or some other groundwater discharge, such as springs or riparian evapotranspiration.

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FIGURES

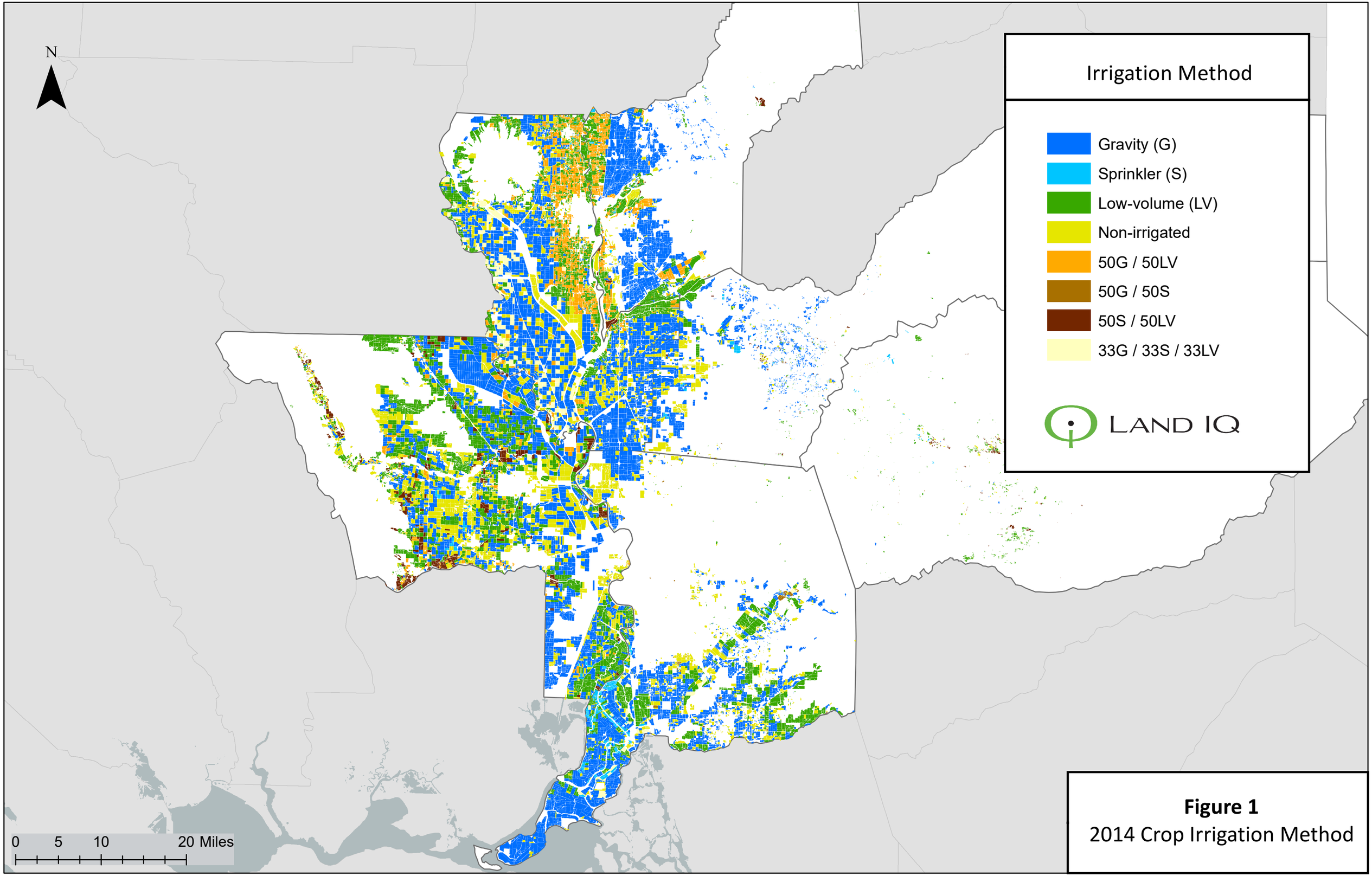

Figure 1
2014 Crop Irrigation Method

N

Biggs - West Gridley WD
Butte WD
Ramirez WD
Browns Valley Irrigation District
Cordua Irrigation District
Browns Valley ID/Cordua ID
Hallwood Irrigation Company
Sutter Community Service District / Sutter Extension WD
Sutter Community Service District
California Water Service
Meridian Farms Water Co
Butte Slough Irrigation Co
Sutter Extension WD
Linda County Water District
Brophy WD
Newhall Land & Farming Co
Wheatland WD
Oswald WD
Tisdale Irrigation And Drainage Co
Feather Water District
Yuba WD
South
Camp Far West ID
Tudor Mutual Water Co
Plumas Mutual Water Co
Dry Creek Mutual Water Co
Nevada ID
Colusa County WD
Dunnigan Water District
Pelger Mutual Water Co
Sutter Mutual Water Co
Garden Highway Mutual Water Co
South Sutter WD
Western Placer ID
River Garden Farms Company
Pleasant Grove Verona Municipal WD
Placer County Water Agency
Hershey Land Company
Deseret Farms
California American Water Co
San Juan WD
Natomas Central MWC
Rio Linda/ Elverta WD
Citrus Heights WD
Fair Oaks WD
Carmichael WD
Yolo County Flood Control And Water Conservation District
YCFC&W / UC Davis
UC Davis
Sacramento County Water Agency
Omochumne-Hartnell/ SCWA Overlap Service
Omochumne-Hartnell WD
Elk Grove Water Service Retail/ SCWA WSA
Elk Grove Water District
Clay WD
Galt ID
SMUD Rancho Seco
N. San Joaquin Water Conservation District

0 5 10 20 Miles

Figure 2
Irrigation Districts in Focused Study Area

LAND IQ

N

RD No 2054
RD No 2056
RD No 777
RD No 10
RD 1004
RD No 1660
RD No 784
RD No 1001
RD No 823
RD No 1500
RD No 108
RD No 787
RD No 783
RD No 730
RD No 1000
RD No 2035
RD No 2068

0 5 10 20 Miles

Figure 3
Reclamation Districts in Focused Study Area

LAND IQ

APPENDIX A

LAND IQ IRRIGATION METHOD MAPPING

Land IQ
November 2017

IRRIGATION METHOD GIS LAYER

DATE: August 23, 2017

SUBJECT: Documentation for 2014 Irrigation Methods Mapping

