SAN JOAQUIN LAND AND WATER STRATEGY

Exploring the Intersection of Agricultural Land & Water Resources in California's San Joaquin Valley

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AMERICAN FARMLAND TRUST
IN PARTNERSHIP WITH
CONSERVATION BIOLOGY INSTITUTE

ACKNOWLEDGMENTS

American Farmland Trust
SAVING THE LAND THAT SUSTAINS US

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A Research Report of the
HELEN K. CAHILL CENTER FOR
FARMLAND CONSERVATION POLICY INNOVATION

This project was conducted under the auspices of the Helen K. Cahill Center for Farmland Conservation Policy Innovation. The Cahill Center supports the research, policy and conservation work of American Farmland Trust in California. Its namesake, Helen Kennedy “Peggy” Cahill (1916–2013), was a proud fourth generation descendant of California pioneers who in 1849 founded the city of Stockton. A teacher, outdoors enthusiast and philanthropist, Peggy had an abiding interest in the conservation of farmland, especially in the San Joaquin Valley. In her memory, her family has endowed the Cahill Center as a living legacy for future generations who will depend on the land that feeds and sustains us.

COVER IMAGE BY INGA SPENCE/ALAMY

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INGA SPENCE/ALAMY

Executive Summary


JIM WEST/ALAMY

California's San Joaquin Valley is one of the most productive agricultural regions in the world, but it's facing numerous challenges. Water availability, a variable climate, new regulations, and a growing population threaten the future of agriculture in the region. For over 30 years, American Farmland Trust (AFT) has been tracking urban growth patterns and promoting farmland conservation in the valley. This report continues the work of AFT and its partners by leveraging existing data from earlier reports—the *San Joaquin Valley Greenprint: State of the Valley Report* and *Saving Farmland, Growing Cities*—to understand the ever-changing dynamics of land and water and assess new threats to the sustainability of valley agriculture.

In order to help planners, municipalities, and natural resource agencies support the agricultural community where it is most vulnerable, AFT and the Conservation Biology Institute (CBI) assessed the capacity and resilience of agricultural production in the valley. This work was completed by analyzing the current distribution of quality agricultural land and water resources as well as the future impacts these resources face. Using the San Joaquin Valley Gateway, part of the Data Basin online mapping platform created by CBI, as a baseline for current trends in water, agriculture, biodiversity, and energy, AFT and CBI created a spatial analysis reflecting how agricultural land and water resources intersect in the valley.

This quantitative and spatial analysis shows that the highest-quality farmland with the most reliable water resources is located mainly around cities, where the risk of development for non-farm uses is highest. While strides have been made by farmers to increase irrigation efficiency and improve groundwater infiltration, future water regulations and an uncertain water supply may reduce the amount of land under cultivation. In addition, land use policy will further influence how much farmland is available in the years ahead.

This report and the San Joaquin Valley Gateway platform (https://sjvp.databasin.org) are critical to properly prioritize and preserve the region's best farmland and assist in the protection of its water supply.

INGA SPENCE/ALAMY

Introduction

As part of the San Joaquin Valley Greenprint project,[1] AFT and CBI explored the intersection of land and water resources in the valley as they affect agricultural production. Our inquiry focused on several key questions:

- How is the quality of agricultural land distributed in the valley?
- Where are irrigation water resources more or less abundant and reliable?
- How and where does the combination of land quality and water reliability appear to make agriculture more or less resilient?
- How and where will future urban growth, new proposed water regulations, and climate change affect agricultural land and water resources?

We utilized the Data Basin platform to respond to these key questions and also to demonstrate its use as an analytic planning tool for local governments, state agencies, and the private sector.

With credible and transparent science as its foundation, Data Basin (www.databasin.org) is a robust and versatile online mapping service that was developed and launched by CBI in 2010. All of the results of our analysis, including the data, maps, and a detailed explanation of our process, are available in a designated gallery (or folder) in the Data Basin San Joaquin Valley Gateway.[2] This report is a summary of our findings based on the data we chose and set of assumptions we made in conducting our analysis.

Both land and water resources are critical to agriculture in the semi-arid San Joaquin Valley.

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[1] AFT and CBI wish to thank the Fresno Council of Governments, the sponsor and fiscal agent for the Greenprint project, for selecting this project as a demonstration, and the state Strategic Growth Council and Kern County Department of Planning for funding it. The findings and conclusions of this report are solely those of AFT and CBI, and not necessarily of any of the project funders.

[2] *See* https://sjvp.databasin.org/.

Basic Analytical Approach


DESIGN PICS INC/ALAMY

The scope of our study was limited to the floor of the San Joaquin Valley—comprising roughly six million acres—where irrigated agriculture predominates and both land and water resources are essential to food production. To answer the questions we posed, AFT partnered with CBI to compile and analyze relevant quantitative spatial data, some of which was generated by the Greenprint project itself. The analysis of agricultural land resources was undertaken using the Environmental Evaluation Modeling System (or EEMS)[3] logic modeling software, developed by CBI. EEMS allows for the integration of numerous, varied spatial data layers using an analytical framework that is easy to use and understand and that supported the exploration of different assumptions and approaches. The logic modeling we undertook included components related to both the assets and impairments to agricultural land quality and agricultural water resources. Development risk was modeled using an individual multicriteria approach as opposed to a logic model framework.

In the process of assembling spatial data and constructing models for each topic area, we held a series of workshops throughout the valley and a number of online webinars to engage stakeholders. We asked for their perspectives on the questions we were investigating and sought their advice on what kind of factors (represented by the data) were most relevant and how much weight they should carry. Through this process, we gained valuable insights which we will use to further engage valley stakeholders in conservation and management strategies for land and water resources.[4]

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[3] See https://databasin.org/articles/e48fb1ac5ffe4454a324dff834de2ede for EEMS overview

[4] We acknowledge that, by focusing exclusively on agriculture, this report only tangentially addresses concerns related to urban land and water use, and to the health of natural resources and the environment. The scope of our analysis was, unfortunately, limited by the amount of funding available. But AFT and CBI would gladly incorporate these other important concerns, given additional resources. For an example of how Data Basin was used to address environmental as well as agricultural concerns, *see* University of California Berkeley Center for Law, Energy & Environment and Conservation Biology Institute, *A Path Forward: Identifying Least-Conflict Solar PV Development in California's San Joaquin Valley*, May 2016 at https://consbio.org/products/reports/path-forward-identifying-least-conflict-solar-pv-development-californias-san-joaquin-valley.

Agricultural Land Resources


RICHARD THORNTON/SHUTTERSTOCK

Land is the foundation of agriculture. Indeed, the word "agriculture" derives from the Latin word "agri," meaning field. Although it's obvious that not all land is the same, the very real practical differences are often overlooked when decisions affecting agricultural land are made.

Methodology for Assessing Agricultural Land Quality

Our first inquiry addressed the intrinsic quality or agricultural resource value of the land in the valley. The focus was on characteristics that are inherent in the land and soil itself and, as such, are extremely difficult to improve or overcome by human intervention. Our assumption was that, all else being equal, land with more favorable intrinsic characteristics is more likely to be productive, versatile, sustainable, and profitable for agriculture. Thus, we sought to identify and integrate spatial data that reflected both positive and negative attributes to define relative agricultural land quality in the valley.

The datasets representing positive attributes included:

- California Storie Index (a formal measure of soil productivity for agricultural uses)[5]
- Farmland Mapping & Monitoring Program (FMMP) rank categories (reflecting soil productivity and active irrigation)[6]
- Aquifer recharge potential (Soil Agricultural Groundwater Banking Index—a direct link between land and the availability of water)[7]
- Microclimate (particularly for high value citrus production)[8]

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[5] Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Soil Survey Geographic (SSURGO) Database. Available online at https://sdmdataaccess.sc.egov.usda.gov. California Storie Index description available at: http://anrcatalog.ucanr.edu/pdf/8335.pdf.

[6] California Department of Conservation Division of Land Resource Protection, Farmland Mapping and Monitoring Program. Data available at http://www.conservation.ca.gov/dlrp/fmmp.

[7] O'Geen A, Saal M, Dahlke H, Doll D, Elkins R, Fulton A, Fogg G, Harter T, Hopmans J, Ingels C, Niederholzer F, Sandoval Solis S, Verdegaal P, Walkinshaw M. 2015. Soil suitability index identifies potential areas for groundwater banking on agricultural lands. Calif Agr 69(2):75–84. https://doi.org/10.3733/ca.v069n02p75.

[8] Developed using Maxent Software to identify the climatic space that citrus crops were primarily found in in the San Joaquin Valley. Environmental variables used include Potential Evapotranspiration, Minimum Temperature of the Winter Months, Annual Precipitation, and Maximum Temperature of the Hottest Months. All environmental variables were downloaded from Climate Commons available here: http://climate.calcommons.org/dataset/2014-CA-BCM. Point locations for citrus were extracted from 2016 USDA cropscape data using the citrus and orange variables available here: https://nassgeodata.gmu.edu/CropScape/.

These data were processed for just over six million acres on the valley floor using 270-meter resolution with each reporting unit equivalent to roughly 18 acres. Areas were identified as having active agricultural land if they contained any known crop production as determined by the California Department of Conservation through the Farmland Mapping & Monitoring Program, a biennial aerial survey of agricultural land throughout California.

We took the same approach in combining datasets representing negative attributes of the land, including:

- Soil salinity and sodicity (which limit productivity and what can be grown on the land)[9]
- Shallow groundwater tables (also a limitation on production due to restricted root development and health)[10]
- Pattern of recent (2011–2016) fallowing (reflecting economic decisions based on land or water limitations during the recent drought)[11]

Within the EEMS modeling environment, the positive attribute data were combined to produce an index of land asset value, and the negative attribute data were combined to produce an index of land impairment value. All datasets used to form the individual indeces were given equal weight—though alternative weighting would be possible—and normalized to fit on the same scale (-1 to +1) in order to combine and assess varying input data[12]. While valuable individually, the combination of these two indices produced a superior overall Land Quality score (Figure 1). The Land Quality scores for all locations throughout the valley were then grouped into high, medium, or low ranges using a mathematical algorithm called the Jenks Natural Breaks method. This approach identifies natural breaks—like stair steps—in the data by maximizing similarities and differences between groups, allowing for a simple and unbiased grouping process.

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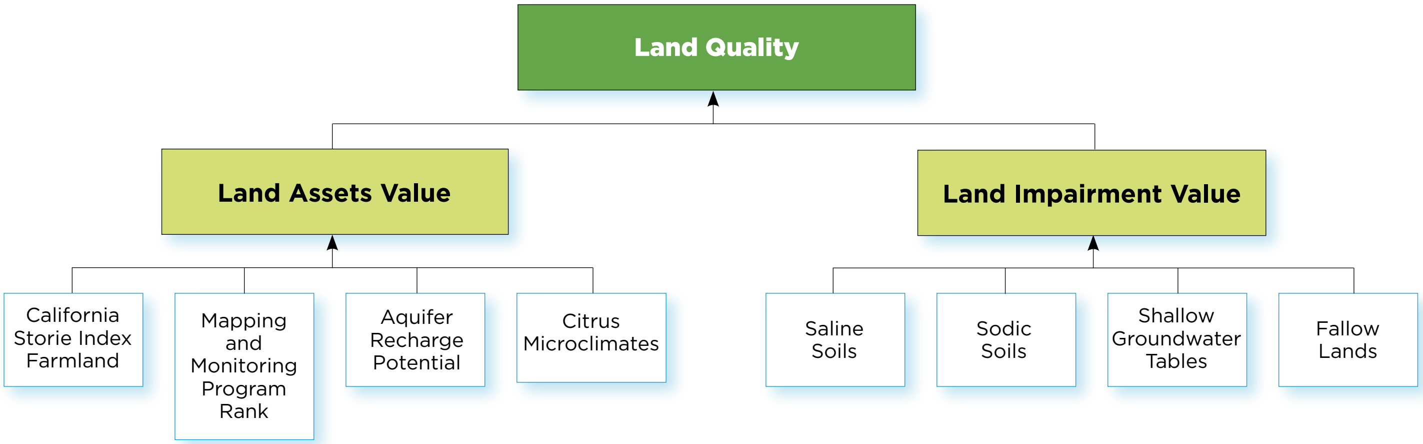
[9] Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Soil Survey Geographic (SSURGO) Database. Available online at https://sdmdataaccess.sc.egov.usda.gov. Salinity and Sodicity were chosen based upon this preliminary study by the California Department of Conservation available here: ftp://ftp.consrv.ca.gov/pub/dlrp/FMMP/special_projects/soil/CA_ec4_and_sar13_100cm.pdf.

[10] California Department of Water Resources, San Joaquin Valley Agricultural Drainage Data. Shallow Groundwater Data was provided for the following years 2010–2012 for the greater San Joaquin Valley and can be viewed here: http://water.ca.gov/drainage/sgwec/index.cfm.

[11] Data processed from USDA NRCS Cropscape Data from 2011-2016 here: https://nassgeodata.gmu.edu/CropScape/ and from NASA fallow cropland analyses for 2011, 2015, and 2016 available here: https://nex.nasa.gov/nex/resources/370/.

[12] Please see the appendix for a full explanation of the EEMS modeling process, including the normalization of input data. Normalizing data simply involves taking a scale that the current data is in (0-100 for example) and stretching it across a new scale (-1 to +1 for use in EEMS).

Figure 1. EEMS logic model diagram depicting land quality diagram integrating positive and negative attributes.



To test the accuracy of our Land Quality model, we compared our results with the cropping patterns in selected parts of the valley (Figure 2). Our assumption was that, if the land identified by our model as being of high quality closely mirrored where the highest value crops are currently grown, it would validate that our model reasonably captured the intrinsic characteristics of the land, as, indeed, it seems to do.[13]

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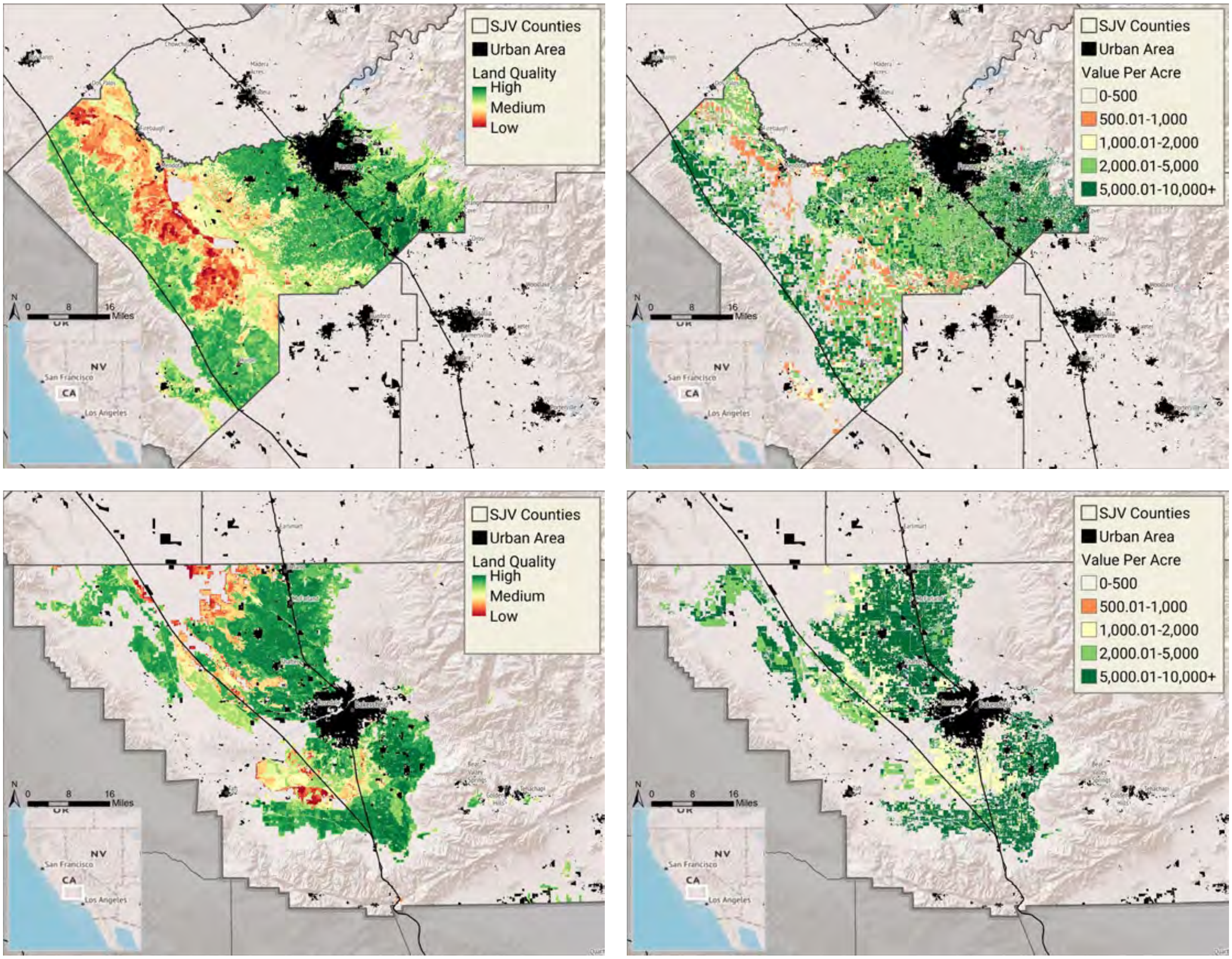
[13] As stakeholders noted, some "lower" value land may contribute more to agriculture than the quality of the land itself would suggest. Examples are land producing low-value forage crops that support the valley's high-value dairy industry or annual crops that support more farm worker jobs per acre than higher-value permanent crops.

Figure 2. Companion map results for land quality (left) and crop value (right) for Fresno (top) and Kern (bottom) counties.

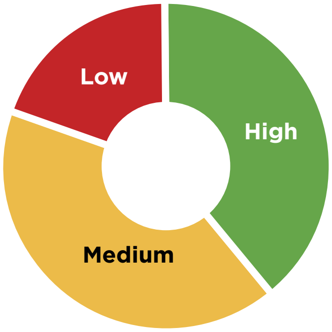


Major Findings about Agricultural Land Quality

Based on our analysis of its intrinsic characteristics about 40 percent of the agricultural land in the San Joaquin Valley was determined to be of the highest quality (Figure 3). Forty-one percent of the agricultural land area was classified as medium quality with 20 percent in the low quality category. This is not to suggest that these lands are not productive or valuable to the overall agricultural portfolio in the valley. The San Joaquin would not be the most productive agricultural region in the country without all of its land. But high-quality land is generally more productive, versatile, and has fewer limitations making it the most resilient and important land to retain in agricultural use if the goal is to

Only 4 in 10 acres of the agricultural land in the valley was determined to be of the highest quality.

Figure 3. General profile of agricultural land quality in the San Joaquin Valley.



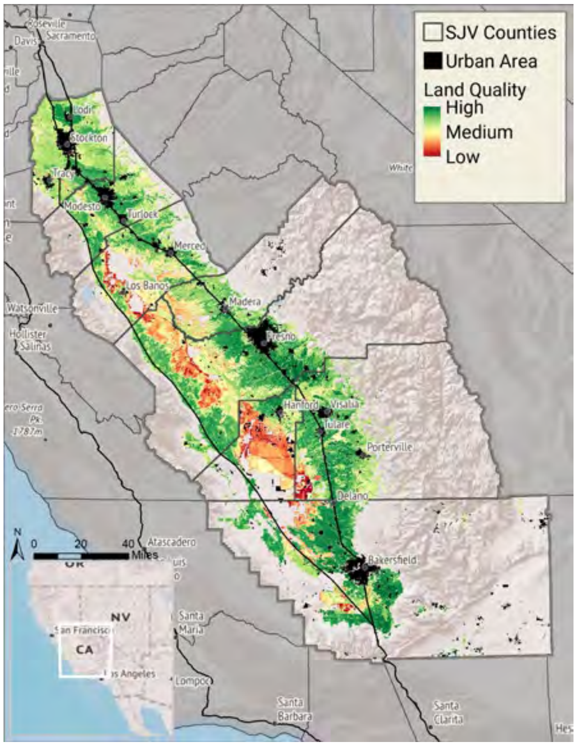
Acreage in each land quality category

High	2,394,545	39%
Medium	2,543,106	41%
Low	1,209,869	20%

maintain or, indeed, increase agricultural production. It will simply be more costly and technically difficult to rely on lower-quality land at the expense of high-quality land.

Most of the valley's high-quality land is found along the Highway 99 corridor on the east side of the valley (Figure 4). The fact that most of the valley's cities are located on or near the largest concentration of high-quality agricultural land reflects the original agrarian settlers' awareness of the superior nature of this land. Those decisions are now working at cross purposes with the goal of sustaining agricultural production, because urban growth is permanently removing the highest-quality agricultural land from production as cities expand. As shown later in this report, the valley's high-quality agricultural land is at greater risk of being converted to non-agricultural uses than land of lower quality.

Figure 4. Geographic distribution of agricultural land quality in the San Joaquin Valley.



Most of the high-quality agricultural land in the valley is found along the Highway 99 corridor where it is most vulnerable to development.

Agricultural land where underground water supplies are most readily replenished is also located primarily around the valley's cities.

A special subset of the valley's agricultural land deserves to be highlighted: land that serves as groundwater recharge areas that are critical to the water supply for both agriculture and urban uses. One of the criteria we used to determine the quality of land was its capacity to allow groundwater recharge, so it is not a coincidence that there is significant overlap between aquifer recharge areas and high-quality land. This land is typically prime farmland with well-drained soils that easily allow precipitation and irrigation water to percolate down into underground aquifers or storage basins. Compared to other high-quality agricultural land, it is concentrated predominantly around the valley's cities where it is vulnerable to being paved over, thus negating its recharge function. (Figure 5)

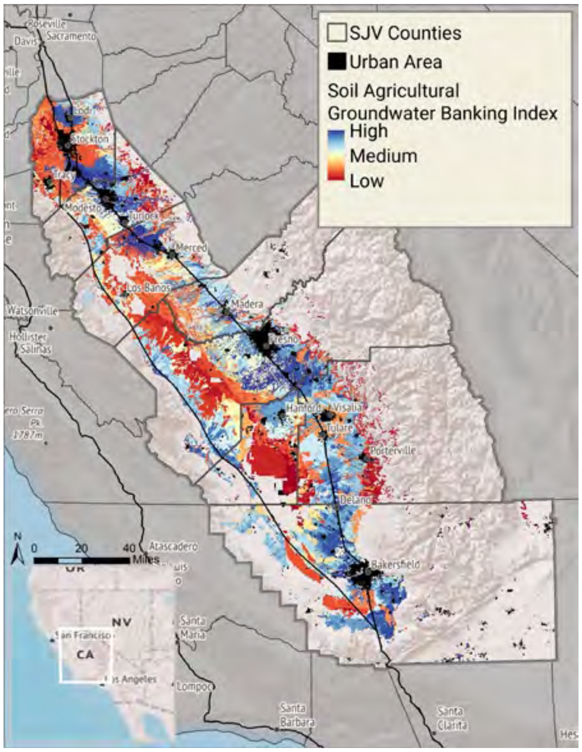


Figure 5. Aquifer recharge areas in the San Joaquin Valley (blue) as indicated by Soil Agricultural Groundwater Banking Index.[14]

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[14] O'Geen A, Saal M, Dahlke H, Doll D, Elkins R, Fulton A, Fogg G, Harter T, Hopmans J, Ingels C, Niederholzer F, Sandoval Solis S, Verdegaal P, Walkinshaw M. 2015. Soil suitability index identifies potential areas for groundwater banking on agricultural lands. Calif Agr 69(2):75–84. https://doi.org/10.3733/ca.v069n02p75.

Agricultural Water Resources

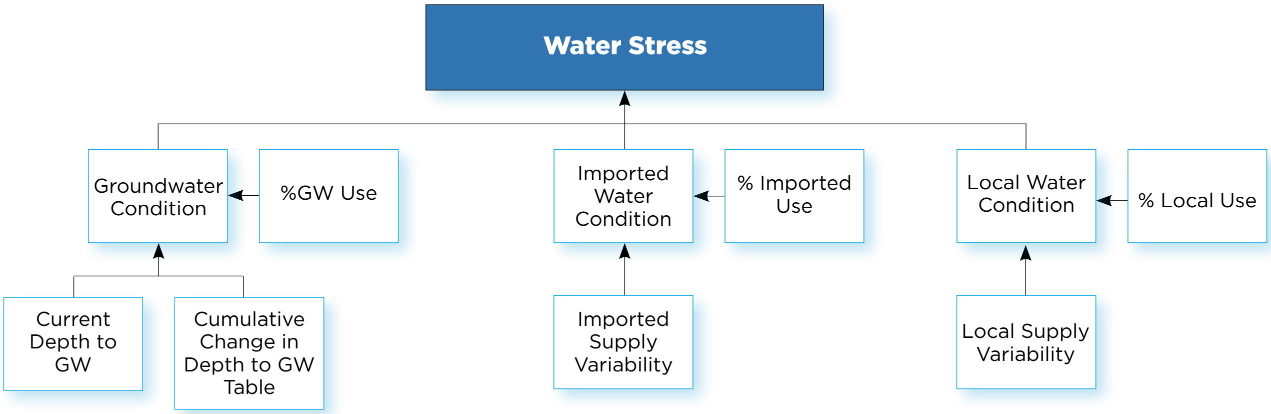
Of course, land is only half of the equation for agricultural production in the San Joaquin Valley. Irrigation water is its lifeblood, and the quality of the land in this region matters little if it does not have adequate water supplies. Thus, as the recent drought has underscored, it is crucial to understand where and to what extent agricultural water supplies are under stress or subject to uncertainty that could affect the reliability of future water supplies and, hence, of agricultural production. The second focus of our inquiry attempted to address this question.

Irrigation water is the lifeblood of agriculture in the San Joaquin valley.

Methodology for Assessing Agricultural Water Stress

Our assessment of the condition of water resources looked at the three principal sources on which San Joaquin Valley agriculture relies: local surface water from watersheds draining regions in the valley, imported surface water from outside regions in the valley (e.g., Sacramento River water delivered through the Delta, or imported water along the Friant-Kern Canal) and groundwater. The analysis considered both the degree of reliance on the different sources of water, measured as a percentage of total agricultural water use (Figure 6), and the year-to-year variability in the supply of these sources. The underlying assumption was that areas with a high degree of reliance on water supplies that vary significantly from year-to-year are more water stressed. Conversely, areas with diverse water supplies and/or water supplies that were steady from year-

Figure 6. Water stress logic model diagram.

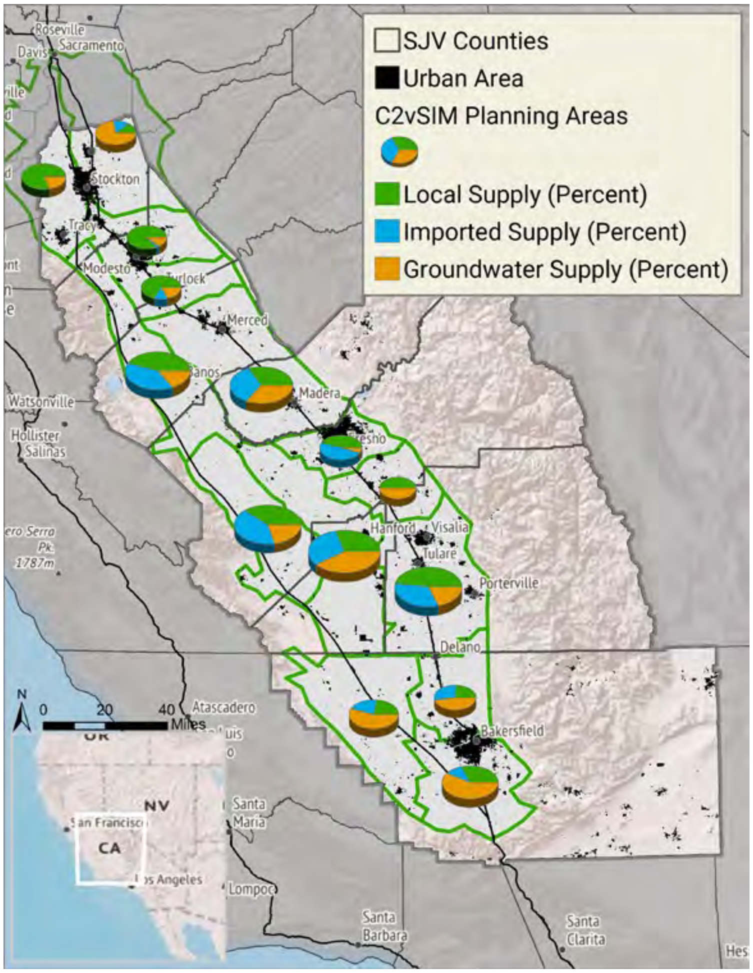


to-year would be less water stressed. For groundwater, the assumption was that areas with deeper groundwater tables and those areas that have experienced the greatest increase in depth to groundwater over the drought are more water stressed.

For surface water, we used data from the California Department of Water Resources (DWR) to measure the amount and percentage of total agricultural water supplies that come from both local and imported sources in each C2VSim planning area[15] as well as the variability of those supplies over the longest and most recent period for which comparable data of a recent time period were available (1973–2009).[16] Variability was defined as the extent by which annual agricultural use over the period deviated from the mean annual usage (coefficient of variation) with higher scores representing the greatest deviation, i.e. less reliability and, hence, greater water stress.