An irrigation method was assigned to every field in the SACOG area based on 2014 crop mapping by Land IQ. The methods assigned were Level 1 irrigation system types (surface/gravity; sprinkler; low-volume; subsurface; non-irrigated), which include specific irrigation methods as follows:

Surface /Gravity (G):

- Wild Flood
- Flood
- Border Check
- Furrow

Sprinkler (S):

- Center Pivot
- Hand Move Impact Head Sprinkler
- Permanent Impact Head Sprinkler
- Wheel Line Sprinkler

Low-volume (LV):

- Micro Sprinkler
- Surface Drip
- Sub surface drip
- Drip/Flood
- Micro/Flood

Subsurface:

- Subsurface (not drip) – Delta and Imperial district

Non-irrigated:

- Non-irrigated

50 G / 50 LV

- 50% of the acreage for given crop in County is on gravity and the other half is on low volume

50 G / 50 S

- 50% of the acreage for given crop in County is on gravity and the other half is on sprinkler

50 S / 50 LV

- 50% of the acreage for given crop in County is on sprinkler and the other half is on low volume

33 G / 33 S / 33 LV

- 33% of the acreage for given crop in County is on gravity, 33% is on sprinkler, and 33% is on low volume

Variables that were considered included:

- Irrigation District
- Permanent Crop Age
- Region (e.g. north/south)
- Crop Type
- Topography

Lines of evidence included

- Ground Truthing conducted by Land IQ in 2017
- Irrigation District Water Management Plans
- Survey of Irrigation Methods in California 2010
    - http://www.water.ca.gov/waterplan/docs/cwpu2013/Final/vol4/crop_water_use/21Survey_Irrigation_Methods_2010_CA.pdf
- DWR Land Use Dataset by county (GIS):
    a. 2015 Sacramento County (15SA)
    b. 2014 San Francisco County (14SF)
    c. 2014 Santa Clara County (14SC)
    d. 2013 Alpine County (13AP)
    e. 2013 Tuolumne County (13TO)
    f. 2012 San Mateo County (12SM)
    g. 2011 Madera County (11MA)
    h. 2011 Marin County (11MR)
    i. 2010 Mendocino County Southwest (10MD_SW)
    j. 2010 Northern Mono County (10nMN)
    k. 2010 Stanislaus County (10SS)
    l. 2009 Eastern Fresno County (09eFR)
    m. 2009 El Dorado County (09ED)
    n. 2008 Yolo County (08YO)
    o. 2007 Tulare County (07TU)
    p. 2004 Sutter County (04SU)
- Subsurface (not drip): only in the Delta and Imperial Valley
- Crop type, categorized by the DWR Standard Land Use Legend Modified for Remote Sensing as follows:

GRAIN AND HAY CROPS

- Wheat
- Miscellaneous grain and hay

RICE

- Rice
- Wild rice

FIELD CROPS

- Cotton
- Safflower
- Corn, sorghum and Sudan
- Beans
- Sunflowers
- Miscellaneous Field Crops

PASTURE

- Alfalfa & alfalfa mixtures
- Mixed pasture
- Miscellaneous grasses

YOUNG PERRENNIAL

- Young perennial fruits and nuts (includes young orchards and vineyards)

TRUCK, NURSERY, AND BERRY CROPS

- Cole crops (includes broccoli, cauliflower, cabbage, brussel sprouts, mixed cole crops or cole crops not specifically listed in the legend)
- Carrots
- Lettuce/leafy greens
- Melons, squash, and cucumbers (all types)
- Onions and garlic
- Potatoes and sweet potatoes
- Tomatoes (processing and fresh)
- Flowers, nursery & Christmas tree farms
- Bush berries (includes blueberries, blackberries, raspberries, and other bush berries)
- Strawberries
- Peppers (chili, bell, etc.)
- Miscellaneous truck (a truck crop not specifically listed in the legend)

DECIDUOUS FRUITS AND NUTS

- Apples
- Cherries
- Peaches/nectarines

- Pears
- Plums, prunes, and apricots
- Almonds
- Walnuts
- Pistachios
- Pomegranates
- Miscellaneous deciduous (deciduous orchards not specifically listed in the legend)

CITRUS AND SUBTROPICAL

- Citrus
- Dates
- Avocados
- Olives
- Kiwis
- Miscellaneous subtropical fruits

VINEYARDS

- Grapes

IDLE

- Idle (recent and longer-term fallow/idle)