Figure 7. Mix of agricultural water supplies in C2VSim planning areas in the San Joaquin Valley

(diameter of pies indicates total amount of water used annually in each planning area. Annual agricultural water use data is provided in the Appendix).



Water usage was estimated using the DWR data providing us with the percentage of water for each planning area that came from groundwater, local water supplies, and imported water supplies. The groundwater usage percentage was combined with data reflecting the condition of groundwater resources including both the depth to groundwater in fall of 2017, and the change in depth to groundwater over the recent drought period up to the current year (2011–2017).[17] Depth to groundwater reflects the cost of pumping irrigation water to the surface, while the change in depth is a direct indicator of how much groundwater is being drawn down and, in some cases, depleted, increasing the risk of wells going dry.

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[15] Surface water data are collected for each of C2VSim water management planning areas that encompass at least part of the valley. Our analysis focused on planning areas that account for the overwhelming majority of agricultural water used in the region. These data are not available for individual parcels of land as they are for land quality data. Thus, our analysis of surface water reliability could not be as fine-grained as our land quality analysis. Groundwater data from wells are available on a more detailed basis but require interpolation and, thus are useful only for the kind of large-scale analysis we undertook.

[16] Data processed for each of the C2VSim Planning Areas intersecting the San Joaquin Valley from the Department of Water Resources:Coars Grid C2VSim Model Version R374 (C2VSim-CG_R374) available at: http://baydeltaoffice.water.ca.gov/modeling/hydrology/C2VSim/download/C2VSim_CG_1972IC_R374_Model.zip.

[17] Data processed from the Department of Water Resources: Groundwater Information Center Interactive Map Application for groundwater depth in Spring of 2016 and for all annual Spring to Spring changes in depth to groundwater from 2011 to 2017. Available at: https://gis.water.ca.gov/app/gicima/.

Of the roughly 11 million acre-feet of water used annually by agriculture in the valley, just over 40 percent comes from local surface water sources, 27 percent from imported surface water supplies and the remaining 32 percent from groundwater.[18] But there are significant differences in the mix of these sources from planning area to planning area (Figure 7). Local surface water supplies predominate in the northern part of the valley, while imported surface water becomes more important farther south and on the west side, and reliance on groundwater increases toward the southern end of the region.

All water data inputs, like those for land quality, were normalized on a -1 to +1 scale. The Jenks Natural Breaks method was also used to determine high, medium and low water stress categories. A high stress level generally means that an area relies heavily on a source or sources of water that are more variable or less reliable, while a lower stress level reflects less reliance on variable sources and greater reliance on relatively stable sources or both.[19] Areas with low water stress tend to rely to a much greater extent on local surface water supplies that are less variable. Conversely, areas with medium and high water stress rely more heavily on imported surface water supplies that tend to be more variable. The depth to groundwater is much greater in high stress areas than in moderate and low stress areas. The change in depth to groundwater in high stress areas is also much greater in both absolute terms and percentage decline compared with low and moderate stress areas (Table 1).

Table 1. Average characteristics of areas in different water stress classifications.

	Water Stress Class		
	High	**Medium**	**Low**
Local Surface Water Supplies (%)	36	39	52
Imported Surface Water Supplies (%)	37	34	22
Groundwater (%)	26	26	25
Depth to Groundwater (avg-ft)	253	186	74
Change in Depth to Groundwater (avg-ft)	-33	-12	-6
Change in Depth to Groundwater (%)	-13%	-6%	-8%

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[18] Total Acre Feet Extraction derived from our analysis of agricultural water use in the valley (Figure 15 and Table 3) confirmed also by Ellen Hanak, Jay Lund, Brad Arnold, Alvar Escriva-Bou, Brian Gray, Sarge Green, Thomas Harter, Richard Howitt, Duncan Macewan, Josué Medellín-Azuara, Peter Moyle, Nathaniel Seavy. *Water Stress and A Changing San Joaquin Valley.* March 2017. Available at: http://www.ppic.org/publication/water-stress-and-a-changing-san-joaquin-valley/. Percentages of water use are from our analysis of C2VSim Planning Area Data (1973–2009).

[19] Maps and data showing the breakdown of how local, imported, and groundwater scores contributed to overall water stress scores can be found in the Appendix.

All that said, it is important to keep in mind that our ranking of water stress, like that of land quality, is on a relative, not an absolute scale. What it shows are the differences in the comparative reliability of water supplies across the region.

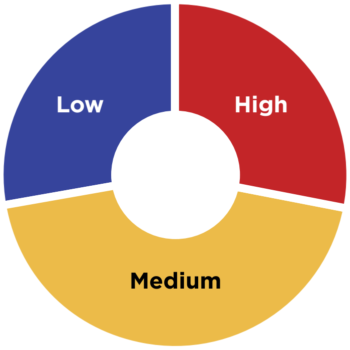
Major Findings about Agricultural Water Stress

According to our analysis, about 1.7 million of the six million acres of irrigated farmland in the valley (28.1 percent) is experiencing high water stress. A comparable amount (27.7 percent) is experiencing low water stress, with another 44.2 percent or 2.7 million acres experiencing medium stress. (Figure 8).

Just as with the quality of agricultural land, there are significant geographic differences in the profile of water stressed lands (Figure 9). Generally, water stress increases from north to south, reflecting variations in temperature and precipitation, but also the reliance on imported surface water supplies and groundwater increases. Higher temperatures and lower precipitation create a need for proportionately more water to produce crops (Figures 15 and 17), while the relative lack of surface water supplies in the southern portion of the valley and, hence, a greater reliance on groundwater, seems to have resulted in a greater drawdown of aquifers in that subregion.

The water stress profile of the valley's agricultural land could change significantly due to pending state water regulatory decisions and climate change. The potential impacts of these events are explored in the section on future scenarios described below. Of course, other water management decisions such as groundwater banking and redistribution of surface water—as potential solutions to current problems—could also affect the profile of water stress throughout the valley.

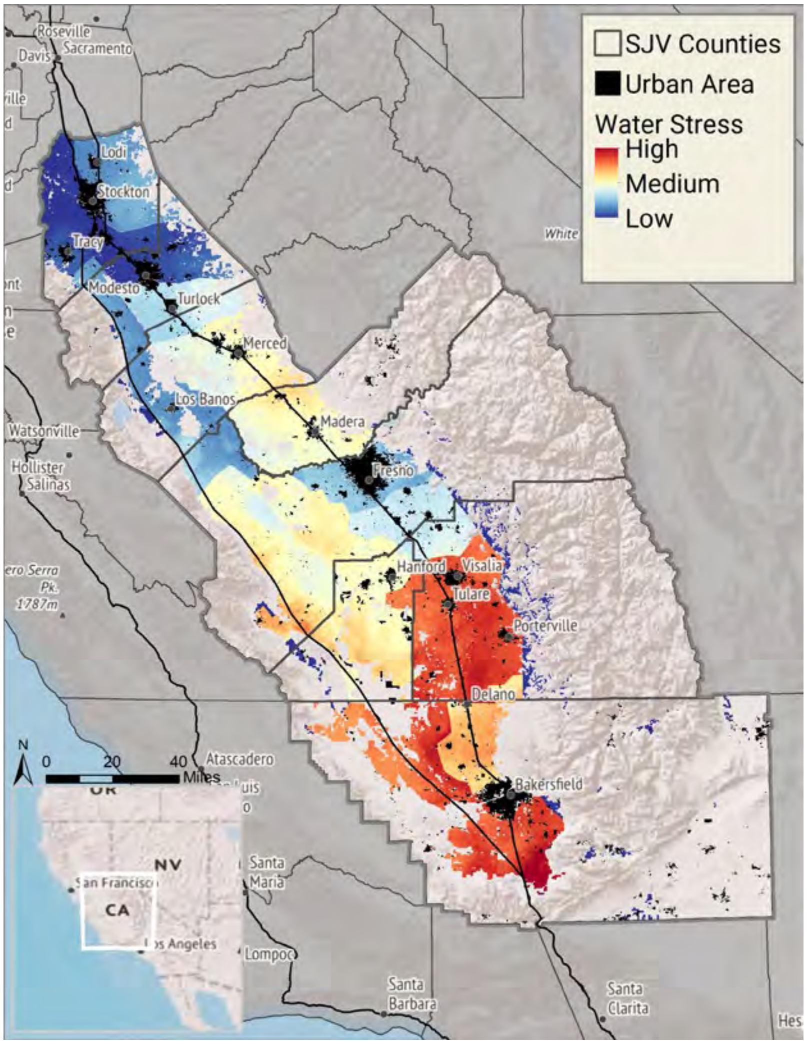
Figure 8. General profile of water stress on agricultural land in the San Joaquin Valley.



Acreage in each classification

High	1,713,274	28%
Medium	2,700,887	44%
Low	1,691,882	28%

Figure 9. Geographic distribution of agricultural water stress in the San Joaquin Valley.



Almost three quarters of the valley's farmland is now experiencing high to medium levels of water stress.

Intersection of Agricultural Land and Water Resources

By themselves, the findings about the quantitative profile and spatial distribution of agricultural land and water resources shed light on the value, importance, and stress on those resources in the valley. But when the land quality and water stress findings are combined, an even more interesting and useful perspective emerges. By dividing the valley's agricultural acreage into nine separate categories, representing all the possible combinations of land quality and water stress level in our logic model, we obtained a much more refined picture of its resources (Table 2).

Table 2. Profile of the intersection of agricultural land quality and water stress (all values are in acres).

		Water Stress Category			
		High	**Medium**	**Low**	**Total**
Land Quality Category	**High**	1,020,368	982,040	563,671	2,566,080
	Medium	477,101	1,052,489	916,503	2,446,092
	Low	215,805	666,358	211,708	1,093,872
	Total	1,713,274	2,700,888	1,691,883	

Of the roughly six million acres of irrigated agricultural land in the valley, only nine percent is both of high quality and experiencing low water stress; this amounts to 564,000 acres or an area just fractionally larger than the city of Fresno. On the other hand, the land that either has high water stress *or* is of low quality comprises 42 percent, or about 2.6 million acres of all valley farmland. And of this, roughly a million acres are high-quality land with highly stressed water supplies, comprising 17 percent of all valley land.[20]

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[20] Profiles of the land-water intersection for each of the valley's eight counties can be found in the Appendix to this report.

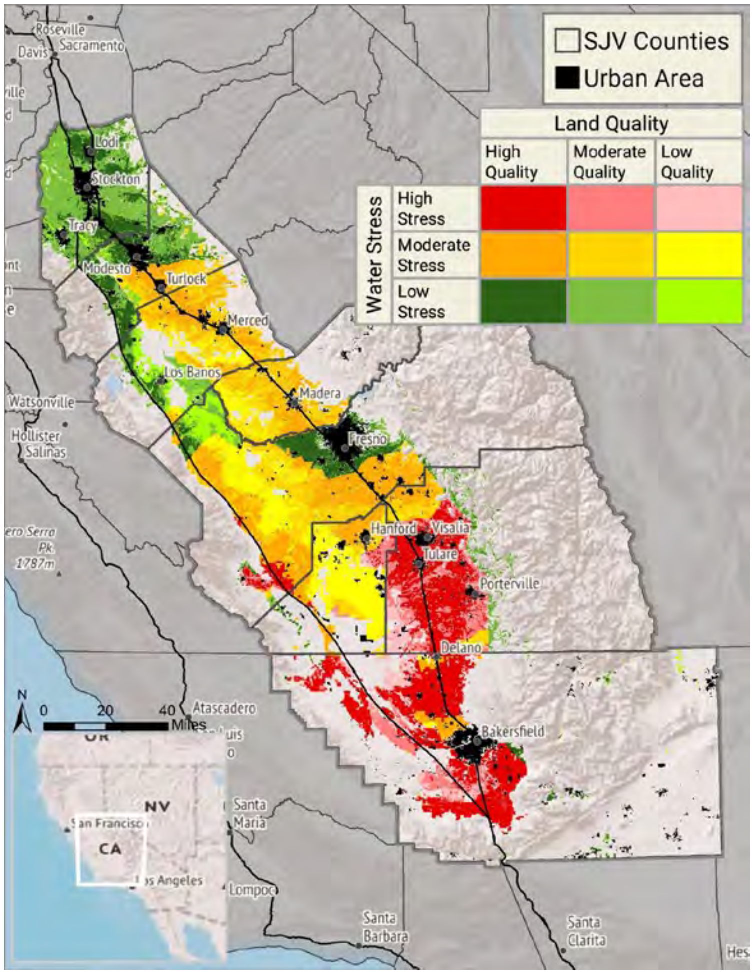
Another important finding is that the valley's higher-quality land tends to experience disproportionately more water stress than lower-quality land. Forty percent of the valley's high-quality land has high water stress, twice the percentage of medium- and lower-quality land. Conversely, 60 percent of high water stressed land is of high quality, while only one-third of the land with low water stress is of similar quality.

The geography of the agricultural land-water intersection paints an even more dramatic picture of the differences that exist in this region (Figure 10). On this map, the degree of water stress is represented by the basic colors: green for low, yellow-orange for moderate, and red for high. The quality of the land is represented by variations within this color scheme, with the darkest and most intense colors indicating high-quality land, the more muted hues medium-quality land and the lightest hues the lower-quality land.

> *Less than one out of ten acres of agricultural land in the valley is of high-quality with low water stress. In contrast, 4 in 10 acres are of low-quality or experiencing high water stress.*

Much of the agricultural acreage with the most advantageous combination of land and water resources is located in San Joaquin and Stanislaus counties, on the west side of the valley as far south as Los Banos, and around the city of Fresno. Farther south, particularly on the east side of the valley, a large percentage of the land is of high quality but has less reliable water supplies. In Tulare and Kern counties, the high-quality land on the east side has even less reliable water and appears to be the most stressed in the region.

Figure 10. Geographic intersection between agricultural land quality and water stress in the San Joaquin Valley.



Impact of Potential Future Scenarios on Agricultural Land and Water Resources

Given the likelihood of change, the sustainability of valley agriculture will depend on actively managing land and water resources, not just on an individual farm basis, but from a system-wide perspective with a view to optimizing the combination of land quality and water security.

The *status quo* of the valley's agricultural land and water resources is not likely to remain static. A number of important regulatory decisions yet to be fully realized, and the prospect of climate change, are likely to bring about fundamental changes in the land-water resources profile and, hence, in agriculture itself. Further expansion of cities onto agricultural land will bring about additional change. Given this likelihood, the sustainability of valley agriculture cannot be taken for granted, but will depend on actively managing the land and water resources on which the industry depends—not just on an individual farm and ranch basis but from a system-wide perspective with a view to optimizing the combination and intersection of land quality and water security.