APPENDIX B

2014 IRRIGATION METHOD ACREAGE BY WATER DISTRICT

Land IQ
November 2017

	Irrigation Classification (acres)									
Reclamation District	**Sprinkler**	**Non-irrigated**	**Low-volume**	**Gravity**	**50S/50LV**	**50G/50S**	**50G/50LV**	**33G/33S/33LV**	**Not Classified**	**Sprinkler**
Reclamation District No 823	0	16	338	4	0	0	202	0	161	0
Reclamation District No 787	0	0	0	101	0	0	0	0	78	0
Reclamation District No 784	9	498	448	150	125	0	280	0	1,236	0
Reclamation District No 777	79	292	1,881	106	0	0	2,807	0	2,349	1%
Reclamation District No 730	0	48	38	45	148	0	0	0	135	0
Reclamation District No 2068	0	0	0	0	0	0	0	0	0	0
Reclamation District No 2056	12	304	425	333	0	0	413	0	278	0
Reclamation District No 2054	0	175	100	243	0	0	131	0	87	0
Reclamation District No 2035	0	12	74	6	0	0	0	0	3	0
Reclamation District No 1660	0	3	194	347	0	0	0	367	212	0
Reclamation District No 1500	0	101	111	132	0	0	110	280	275	0
Reclamation District No 108	0	2	116	891	156	0	105	0	267	0
Reclamation District No 1001	0	1,931	3,756	4,190	0	0	1,156	37	3,163	0
Reclamation District No 1000	0	608	11	3,254	0	0	0	0	1,349	0
Reclamation District No 10	73	121	2,087	57	50	0	4,165	0	1,522	0
Water Irrigation District	**Sprinkler**	**Non-irrigated**	**Low-volume**	**Gravity**	**50S/50LV**	**50G/50S**	**50G/50LV**	**33G/33S/33LV**	**Not Classified**	**Sprinkler**
Yolo County Flood Control And Water Conservation District	267	18,686	20,136	18,307	8,080	0	3,035	589	25,953	0
YCFC&W / UC Davis	0	238	76	296	18	0	241	0	1,126	0
Wheatland Water District	0	266	1,251	2,784	0	0	1,839	0	3,083	0
Western Placer Irrigation District	0	1,838	0	426	1	0	0	0	1,324	0
UC Davis	0	0	0	0	0	0	0	0	175	0
Tudor Mutual Water Company	0	121	458	18	0	0	807	0	328	0
Tisdale Irrigation And Drainage Company	0	0	103	32	0	0	0	284	37	0
Sutter Mutual Water Company	0	15	0	47	0	0	20	2	19	0
Sutter Extension Water Districts	18	267	796	1,028	0	0	991	40	837	0
Sutter Community Service District / Sutter Extension Water Districts	0	0	46	0	0	0	0	0	11	0
Sutter Community Service District	0	103	365	71	0	0	17	0	875	0
South Yuba Water District	0	576	233	5,463	0	0	1	0	2,126	0
South Sutter Water District	0	6,188	2,773	23,304	34	0	734	134	9,158	0
San Juan Water District	0	0	0	0	0	0	0	0	65	0
Sacramento County Water Agency	0	1,787	47	624	0	106	0	0	23,786	0
River Garden Farms Company	0	0	0	28	0	0	0	0	50	0
Rio Linda/ Elverta Water District	0	177	12	203	0	22	0	0	9,787	0
Ramirez Water District	0	7	17	2,893	0	0	0	0	752	0
Plumas Mutual Water Company	0	169	514	129	280	0	484	0	931	0
Pleasant Grove Verona Municipal Water District	0	633	0	933	0	0	0	0	207	0
Placer County Water Agency	0	0	0	0	0	0	0	0	9	0
Oswald WD	0	0	127	0	0	0	63	0	61	0
Omochumne-Hartnell/ SCWA Overlap Service	0	562	1,069	849	0	3	0	0	1,464	0
Omochumne-Hartnell Water District	0	365	344	831	0	168	0	0	2,138	0
North San Joaquin Water Conservation District	0	0	0	0	0	0	0	0	24	0
Newhall Land & Farming Company	0	0	0	322	0	0	90	0	31	0
Nevada Irrigation District	50	78	154	457	0	0	0	0	1,064	3%
Natomas Central MWC	0	481	0	677	0	0	0	0	1,506	0
Meridian Farms Water Company	0	951	494	2,030	0	0	115	335	591	0

	Irrigation Classification (acres)									
Water Irrigation District	Sprinkler	Non-irrigated	Low-volume	Gravity	50S/50LV	50G/50S	50G/50LV	33G/33S/33LV	Not Classified	Sprinkler
Linda County Water District	0	27	0	9	4	0	33	0	1,706	0
Hershey Land Company	0	0	3	47	0	0	0	0	34	0
Hallwood Irrigation Company	3	96	220	5,380	10	0	210	0	1,564	0
Garden Highway Mutual Water Company	0	0	440	4	0	0	208	0	168	0
Galt Irrigation District	9	2,593	3,191	6,650	0	58	0	0	10,148	0
Feather Water District	0	58	1,708	76	0	0	1,247	210	515	0
Fair Oaks Water District	0	0	0	0	0	0	0	0	184	0
Elk Grove Water Service Retail/ SCWA WSA	0	417	26	62	0	6	0	0	3,671	0
Elk Grove Water District	0	2	0	0	0	0	0	0	2,318	0
Dunnigan Water District	62	314	2,867	1,827	196	0	485	56	1,575	0
Dry Creek Mutual Water Company	0	23	1,375	1,601	0	0	24	0	646	0
Deseret Farms	0	0	71	0	128	0	0	0	34	0
Cordua Irrigation District	0	6	12	5,492	0	0	79	0	1,754	0
Colusa County Water District	0	0	19	0	0	0	0	0	7	0
Clay Water District	0	163	13	209	0	0	0	0	1,182	0
Carmichael Water District	0	0	0	0	0	0	0	0	128	0
Camp Far West Irrigation District	0	0	1,180	29	0	0	0	0	122	0
California Water Service	0	0	0	0	0	0	0	0	1,209	0
California American Water Company	0	919	58	312	0	0	0	0	11,658	0
Butte Water District	86	645	1,074	608	0	0	1,532	0	1,391	2%
Butte Slough Irrigation Company	0	44	10	313	0	0	0	210	125	0
Browns Valley Irrigation District	0	160	198	1,486	0	0	101	0	1,246	0
Browns Valley ID/Cordua ID	0	0	0	75	0	0	0	0	12	0
Brophy Water District	2	205	81	9,953	1	0	893	0	5,038	0