To offer further perspective on the profile and geography of agricultural land and water resources of the San Joaquin Valley, we examined the potential impact of several future scenarios. Two of these involve pending regulatory decisions affecting irrigation water. A third scenario looks at the potential impact of climate change on both the supply of, and demand for, irrigation water. The final scenario compares future urban development patterns and their impact on agricultural land. These offer a first glimpse and cursory evaluation of the impacts each will have on the valley's agricultural landscape, but no attempt to measure the potential cumulative impact was made in this report. This was due to time limitations within this project, but it highlights how the Data Basin platform we used for our analyses can be updated with additional data and used for further planning into the valley's future.

Regulatory Proposals Affecting Irrigation Water

The two regulatory scenarios we examined include implementation of the Sustainable Groundwater Management Act (SGMA) and of a current proposal by the State Water Resources Control Board (SWRCB) that would reduce withdrawals of irrigation water from three tributaries—the Stanislaus, Tuolumne and Merced—of the lower (northern) San Joaquin River. Both are likely to significantly change the profile and geography of land and water resources in the region. In order to develop these scenarios and their impacts, we used original data from the Department of Water Resources[21] and information available from SWRCB[22] to determine where reductions in irrigation water supplies were most likely to occur in the valley.

JURE DIVICH/SHUTTERSTOCK

The Sustainable Groundwater Management Act (SGMA), signed into California state law in 2014, requires that groundwater extraction and recharge be brought into balance in groundwater-dependent regions of the state. For the most critical groundwater basins, local management plans to accomplish this must be in place by 2020, though full implementation of the plans is not required for an additional 20 years. According to a report by the Public Policy Institute of California, an estimated 13 percent of all agricultural water in the valley comes from over-drafted groundwater sources.[23] So, significant reductions in groundwater withdrawals will almost certainly be necessary to comply with the law, but the impact will vary from place to place.

Using the same Department of Water Resources data for the period 1973–2009, we calculated the percentage of groundwater overdraft attributable to agricultural water use in each of the agency's planning areas. This represents the potential reduction in groundwater use for agriculture if they position each region to come into balance based on existing recharge and groundwater extraction data.[24] Figure 11 highlights those areas where the potential reduction in water supplies to stop overdraft of groundwater basins is at least 25 percent of current agricultural use. This cutoff was used to highlight those areas that are expected to see the biggest impact from SGMA implementation.

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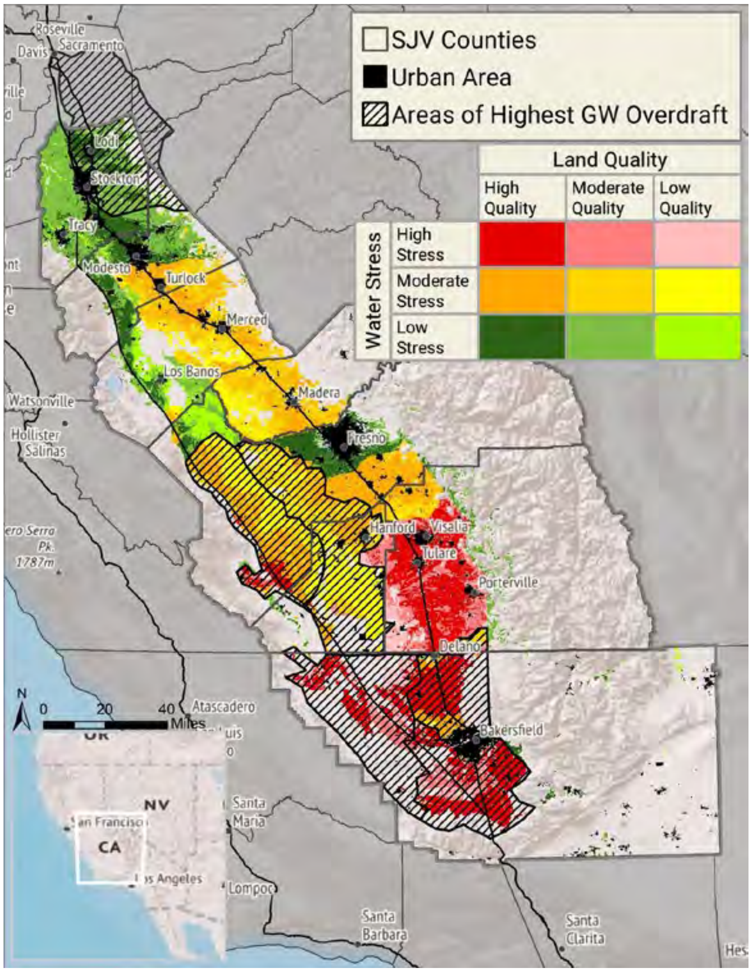
[21] Data processed for each of the 22 Planning Areas intersecting the San Joaquin Valley from the Department of Water Resources: California Water Plan Update 2013 Volume 5—Technical Guide (10. Water Portfolios—Data Detail 2002–2010). Available at: https://water.ca.gov/Programs/California-Water-Plan/Water-Plan-Updates/Technical-Documentation.

[22] State Water Resources Control Board. Bay-Delta Water Quality Control Plan Update and Recirculated Draft Substite Environmental Document. Staff Presentation. Pg. 20. Critical Years only used (Baseline—Critical Year Average vs. 40% UF—Critical Year Average). Available here: www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/bay_delta_plan/water_quality_control_planning/2016_sed/docs/workshop_presentations/01032017_swb_staff.pdf .

[23] Hanak, Lund, et al., *Water Stress and A Changing San Joaquin Valley,* Public Policy Institute of California, March 2017, at 16.

[24] Data processed for each of the C2VSim Planning Areas intersecting the San Joaquin Valley from the Department of Water Resources: Coars Grid C2VSim Model Version R374 (C2VSim-CG_R374) available at: http://baydeltaoffice.water.ca.gov/modeling/hydrology/C2VSim/download/C2VSim_CG_1972IC_R374_Model.zip.

Figure 11. Areas most impacted by SGMA implementation.



The implementation of SGMA will have a profound impact on San Joaquin Valley agriculture. Irrigation water supplies will become problematic for a much larger number of farms encompassing many more acres than today. It should be noted, however, that even if SGMA is not fully implemented, the current unsustainable extraction levels will eventually result in groundwater pumping becoming uneconomic or wells simply going dry. The recent Public Policy Institute of California (PPIC) report[25] outlines a number of strategies that could be employed over the next two decades to reduce the practical impact on agriculture, ranging from improving the efficiency of irrigation and changing the mix of crops to actively recharging aquifers and retiring some cropland.

We took a similar approach to highlighting the areas most likely to be affected by SWRCB's proposal to reduce irrigation withdrawals from the northern San Joaquin River tributaries. As part of its Bay-Delta Water Quality Control Plan, the SWRCB is proposing new standards for maintaining stream flows in the three major tributaries of the lower San Joaquin River.[26] Current flows in the Stanislaus, Tuolumne and Merced rivers now average below levels that SWRCB has determined are necessary to support salmon and other at-risk fish species in these rivers. It proposes that withdrawals from these streams for irrigation and other purposes be reduced to maintain a minimum flow of 30 to 50 percent of "unimpaired" or natural flows during the February through June period when adequate flows are most critical to fish.

A significant decrease in available groundwater supplies could eventually occur even if SGMA is not fully implemented, if unsustainable extraction levels continue.

These three tributaries are at the heart of several irrigation districts located in areas that, according to our analysis, not only feature some of the highest-quality land in the San Joaquin Valley, but also experience some of the lowest water stress levels—for now. Implementation of the SWRCB proposal to achieve a compromise level of 40 percent of unimpaired flows would have the greatest potential impact in those areas identified in Figure 12.

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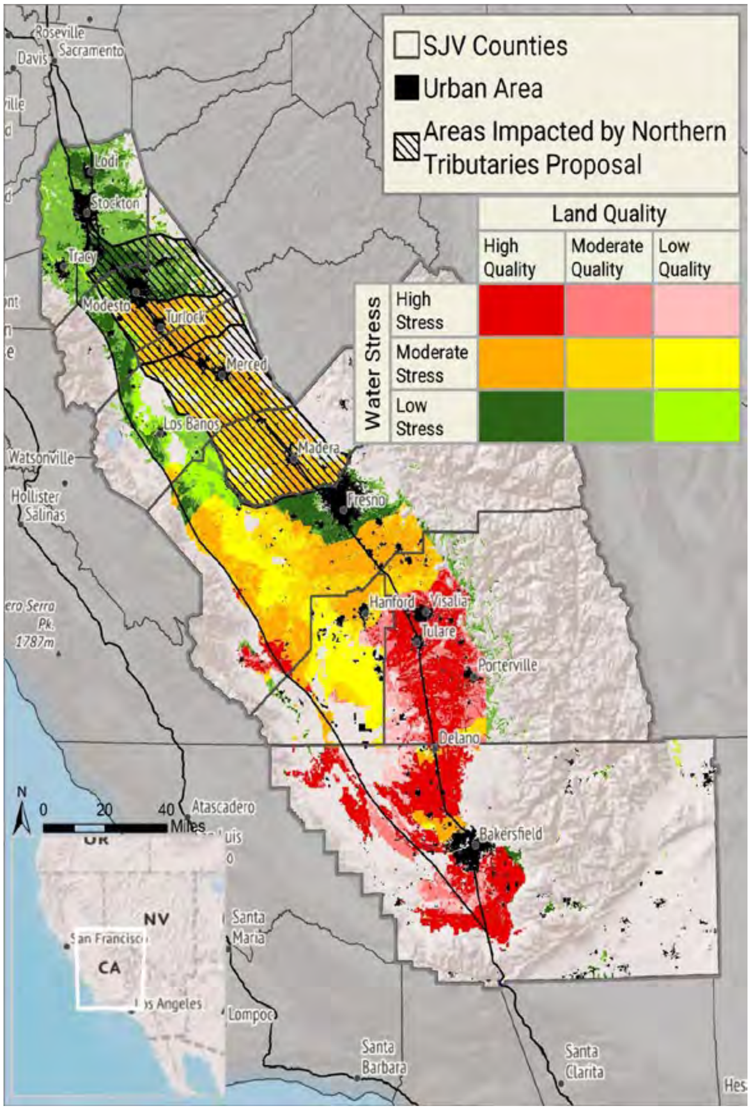
[25] *Supra*, n. 12.

[26] State Water Resources Control Board, *Draft Revised Substitute Environmental Document, Phase I, Bay-Delta Plan*, issued September 15, 2016, www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/bay_delta_plan/water_quality_control_planning/2016_sed/index.shtml.

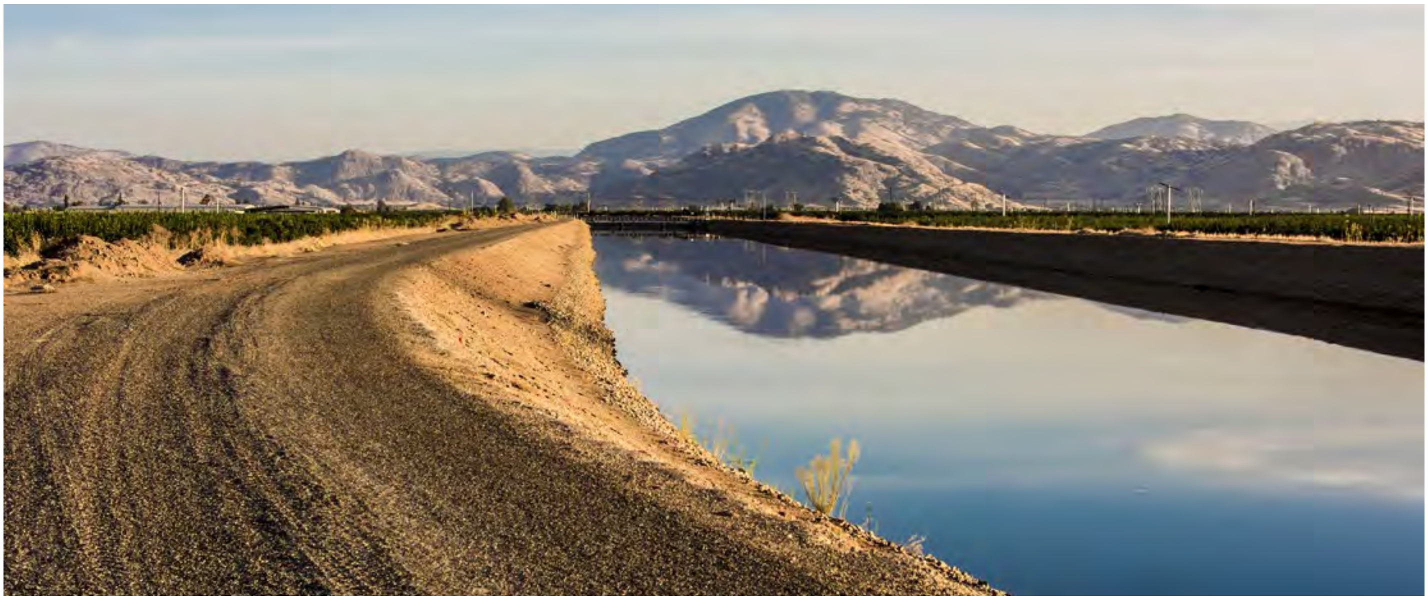
Figure 12. Areas impacted by SWRCB Northern San Joaquin River Tributaries Proposal.



Impact of Climate Change on Irrigation Water Supply and Demand

It is inevitable that climate change and its associated impacts on snowfall, precipitation and temperatures will have a significant influence on the future of agricultural land and water in the San Joaquin Valley. The impacts from climate change in the San Joaquin Valley are already being felt as reductions in winter chill hours have been on the rise, limiting where various tree fruit and nut crops can be grown. Additionally, a warming climate is also likely to reduce annual precipitation and/or cause more precipitation to fall as rain rather than snow. Both are likely to result in a smaller Sierra snowpack—the valley's biggest "reservoir"—reducing overall agricultural water supplies unless heroic measures are taken to capture more runoff. Higher temperatures are also likely to increase evapotranspiration rates of many crops—the process of taking up and releasing water to the atmosphere—leading to the need for more irrigation water if crop production is to be maintained.

To underscore the fact that a changing climate will alter our findings about the current state of land and water resources in the valley, we investigated two climate-related phenomena that will have the greatest impact: the loss of Sierra snowpack and increased evapotranspiration.