	Percentage of Irrigation Classification per District within FSA							
Reclamation District	**Non-irrigated**	**Low-volume**	**Gravity**	**50S/50LV**	**50G/50S**	**50G/50LV**	**33G/33S/33LV**	**Not Classified**
Reclamation District No 823	2%	47%	0	0	0	28%	0	22%
Reclamation District No 787	0	0	56%	0	0	0	0	44%
Reclamation District No 784	18%	16%	5%	5%	0	10%	0	45%
Reclamation District No 777	4%	25%	1%	0	0	37%	0	31%
Reclamation District No 730	12%	9%	11%	36%	0	0	0	33%
Reclamation District No 2068	0	0	0	0	0	0	0	100%
Reclamation District No 2056	17%	24%	19%	0	0	23%	0	16%
Reclamation District No 2054	24%	14%	33%	0	0	18%	0	12%
Reclamation District No 2035	12%	79%	6%	0	0	0	0	3%
Reclamation District No 1660	0	17%	31%	0	0	0	33%	19%
Reclamation District No 1500	10%	11%	13%	0	0	11%	28%	27%
Reclamation District No 108	0	8%	58%	10%	0	7%	0	17%
Reclamation District No 1001	14%	26%	29%	0	0	8%	0	22%
Reclamation District No 1000	12%	0	62%	0	0	0	0	26%
Reclamation District No 10	2%	26%	0	0	0	52%	0	19%
Water Irrigation District	**Non-irrigated**	**Low-volume**	**Gravity**	**50S/50LV**	**50G/50S**	**50G/50LV**	**33G/33S/33LV**	**Not Classified**
Yolo County Flood Control And Water Conservation District	20%	21%	19%	9%	0	3%	0	27%
YCFC&W / UC Davis	12%	4%	15%	0	0	12%	0	56%
Wheatland Water District	3%	14%	30%	0	0	20%	0	33%
Western Placer Irrigation District	51%	0	12%	0	0	0	0	37%
UC Davis	0	0	0	0	0	0	0	100%
Tudor Mutual Water Company	7%	26%	1%	0	0	47%	0	19%
Tisdale Irrigation And Drainage Company	0	23%	7%	0	0	0	62%	8%
Sutter Mutual Water Company	14%	0	46%	0	0	19%	2%	18%
Sutter Extension Water Districts	7%	20%	26%	0	0	25%	1%	21%
Sutter Community Service District / Sutter Extension Water Districts	0	80%	0	0	0	0	0	20%
Sutter Community Service District	7%	26%	5%	0	0	1%	0	61%
South Yuba Water District	7%	3%	65%	0	0	0	0	25%
South Sutter Water District	15%	7%	55%	0	0	2%	0	22%
San Juan Water District	0	0	0	0	0	0	0	100%
Sacramento County Water Agency	7%	0	2%	0	0	0	0	90%
River Garden Farms Company	0	0	36%	0	0	0	0	64%
Rio Linda/ Elverta Water District	2%	0	2%	0	0	0	0	96%
Ramirez Water District	0	0	79%	0	0	0	0	21%
Plumas Mutual Water Company	7%	21%	5%	11%	0	19%	0	37%
Pleasant Grove Verona Municipal Water District	36%	0	53%	0	0	0	0	12%
Placer County Water Agency	0	0	0	0	0	0	0	100%
Oswald WD	0	51%	0	0	0	25%	0	24%
Omochumne-Hartnell/ SCWA Overlap Service	14%	27%	22%	0	0	0	0	37%
Omochumne-Hartnell Water District	9%	9%	22%	0	4%	0	0	56%
North San Joaquin Water Conservation District	0	2%	0	0	0	0	0	98%
Newhall Land & Farming Company	0	0	72%	0	0	20%	0	7%
Nevada Irrigation District	4%	9%	25%	0	0	0	0	59%
Natomas Central MWC	18%	0	25%	0	0	0	0	57%
Meridian Farms Water Company	21%	11%	45%	0	0	3%	7%	13%

	Percentage of Irrigation Classification per District within FSA							
Water Irrigation District	**Non-irrigated**	**Low-volume**	**Gravity**	**50S/50LV**	**50G/50S**	**50G/50LV**	**33G/33S/33LV**	**Not Classified**
Linda County Water District	2%	0	0	0	0	2%	0	96%
Hershey Land Company	0	3%	57%	0	0	0	0	40%
Hallwood Irrigation Company	1%	3%	72%	0	0	3%	0	21%
Garden Highway Mutual Water Company	0	54%	0	0	0	25%	0	20%
Galt Irrigation District	11%	14%	29%	0	0	0	0	45%
Feather Water District	2%	45%	2%	0	0	33%	6%	14%
Fair Oaks Water District	0	0	0	0	0	0	0	100%
Elk Grove Water Service Retail/ SCWA WSA	10%	0	1%	0	0	0	0	88%
Elk Grove Water District	0	0	0	0	0	0	0	100%
Dunnigan Water District	4%	39%	25%	3%	0	7%	0	21%
Dry Creek Mutual Water Company	0	37%	44%	0	0	0	0	18%
Deseret Farms	0	31%	0	55%	0	0	0	14%
Cordua Irrigation District	0	0	75%	0	0	1%	0	24%
Colusa County Water District	0	74%	0	0	0	0	0	26%
Clay Water District	10%	0	13%	0	0	0	0	75%
Carmichael Water District	0	0	0	0	0	0	0	100%
Camp Far West Irrigation District	0	89%	2%	0	0	0	0	9%
California Water Service	0	0	0	0	0	0	0	100%
California American Water Company	7%	0	2%	0	0	0	0	90%
Butte Water District	12%	20%	11%	0	0	29%	0	26%
Butte Slough Irrigation Company	6%	1%	45%	0	0	0	30%	18%
Browns Valley Irrigation District	5%	6%	47%	0	0	3%	0	39%
Browns Valley ID/Cordua ID	0	0	86%	0	0	0	0	14%
Brophy Water District	1%	0	62%	0	0	6%	0	31%

APPENDIX C

2014 IRRIGATION METHOD ACREAGE BY CROP

Land IQ
November 2017

	Irrigation Method - Acres								
2014 Crop	**Gravity**	**Low-volume**	**Non-irrigated**	**Sprinkler**	**50G/50LV**	**50G/50S**	**50S/50LV**	**33G/33S/33LV**	**Total**
Specialty Crops									
Walnuts		50,801					15,311		66,112
Tomatoes		39,192						14,692	53,883
Grapes	85	53,087							53,172
Almonds		33,167							33,167
Plums, Prunes and Apricots		63			27,201				27,264
Peaches/Nectarines	120				10,492				10,612
Beans (Dry)	1,031	469						7,841	9,342
Melons, Squash and Cucumbers	789				8,006				8,795
Young Perennials					5,039		1,536		6,575
Pears	28	385		4,954					5,366
Olives		4,877							4,877
Miscellaneous Truck Crops	295				2,045	1,006	72		3,417
Miscellaneous Deciduous		467			601		1,582		2,651
Cherries		1,773							1,773
Onions and Garlic	72			68				1,405	1,544
Apples	52	314					876		1,243
Flowers, Nursery and Christmas Tree Farms	521			96			367		983
Pistachios		818							818
Carrots	4			599					603
Kiwis				500					500
Citrus		419							419
Peppers	286								286
Strawberries		151							151
Pomegranates		113							113
Lettuce/Leafy Greens				102					102
Miscellaneous Subtropical Fruits		99							99
Bush Berries		62							62
Potatoes and Sweet Potatoes	12								12
Dates	6								6
Non-Specialty Crops									
Rice	176,914								176,914
Mixed Pasture	56,058			263					56,322
Alfalfa and Alfalfa Mixtures	56,212								56,212
Corn, Sorghum and Sudan	44,397								44,397
Sunflowers	28,181								28,181
Wheat	15,686								15,686
Safflower	10,484								10,484
Miscellaneous Grain and Hay	8,751								8,751
Miscellaneous Grasses	2,604			2,839					5,442
Wild Rice	2,232								2,232
Miscellaneous Field Crops	995								995
Cotton	462								462
Idle			163,745						163,745
Total	**23,938**	**53,385**	**1,006**	**19,744**	**406,276**	**186,258**	**163,745**	**9,420**	**863,771**