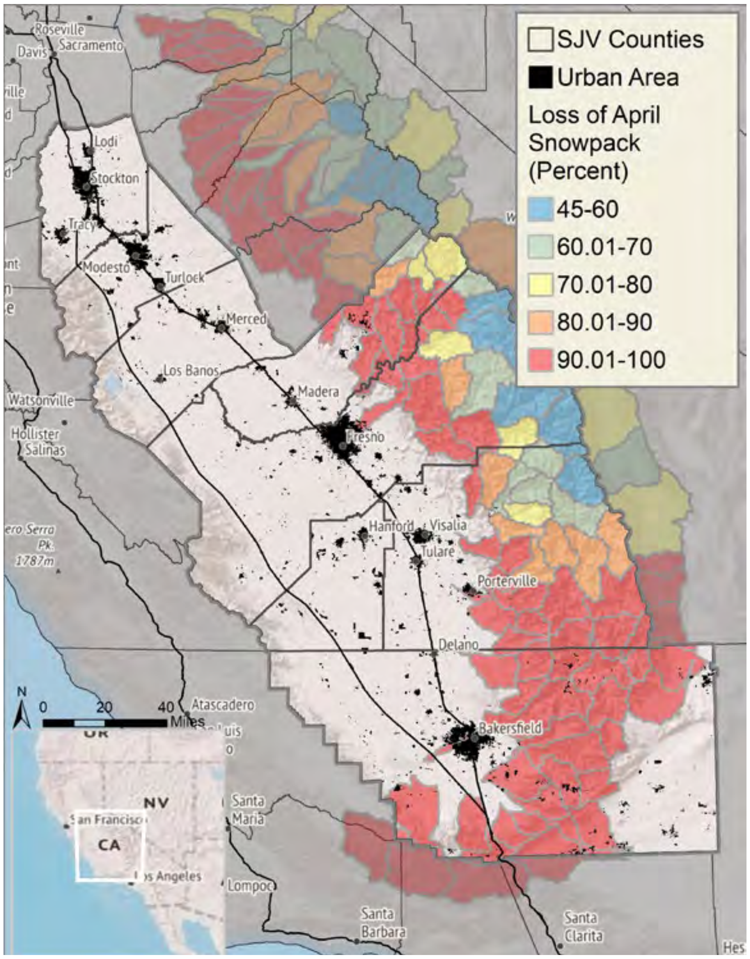
DENNIS SILVAS/SHUTTERSTOCK

Methodology for Assessing Reductions from Climate Change-Induced Loss of Sierra Snowpack

Our analysis of snowpack loss in the Sierra Nevada mountain range used the Basin Characterization Model's April snowpack estimate for the time period 1981–2010 compared to the 2040–2069 time period. We used a hot-dry global climate model for the predicted time period (MIROC RCP 8.5). After comparing the difference between periods, we then summarized that change over HUC 8 watersheds and converted it to a percentage of the original historical (1981–2010) snowpack (Figure 13).

While climate change may significantly reduce potential agricultural water supplies, it could also increase the demand for irrigation water. That is because a warming climate is likely to increase evapotranspiration rates, the natural process by which plants take up and release water to the atmosphere, necessitating the application of additional irrigation water to grow the same crops using the same irrigation methods.[27]

Figure 13. Projected reduction in local surface water supplies from climate-induced loss of Sierra snowpack.



Methodology for Assessing Additional Water Demand from Climate Change-Induced Increase in Evapotranspiration

To estimate the potential impact on water demand as a result of increased evapotranspiration, we first determined current water demand throughout the valley based on the current annual water demand of 20 different crop types grown in the San Joaquin Valley, obtained from Department of Water Resources data,[28] and the U.S. Department of Agriculture 2016 cropland data layer showing where those crops are grown in the valley (Figure 14).[29] Combining these datasets produced a map of current water demand throughout the region (Figure 15). To estimate future water demand, we assumed that it would closely mirror changes in potential evapotranspiration.

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[27] Changes in the mix of crops grown and irrigation methods used could reduce or increase demand and, thus, are strategies for adapting to climate change.

[28] California Department of Water Resources. Agricultural Land and Water Use Estimates. Planning Area Values. 2010. Available here: https://water.ca.gov/Programs/Water-Use-And-Efficiency/Land-And-Water-Use/Agricultural-Land-And-Water-Use-Estimates.

[29] USDA National Agricultural Statistics Service Cropland Data Layer. 2016. Published crop-specific data layer [Online]. Available at https://nassgeodata.gmu.edu/CropScape/. USDA-NASS, Washington, D.C.

Figure 14. Crop map of the San Joaquin Valley.

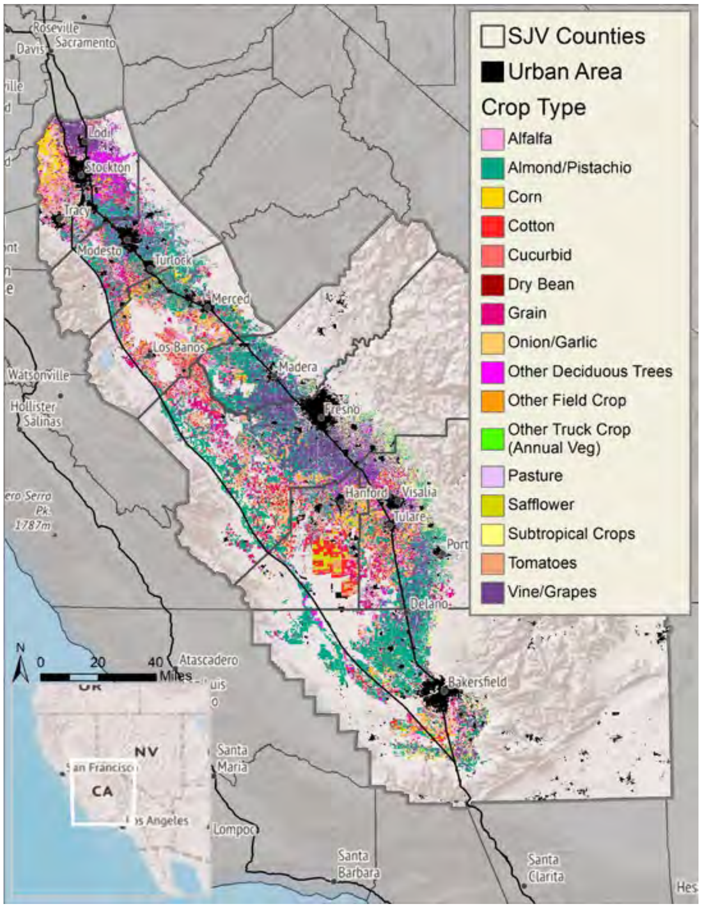
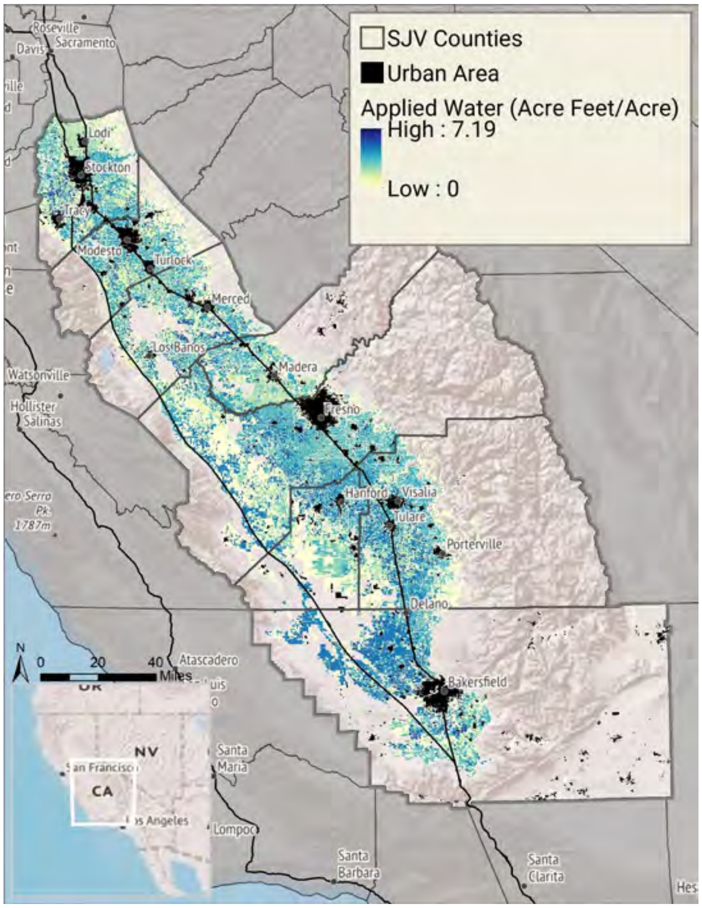


Figure 15. Current agricultural irrigation demand in the San Joaquin Valley (2016).



Using a widely accepted climate model that projects a hot-dry future (MIROC RCP 8.5), we calculated and mapped the likely increase in potential evapotranspiration[30] from 1981–2010 to the 2040–2069 period.[31] The percentage increase in potential evapotranspiration over current rates was mapped as a proxy for future agricultural water demand (Figure 16). This percentage was then applied to actual current water use, based on cropping patterns to obtain a map of the increase in the acre-feet of water that will be needed to sustain agricultural production by mid-century (Figure 17).

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[30] Potential evapotranspiration (PET) measures the amount of water that plants will take up, use and release into the atmosphere, given an unlimited supply of water. This does not always occur in nature due to limitations in precipitation, in which case the actual evapotranspiration rate will be less than the potential rate. On irrigated cropland, however, the application of supplemental water tends to cause plants to achieve their full potential evapotranspiration rates, which is why we chose this measurement.

[31] The model we used for this analysis was the CMIP 5 GCM MIROC rcp 8.5 downscaled to a 270m scale. This data was downloaded from the Climate Commons available here: http://climate.calcommons.org/dataset/2014-CA-BCM.

Figure 16. Projected percent increase in irrigation water demand across the San Joaquin Valley by mid-century assuming a hot, dry future.

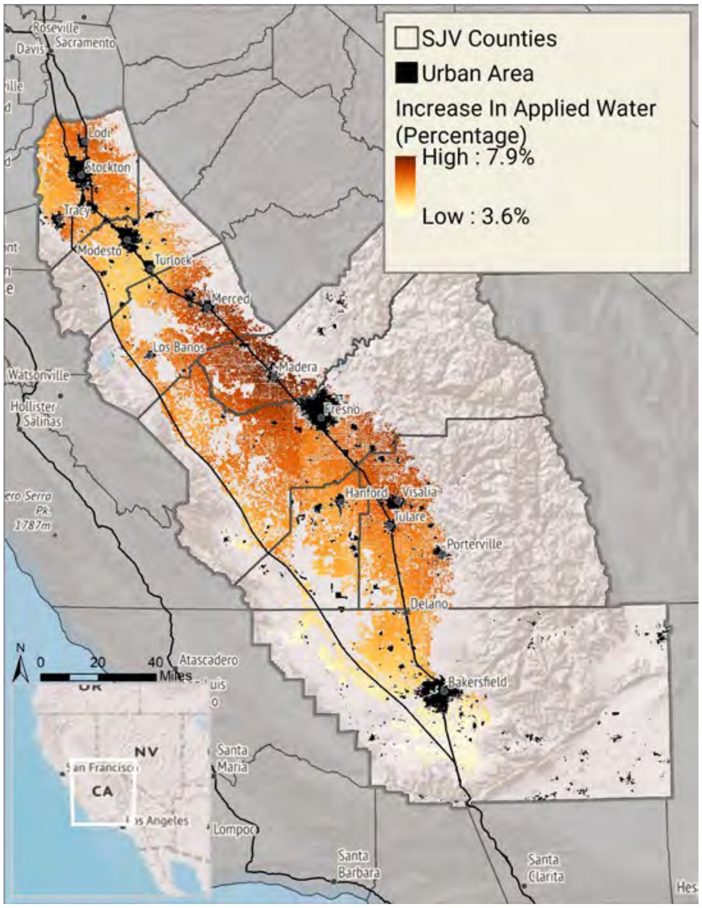
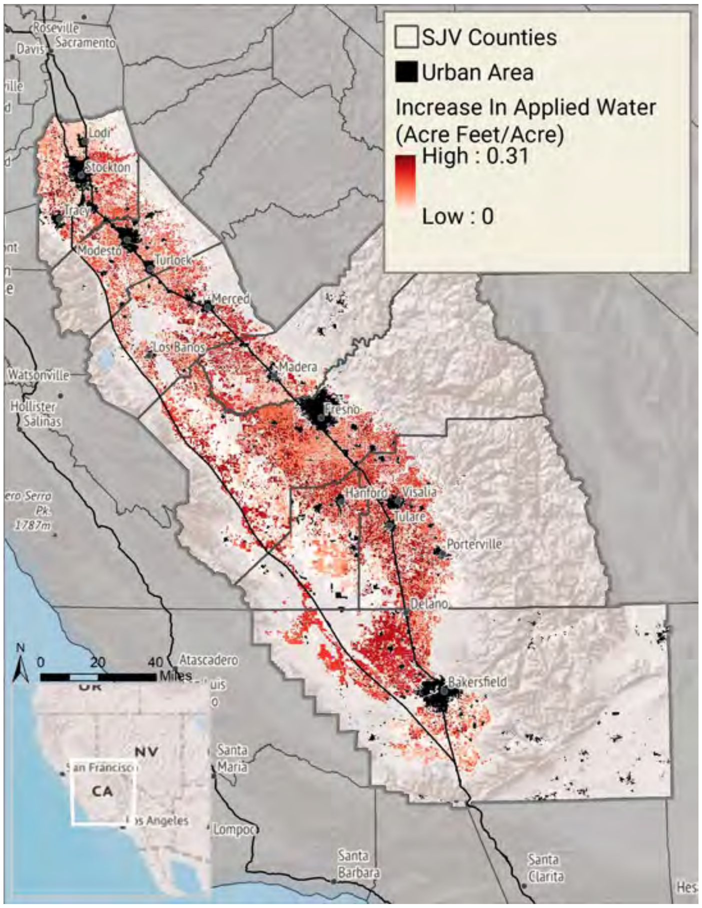


Figure 17. Projected increase in volume of irrigation water needed by mid-century.



Major Findings About Climate-Induced Increase in Irrigation Water Demand

Our assessment of snowpack loss over the Sierra Nevada mountain range shows a very stark change that will occur by mid-century (2040-2069). The minimum loss in snowpack when using the hot-dry scenario was 65 percent with many of the watersheds showing losses closer to 75 percent of their snowpack. The areas hit hardest appear to be the drainages feeding the Kern River and those watersheds in the western foothills of the Sierra Nevada. Our evaluation highlights how future conditions will be drastically changed from the present, with likely more spring runoff and more rainfall occurring before April compared to most historical years. This change in hydrology will necessitate more water storage for agriculture and urban uses. Groundwater storage is likely one of the best methods at present for a changing future in the valley. Not only does this use land that is already available, but it also stores water underground where it will not simply evaporate like all forms of surface storage (e.g. reservoirs, canals, dams).

Our findings on increased irrigation demand determined that irrigation water may need to be augmented by 3.6 to 7.9 percent in various parts of the San Joaquin Valley between now and mid-century (Figure 16), with a valleywide average of 5.4 percent (Table 3). The percentage increase in potential evapotranspiration and, hence, water demand will be greatest toward the northern and eastern portions of the valley. On the other hand, the absolute increase in the acre-feet of water applied per acre of cropland will be greater in the southern sub-region. This contrast is explained by the fact that more water per acre is now applied in the southern sub-region than farther north, owing both to hotter temperatures and a different mix of crops.

While the actual increase in annual irrigation water needed by mid-century appears to be relatively minor—ranging from 0 to 0.31 acre-feet per acre—even this small per acre increase means that the total additional water needed by valley agriculture will be in the range of 600,000-acre-feet per year. This is not an insignificant amount—it is more water than can be stored behind Friant Dam. And its significance will grow as water supplies become tighter due to implementation of SGMA and the loss of Sierra snowpack.

Table 3. Projected increase in irrigation water demand due to climate induced change in evapotranspiration in crops by 2040–2069 (all figures in acre-feet per year unless otherwise indicated).

County	Projected Water Demand Increase	Current Water Demand	Percent Increase
San Joaquin	64,765	1,192,692	5.4%
Stanislaus	41,547	810,444	5.1%
Merced	66,152	1,169,973	5.7%
Madera	44,616	736,325	6.1%
Fresno	139,090	2,501,594	5.6%
Tulare	97,541	1,749,509	5.6%
Kings	49,465	930,055	5.3%
Kern	101,634	2,125,117	4.8%
Total	604,810	11,215,709	5.4%

Development Risk as a Stress on Agricultural Resources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Another important stress factor to be considered in managing resources for sustainable agricultural production is the conversion of productive land to non-agricultural, mostly urban uses—forever and irreversibly removing it from agricultural production. Since records were first kept in 1984, at least 261,000 acres of farmland were converted to urban land uses and an additional 168,000 acres were converted to rural non-farm residences. To put this recent conversion in perspective, it accounts for roughly half of all the land developed since the region was first settled more than a century and a half ago.[32] During this period, the valley's population grew by 1.94 million, implying that only about seven new residents were accommodated for every acre of farmland converted to non-agricultural use.[33] A 2008 study by American Farmland Trust found the average density of developed land in the valley to be only about six people per urbanized acre.[34] Either way, this is one of the lowest densities of any region in California.[35]

Methodology for Assessing Development Risk

As the valley's population continues to grow, additional agricultural land will be lost to urban and rural residential uses. The state Department of Finance projects that the population of the valley's eight counties will increase 1.7 million by 2050 and, at the current average density, this would translate into the conversion of between 240,000 and 323,000 acres of land. Since most growth will occur in and around cities, and because most of the valley's cities are surrounded by farmland, most of the growth will come at the expense of farmland. The question is which farmland and how much of it is at risk of being developed.

To assess the risk that future development poses to agricultural land in the valley, we used a multi-criteria model that included data on various indicators of the likelihood of conversion of land to non-agricultural use.

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[32] See, Farmland Mapping & Monitoring Program, Department of Conservation, California Department of Natural Resources. This does not include farmland converted to what FMMP calls "other" land uses, some of which are ultimately converted to urban use.

[33] U.S. Bureau of Census, Population estimates for 1985 and 2017. Calculation assumes gross density of 0.6 people per acre on rural residential land and 7.4 on urban land.

[34] *Saving Farmland, Growing Cities*, American Farmland Trust, 2008.

[35] See, American Farmland Trust, *Paving Paradise*, 2007.

These data included:

- City limits and spheres of influence (reflecting a government intention to convert these lands)[36]
- General plan designation of land for development[37]
- Forecast of urban growth by California Natural Resources Agency[38]

Land falling within city limits, spheres of influence, or designated for development in general plans was categorized as having a high risk of conversion because these official designations represent an intention that the land within them will be developed. Land outside these areas but forecast for urban growth by CNRA was considered at medium risk of conversion, while all other land was deemed to be at low risk of conversion.[39]

Major Findings About Development Risk to Agricultural Land

High quality agricultural land, especially with low water stress, is at greater risk of development than any other land.

Based on our analysis, about 722,000 acres of San Joaquin Valley agricultural land—about one of every eight acres—are at high-to-medium development risk. (Figure 18) Of this, 543,000 acres are subject to high risk and another 179,000 acres are subject to medium risk. (Table 4). High-quality agricultural land appears to be at disproportionately greater risk with 12 percent experiencing high risk and another four percent medium risk, a total of 416,000 acres in all. This is 58 percent of all land that is at high-to-medium risk, even though high-quality farmland accounts for only 42 percent of all farmland in the region. Agricultural land that is both high quality and with low water stress has an even greater risk of development. Of the 564,000 acres that meet both criteria, 98,600 acres is subject to high-to-medium risk of conversion. This represents 17.5 percent or almost one out of six acres of what is arguably the best farmland in the valley. All of this reflects the fact that the original settlers of the valley located on the most fertile land with easy access to water (See Figure 4). This underscores the need to avoid developing this land where possible and, where it is unavoidable, developing this land as efficiently as possible to accommodate more people, jobs, and dollars of economic growth for every acre converted.

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[36] UC Davis Information Center for the Environment. 2012. Original SJV Greenprint Data. City Limits of the San Joaquin Valley. Available here: https://sjvp.databasin.org/datasets/f999f06d032d40f5aedf07076ca4739b.
UC Davis Information Center for the Environment. 2012. Original SJV Greenprint Data. Spheres of Influence for the San Joaquin Valley. Available here: https://sjvp.databasin.org/datasets/f999f06d032d40f5aedf07076ca4739b.

[37] California Natural Resources Agency, UC Davis. 2014. General Land Use Plans for California USA. Available here: https://sjvp.databasin.org/datasets/1cda3056a4ad4ece86eb5eda4ef17e82.

[38] California Natural Resources Agency. 2002. 50 year Projected Urban Growth scenarios. Available here: https://sjvp.databasin.org/datasets/d60bac1c6fe94c7b9f85b3623481c8d3.

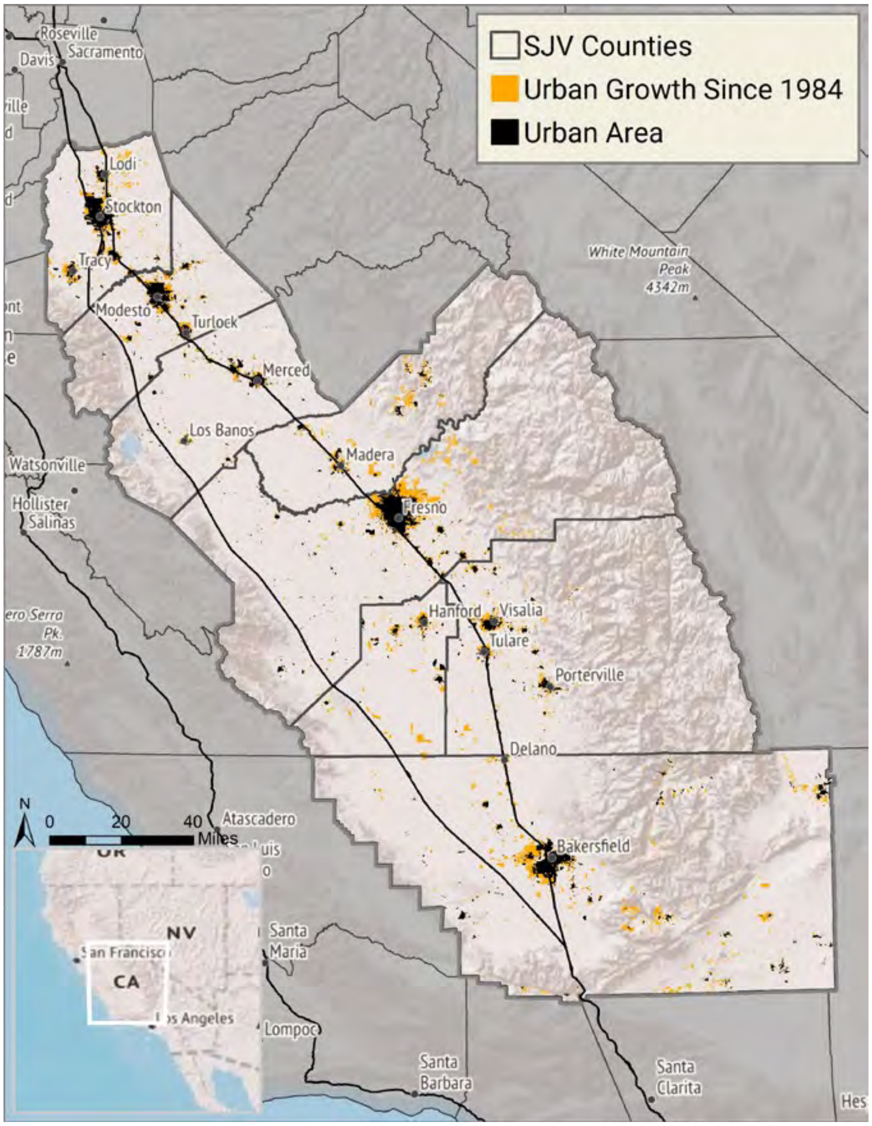
[39] In determining these categories, we did not consider rural residential development because it is widely permitted and can occur almost randomly throughout the region.

It is worth noting in this context that our methodology defines high conversion risk by reference to local government policies—general plans, city limit lines, spheres of influence—that play a major role in determining whether land can be developed. A comparison of the farmland at risk because of these policies (543,000 acres) with the amount of land that will likely be needed to accommodate future development at current densities (240,000 to 323,000 acres), suggests that local governments have earmarked far more land for development than necessary. This not only puts some of the valley's very best farmland at needless risk—from land price inflation, speculation, and agricultural disinvestment—it also gives the false impression that there is no need to develop the land efficiently. And, indeed, low density development seems to be exactly what is happening.

Table 4. Development risk distributed among land quality classes and water stress classes in the San Joaquin Valley (all figures in acres).

	High Development Risk	Medium Development Risk	Low Development Risk	Total
High Quality, High Stress	132,520	40,337	847,511	1,020,368
High Quality, Moderate Stress	96,339	47,811	837,890	982,040
High Quality, Low Stress	67,994	30,651	465,026	563,671
Moderate Quality, High Stress	45,750	10,541	420,810	477,101
Moderate Quality, Moderate Stress	55,795	20,701	975,993	1,052,489
Moderate Quality, Low Stress	89,524	22,490	804,489	916,503
Low Quality, High Stress	6,904	1,874	207,027	215,805
Low Quality, Moderate Stress	25,858	3,661	636,838	666,358
Low Quality, Low Stress	22,650	1,405	187,653	211,708
Total	543,336	179,471	5,383,237	6,106,044

Figure 18. Geographic distribution of development risk to agricultural land in the San Joaquin Valley.



Almost half of the valley's high quality agricultural land is subject to high water stress and/or high development risk.

Plotting the intersection of water stress and development risk yields yet another interesting perspective on the valley's agricultural land resources. Of the six million acres of agricultural land in the valley, about two million acres—one out of every three acres—is subject to either high water stress or high development risk (Table 5). Of the valley's 2.6 million acres of high-quality agricultural land, more than 51 percent—half—is subject to one or both of these negative influences that jeopardize future agricultural production.

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Table 5. Cumulative impact of high water stress and development risk.

	All Agricultural Land	High-Quality Land
High Development Risk	543,336	296,854
High Water Stress	1,713,274	1,020,368
Both	185,175	132,520
Total Dev. Risk or Water Stress	2,256,610	1,317,222
Total Agricultural Land	6,106,044	2,566,080
Percent of Total Agricultural Land	37%	51%

Alternative Future Development Scenario

The risk to agricultural land from future development could be significantly reduced if local governments in the valley were to encourage or require overall development patterns that are more compact and efficient. Some are already moving in this direction, but overall the efficiency of development in the valley remains very low. To demonstrate the potential to reduce this risk, we developed an alternative urban growth scenario. It assumed that land outside spheres of influence now subject to medium development risk would not be developed, and that the efficiency (people per acre) of the development of land subject to high risk would be doubled.

Predictably, the amount of agricultural land subject to high-to-medium development risk would be significantly reduced. The reduction—representing farmland conserved—would be even greater for high-quality land and greater still for high-quality land with low water stress (Table 6). The reduction would also bring the amount of farmland subject to development within the range of the amount of land actually needed to accommodate the valley's growing population.

Table 6. Comparison of impacts on agricultural land under status quo and compact development alternative

(all figures in acres unless otherwise indicated).

	All Farmland		High-Quality Farmland		High-Quality/ Low Stress	
Development Risk	**Status Quo**	**Compact**	**Status Quo**	**Compact**	**Status Quo**	**Compact**
High	543,336	358,551	296,854	191,294	67,994	51,862
Medium	179,471	—	118,799	—	30,651	
Low	5,383,237	5,747,494	2,150,427	2,374,787	465,026	511,809
Total Agricultural Land	6,106,044	6,106,044	2,566,080	2,566,080	563,671	563,671
% High & Medium Risk	12%	6%	16%	7%	18%	9%

Conclusion

Impacts of climate change, new regulations, and a growing population will result in reduced water availability and an increase in water needs in the valley. Additionally, future development scenarios reveal that the more resilient farmland is the most likely to be permanently lost to development.

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While every acre of land in production possesses the attributes necessary to support agriculture, some land is of a higher quality and some land has more reliable water supplies. By identifying where the land is of higher or lower quality, as well as where water resources are more or less abundant, San Joaquin Valley's agricultural and conservation communities, municipalities, and policymakers can work together to make informed decisions about future land development that has the least impact to agriculture and water supplies.

Our findings and the San Joaquin Valley Gateway (https://sjvp.databasin.org/) platform will be used as the foundation of American Farmland Trust's continued efforts to preserve the valley's farmland and water resources. By utilizing the findings of this project, AFT will work with local partners and willing landowners to expand promotion of innovative farming practices that conserve water and recharge groundwater supplies, utilization of agricultural conservation easements, and adoption of local policies that protect the valley's farmland.

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APPENDIX

CONTENTS

EEMS Logic Models—Land Quality and Water Stress

The Land Quality and Water Stress model and output in the Exploring the Intersection of Agricultural Land and Water Resources in the San Joaquin Valley of California report were produced using the EEMS (Environmental Evaluation Modeling System) framework using ArcGIS Model Builder and custom Python Scripts. EEMS is a spatial model framework developed by the Conservation Biology Institute, which allows for integration and comparison of widely varying data types. EEMS is a logic model framework that like other logic models produces a cognitive map presenting spatial datasets and their logical relationships to evaluate a complex topic and question.[40] EEMS is a tree based, 'fuzzy' logic modeling system; this logic model is an open source alternative to the EDMS (Ecosystem Management Decision Support) software package.[41,42,43] Using this EEMS model framework, many complex spatially explicit questions can be answered concerning values across landscapes (e.g. cultural/anthropogenic value or biological/ecological value). Using EEMS, datasets are arranged in a hierarchical fashion to answer a primary question that is located at the top of the diagram. In this case, we had two primary questions:

- What is the relative agricultural value and productivity (land quality model) within each 270m X 270m reporting unit in the San Joaquin Valley; and
- What is the relative agricultural water stress (water stress model) within each 270m X 270m reporting unit in the San Joaquin Valley?

The EEMS model framework allows for comparison of widely varying datasets by allowing users to assign true and false thresholds for different spatial layer datasets. The scale used is from -1 to +1 moving from

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[40] Jensen, M., K. Reynolds, U. Langner, and M. Hart. 2009. Application of logic and decision models in sustainable ecosystem management. 2009. Proceedings of the 42nd Hawaii International Conference on Systems Sciences. Waikoloa, Hawaii. 5–8 January 2009.

[41] Sheehan, T. and M. Gough. 2016. A platform-independent fuzzy logic modeling framework for evironmental decision support. Ecological Informatics 34(1): 92–101.

[42] Reynolds, K.M. 1999. NetWeaver for EMDS version 2.0 user guide: A knowledge base development system. U.S. Forest Service, General Technical Report PNW-GTR-471, U.S. Forest Service, Pacific Northwest Research Station, Portland, Oregon.

[43] Reynolds, K.M. 2001. EMDS: Using a logic framework to assess forest ecosystem sustainability. Journal of Forestry 99(6): 26–30.

completely false to completely true (shown below). Setting false and true thresholds allows for the user to set boundaries on input datasets when necessary and applicable, with the data then being stretched between -1 to +1 effectively normalizing all data inputs on the same scale. All data inputs undergo this normalizing ("fuzzy logic method") regardless if they are ordinal, nominal, or continuous.

Using this normalized approach in the EEMS framework provides many key advantages:

1. Normalizing values (within "fuzzy logic") yields a continuum of data that is more realistic of true values across a landscape, providing 'shades of grey' compared to the traditional modeling methods using binary values
2. The model produced is highly transparent and its process is easy to visualize using the EEMS Explorer in Data Basin
3. Layers produced (final and intermediate results) provide greater value over single map modeling methods
4. Editing the model is an easier process allowing the testing of different assumptions, and inclusion of new data as it becomes available

Figure A-1. Diagram of the EEMS Model for Land Quality starting from the bottom and moving up to the final output.

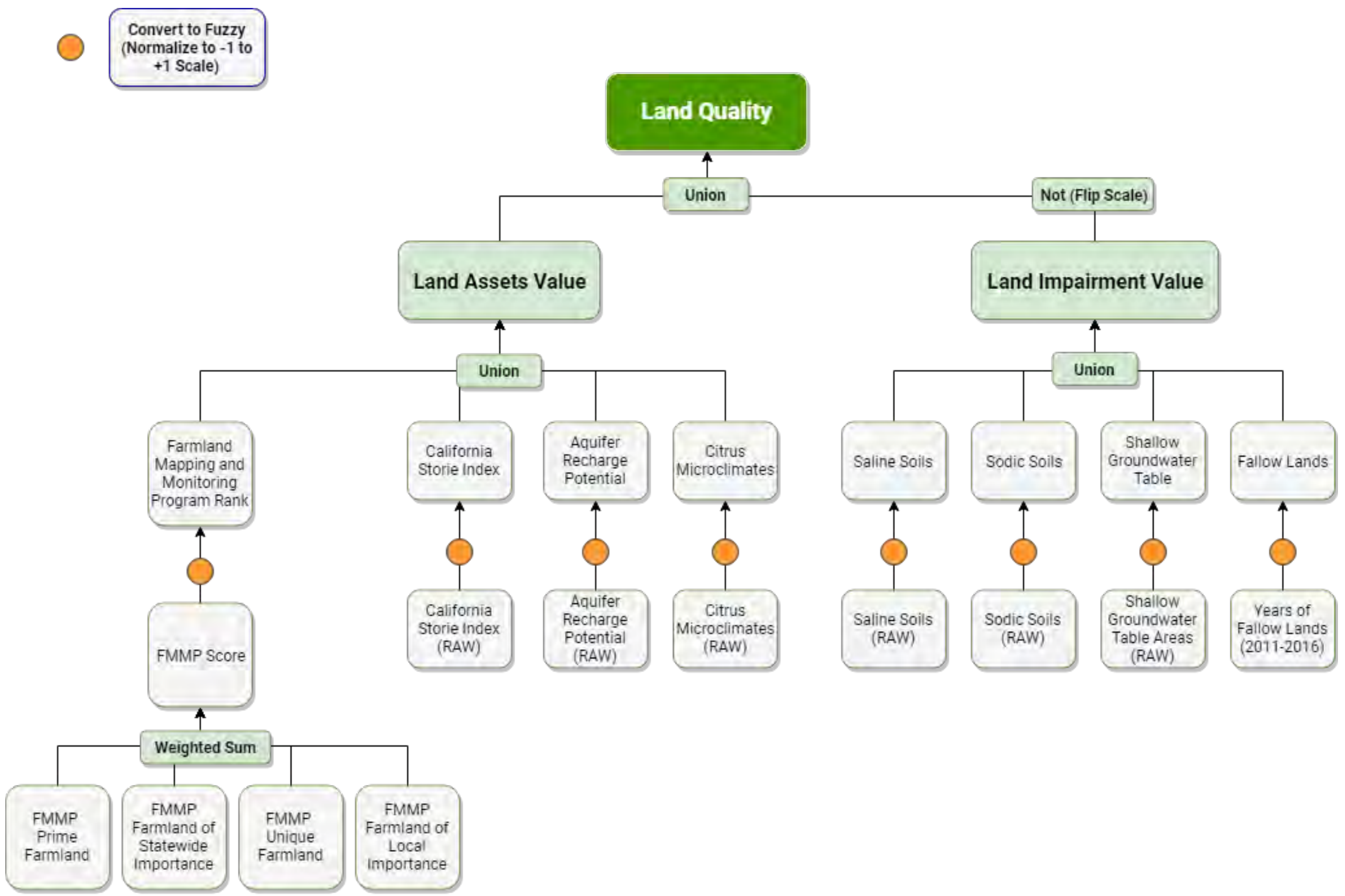
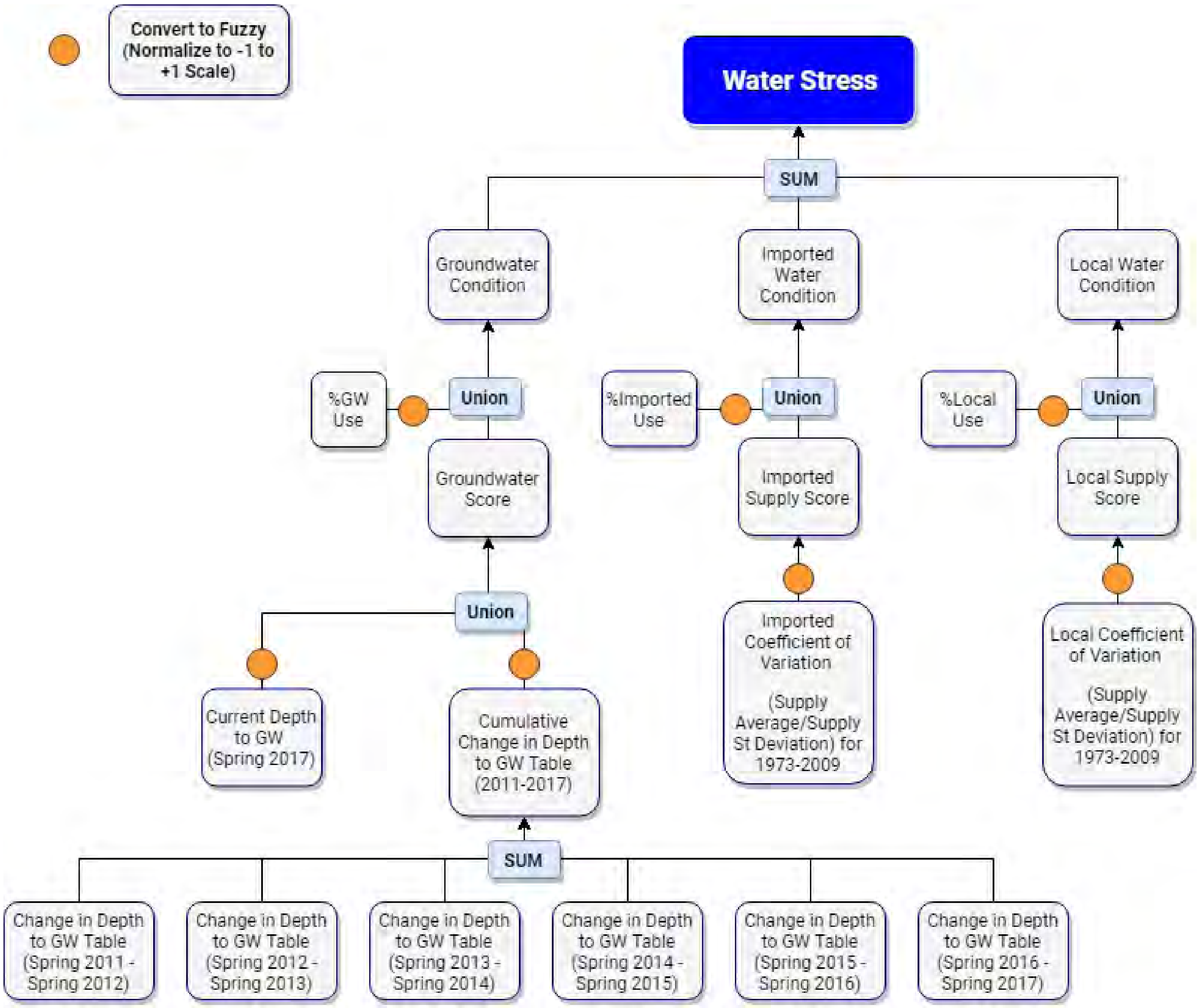


Figure A-2. Diagram of the EEMS Model for Water Stress starting from the bottom and moving up to the final output.



Source Data

The source data in the Land Quality and Water Stress Logic models came from multiple data sources including state and federal agencies and universities. Data are cited in the main report and are referenced in the table below describing all input data, analyses undergone to the data, originator, and time the data was acquired or refers to. All data are available on the San Joaquin Valley Gateway for viewing: https://sjvp.databasin.org/.

Table A-1. Land Quality and Water Stress Input Data are shown including the originator, time period and analyses/comments.

	Model Input	Originator	Time Period	Analyses/Comments
LAND QUALITY MODEL INPUTS	Farmland Mapping and Monitoring Program Rank	California Department of Conservation	2014–2016	Available data were merged from 2014 (San Joaquin, Fresno, Merced) and 2016 (Kern, Kings, Madera, Stanislaus, Tulare) for the entire study area.
	California Storie Index	USDA Soil Survey (GSSURGO)	2017	Data were extracted using the Soil Data Development Toolbox from USDA.
	Aquifer Recharge Potential	UC Davis	2015	Data were acquired from Toby O'Geen directly.
	Citrus Microclimates	Conservation Biology Institute (CBI)	2017	The microclimates suitability index was created running a maxent model using USDA Cropscape locations for citrus with Annual Potential Evapotranspiration (Hst 1981–2010), Minimum Temperature (Dec,Jan,Feb Hst 1981–2010), Annual Precipitation (Hst 1981–2010), Maximum Temperature (Jun, Jul, Aug Hst 1981–2010)
	Saline Soils	USDA Soil Survey (GSSURGO)	2017	Data were extracted using the Soil Data Development Toolbox from USDA.
	Sodic Soils	USDA Soil Survey (GSSURGO)	2017	Data were extracted using the Soil Data Development Toolbox from USDA.
	Shallow Groundwater Table	California Department of Water Resources	2010–2012	Data were obtained directly from the department of water resources.
	Fallow Lands (2011–2016)	USDA Cropland Data Layer/UC Monterey/NASA	2011–2016	USDA CDL fallow cropland data for years 2011-2016 was combined with data from UC Monterey/NASA for the years 2011, 2015, and 2016.

	Model Input	Originator	Time Period	Analyses/Comments
WATER STRESS MODEL INPUTS	Current Depth to Groundwater (Spring 2017)	California Department of Water Resources	2017	Point data from the Department of Water Resources were interpolated to form a valley wide layer for use in the model.
	Cumulative Change in Depth to Groundwater (2011–2017)	California Department of Water Resources	2011–2017	Point data from the Department of Water Resources were interpolated to form a valley wide layer for use in the model. This was done for all years between 2011–2017 with the change between years calculated and used in the model.
	Imported Supply Coefficient of Variation (1973–2009)	California Department of Water Resources	1973–2009	Using C2VSim data from 1973–2009 average imported supply was calculated along with the standard deviation of supply. Then a COV was calculated (Mean/St.Dev).
	Local Supply Coefficient of Variation (1973–2009)	California Department of Water Resources	1973–2009	Using C2VSim data from 1973–2009 average local supply was calculated along with the standard deviation of supply. Then a COV was calculated (Mean/St.Dev).
	Groundwater Supply (Percent)	California Department of Water Resources	1973–2009	Using C2VSim data from 1973–2009 the average percent use of groundwater within each planning region by agriculture was calculated.
	Imported Supply (Percent)	California Department of Water Resources	1973–2009	Using C2VSim data from 1973–2009 the average percent use of imported supply within each planning region by agriculture was calculated.
	Local Supply (Percent)	California Department of Water Resources	1973–2009	Using C2VSim data from 1973–2009 the average percent use of local supply within each planning region by agriculture was calculated.

Model Development

There were five phases involved in the construction of the Land Quality and Water Stress Models: Identify current research and data available, Preprocess Data, Summarize data by Reporting Unit, Execute Logic EEMS Model, Evaluate output and determine High, Medium, Low Cutoff Values. These phases were carried out using a set of models in the ArcGIS 10.3 through the model builder interface, along with custom python scripts.

Table A-2. Phases of the Modeling Process.

Model/Phase	Model Overview
1. Identify current research and data available	● Identify spatial data that is ubiquitous across the study area and discuss relevance of similar datasets
2. Preprocess Data	● Consolidate and process data ● Clip to region of interest and project to NAD 83 California Teale Albers (meters)
3. Summarize Data by Reporting Unit	● Calculate a count of density value for all component of the model. Adds attributes of each input dataset to the reporting units dataset. This feature class is used for the EEMS model.
4. Execute Logic EEMS Model	● Apply "fuzzy logic" based on the hierarchal model framework. Calculate values for each 1km cell
5. Evaluate Output and Determine Cutoff Values	● Review distribution of Land Quality and Water Stress within study region and determine best algorithm to use when determining a cutoff value which will create High, Medium, and Low classes

Logic Model Thresholds, Operators, and Output Classes

When the Logic EEMS Model is ran, all of the preprocessed data that populated the fields in the reporting units shapefile undergo normalization to allow for comparison. This is where the data is converted to “fuzzy” space. The user defines the range of values along a truth continuum (shown below) when values are converted to “fuzzy” space—normalized.

Individual thresholds used for the components of the model are below. There were eight derived inputs that required normalization for the Land Quality model and seven derived inputs that required normalization for the Water Stress Model.

Table A-3. Primary Components of Modeling process, range of values, mean, standard deviation, and true/false thresholds for each 270m^2 reporting unit.

	Model Input	Range	Mean	St. Dev	True Threshold	False Threshold
LAND QUALITY MODEL INPUTS	Land Quality Model Inputs					
	Farmland Mapping and Monitoring Program Rank	5–0	3.67	1.37	5	0
	California Storie Index	1–0	0.56	0.29	1	0
	Aquifer Recharge Potential	99.6–0	49.61	31.38	99.644	0
	Citrus Microclimates	0.816–0	0.43	0.13	0.816	0
	Saline Soils	57.5–0	2.67	3.91	16	2
	Sodic Soils	434–0	5.63	15.55	90	5
	Shallow Groundwater Table	100–0	10.86	30.83	100	0
	Fallow Lands (2011-2016)	6–0	0.75	1.31	5	0
WATER STRESS MODEL INPUTS	Current Depth to Groundwater (Spring 2017)	622.44–4.61	177.01	125.16	622	0
	Cumulative Change in Depth to Groundwater (2011-2017)	157–(-)134	(-)16.62	23.54	-100	0
	Imported Supply Coefficient of Variation (1973-2009)	238.15–0	50.54	50.82	71	0
	Local Supply Coefficient of Variation (1973-2009)	52.38–15.35	32.95	12.49	52	3
	Groundwater Supply (Percent)	0.72–0.05	0.32	0.17	1	-1
	Imported Supply (Percent)	0.48–0.0	0.25	0.13	1	-1
	Local Supply (Percent)	0.85–º0.11	0.42	0.17	1	-1

When evaluating the true and false thresholds above, keep in mind that the thresholds set the points (-1 to +1) between which the data will be stretched or compressed in between. During the initial model runs, the thresholds were set to the minimum and maximum range values with alterations made throughout to reflect upon research available and distributions of the data (i.e. excluding outlier data that skewed thresholds).

After the input components undergo normalization (using the thresholds) they are put through the hierarchal structure of the EEMS logic model. Operators are used to exert logic within the model and the operators used within this model are described in table below.

Table A-4. Logic Operators used within the Land Quality and Water Stress Models.

Operator	Input Data	Description
Sum	Raw	Computes the sum of the inputs
Union	Fuzzy	Returns the mean of the inputs
Weighted Sum	Raw	Finds the weighted sum for each row of the input fields. Multiplies each field by its weight before adding.
Weighted Union	Fuzzy	Finds the weighted union (mean) for each row of the input fields
Not	Fuzzy	Logical NOT for fuzzy modeling. Reverses the sign of values of the input field.

Logic models produce intermediate and final maps on a “fuzzy scale” from -1 (completely false) to +1 (completely true). The range of continuous values for cells can be represented and organized in multiple ways using GIS binning such as natural breaks, geometric interval and others. In order to help identify areas into classes we used a natural jenks algorithm to sort the data based into 3 groups. The value for each of the classes is shown below.

Table A-5. Class Value Ranges.

Land Quality Values	Legend
1.00 to 0.559643	High
0.559644 to 0.183190	Medium
0.183191 to (-)1.00	Low

Water Stress Values	Legend
1.00 to 0.167082	High
0.167083 to (-)0.442597	Medium
(-)0.442598 to (-)1.00	Low

Annual Agricultural Water Use

For all C2VSim planning areas in the San Joaquin Valley, agricultural diversions were calculated for local supply, imported supply, and groundwater supply for the period 1973–2009. These numbers and the

Table A-6. Annual agricultural water use by C2VSim planning region.

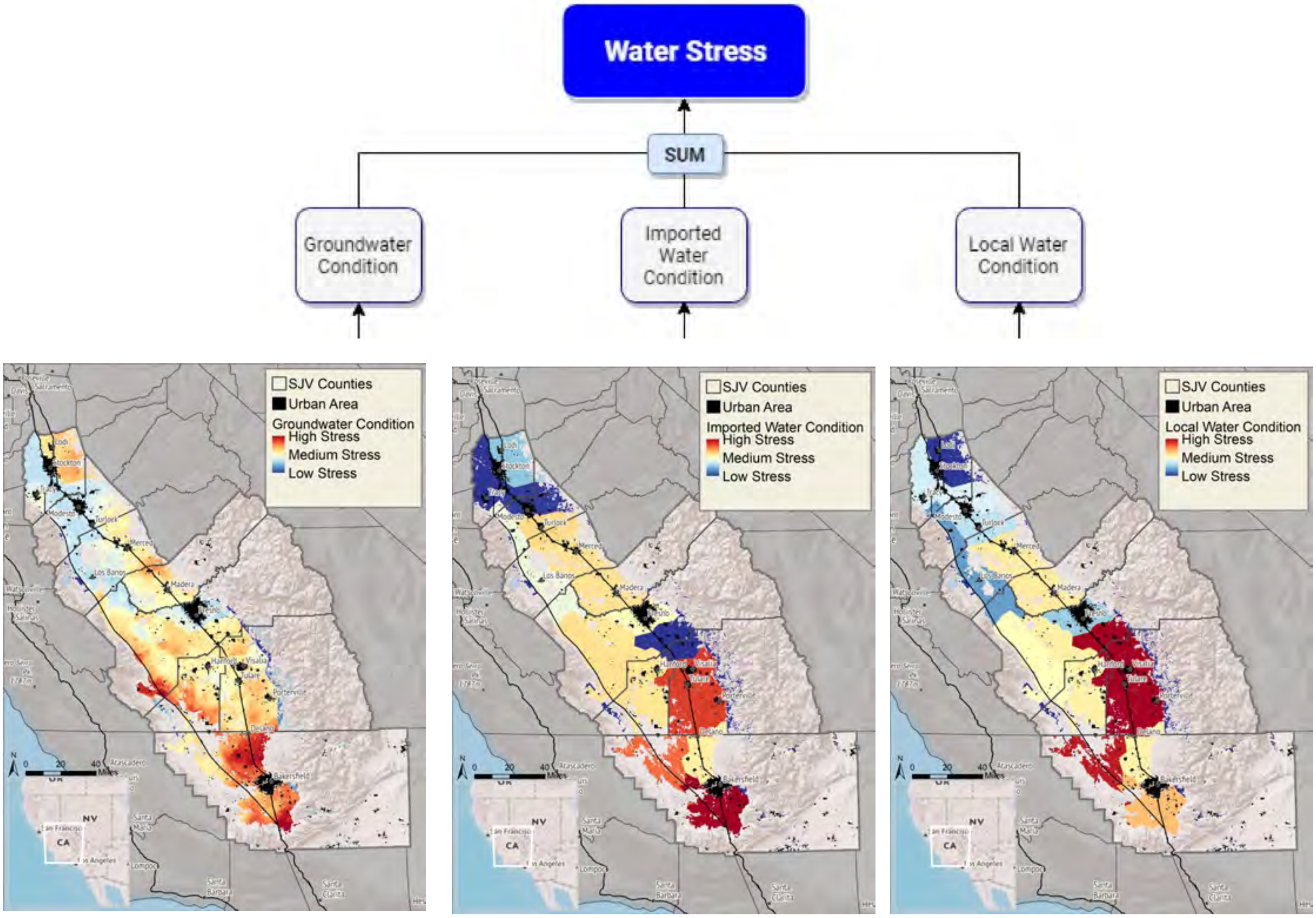
	Region 6	Region 7	Region 8	Region 9	Region 10	Region 11	Region 12	Region 13
Yearly Ag Diversion (Local Supply)								
Average	335,506	309,042	99,498	839,416	1,006,128	708,804	562,476	703,308
St Deviation	55,231	52,674	18,452	132,577	168,959	108,847	99,110	243,085
Coefficient of Variation	16	17	19	16	17	15	18	35
Yearly Ag Imports (Imported Supply)								
Average	196,840	283,455	140,724	-	891,185	21,676	117,876	645,590
St Deviation	58,328	50,926	19,391	-	172,004	22,772	48,448	216,196
Coefficient of Variation	30	18	14	-	19	105	41	33
Yearly Ag Pumping (GW Supply)								
Average	254,370	323,213	638,724	198,078	336,330	99,656	152,153	732,626
St Deviation	79,151	70,415	83,006	53,158	164,545	100,141	92,119	238,477
Coefficient of Variation	31	22	13	27	49	100	61	33
Average GW Imbalance	37,395	(133,953)	(266,299)	64,890	24,234	96,735	(29,438)	(163,263)
Total Water Usage (Acre Feet)	786,716	915,710	878,946	1,037,494	2,233,642	830,136	832,505	2,081,524
Local Supply Percentage	43%	34%	11%	81%	45%	85%	68%	34%
Imported Supply Percentage	25%	31%	16%	0%	40%	3%	14%	31%
GW Supply Percentage	32%	35%	73%	19%	15%	12%	18%	35%

C2VSim model are currently being updated by the Department of Water Resources and are expected to change as a result. All information below is based upon modeled use data across the regions.

Region 14	Region 15	Region 16	Region 17	Region 18	Region 19	Region 20	Region 21	
Yearly Ag Diversion (Local Supply)								
929,706	834,318	429,323	356,266	1,152,002	289,228	225,209	529,432	Average
283,344	289,851	88,308	167,544	592,429	151,510	80,994	206,345	St Deviation
30	35	21	47	51	52	36	39	Coefficient of Variation
Yearly Ag Imports (Imported Supply)								
934,047	769,489	459,487	232	808,565	292,746	262,454	185,378	Average
283,907	261,961	92,620	552	435,232	152,830	82,266	131,275	St Deviation
30	34	20	238	54	52	31	71	Coefficient of Variation
Yearly Ag Pumping (GW Supply)								
478,653	1,148,127	51,787	350,441	447,665	714,855	443,417	960,297	Average
177,866	275,643	64,934	161,280	348,499	178,824	104,338	192,201	St Deviation
37	24	125	46	78	25	24	20	Coefficient of Variation
(190,615)	(510,865)	159,323	(25,028)	336,521	(301,800)	(118,891)	(470,358)	Average GW Imbalance
2,342,406	2,751,934	940,597	706,938	2,408,232	1,296,829	931,079	1,675,107	**Total Water Usage (Acre Feet)**
40%	30%	46%	50%	48%	22%	24%	32%	**Local Supply Percentage**
40%	28%	49%	0%	34%	23%	28%	11%	**Imported Supply Percentage**
20%	42%	6%	50%	19%	55%	48%	57%	**GW Supply Percentage**

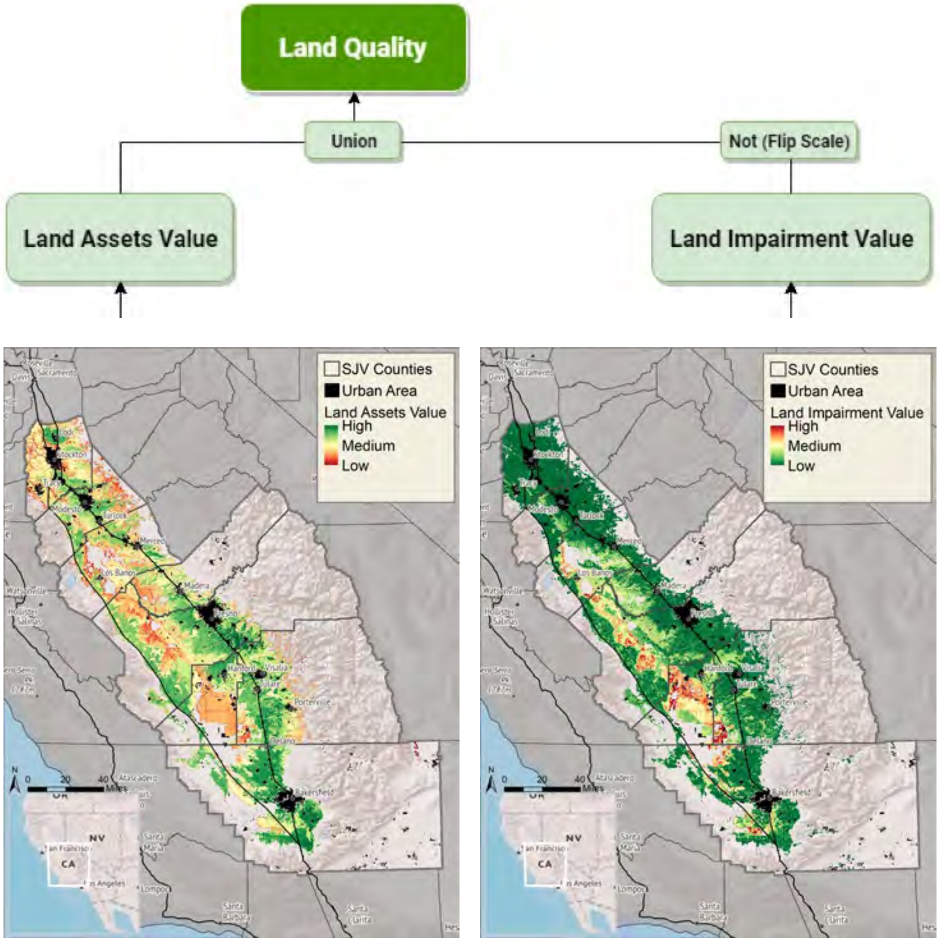
Water Stress Score Overview Maps

Figure A-3. Diagram of the EEMS Model for Water Stress showing the three primary inputs that fed into the final output of the model.



Land Quality Overview Maps

Figure A-4. Diagram of the EEMS Model for Land Quality showing the two primary inputs that fed into the final output of the model.



Land Water Intersection County Profiles

Table A-7. Acreage for each Land Quality and Water Stress Combination Class across the 8 San Joaquin Valley Counties.

Combination Class (Land Quality, Water Stress)	Fresno	Kern	Kings	Madera	Merced	San Joaquin	Stanislaus	Tulare
High Value, High Stress	42,907	558,329	11,220	-	-	-	-	407,912
High Value, Moderate Stress	426,414	52,991	89,724	122,341	163,549	262	70,104	56,656
High Value, Low Stress	157,832	17,629	3,430	581	31,307	194,286	144,246	14,360
Moderate Value, High Stress	20,074	186,018	33,807	-	-	-	-	237,202
Moderate Value, Moderate Stress	359,300	5,246	83,746	212,571	225,724	1,476	86,962	77,464
Moderate Value, Low Stress	108,192	13,957	4,605	2,544	99,785	440,753	166,067	80,599
Low Value, High Stress	1,891	129,566	22,581	-	-	-	-	61,767
Low Value, Moderate Stress	224,474	9,209	267,302	71,935	77,753	147	5,087	10,451
Low Value, Low Stress	79,683	8,877	577	2,544	73,495	28,632	18,346	1,864

For More Information

- **farmland.org/California**
- **AFT Sacramento office:** 916-448-1064
- **sjvp.databasin.org** (San Joaquin Valley Gateway)

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