

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

Task 3 Report:

Hydrological and Hydrogeological Assessment and Recharge-Specific Conceptual Model

Prepared for
Sacramento Area Council of Governments



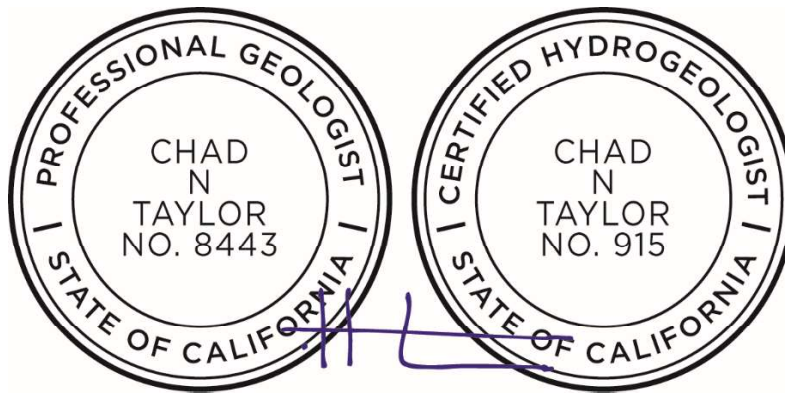
Task 3 Report: Hydrological and Hydrogeological Assessment and Recharge-Specific Conceptual Model

Prepared for
Sacramento Area Council of Governments

Prepared by
 **LAND IQ**

NOVEMBER, 2017

SIGNATURE PAGE



Chad N Taylor, PG, CHG
Senior Hydrogeologist



Handwritten signature of Maureen Reilly in black ink.

Maureen Reilly, PE
Senior Engineer

TABLE OF CONTENTS

List of Tables	v
List of Figures	v
List of Appendices	vi
List of Acronyms	vii
1 Introduction	1
1.1 Project Background	1
1.2 Task 1 Review and Summary	1
1.3 Task 2 Review and Summary	2
1.4 Task 3 Purpose	2
2 Task 3 Summary	2
3 Overview of Approach	3
4 Hydrogeologic (Subsurface) Recharge Suitability Index	5
4.1 Hydraulic Conductivity Recharge Suitability Index	6
4.2 Unsaturated Zone Thickness Recharge Suitability Index	7
4.3 Combined Hydrogeologic Recharge Suitability (Subsurface) Index	8
5 Surface Soil Recharge Suitability Index	8
5.1 Deep Percolation	9
5.2 Root Zone Residence Time	9
5.3 Topography	9
5.4 Chemical Limitations	9
5.5 Surface Conditions	9
5.6 SAGBI Final Ranks	10
5.7 Application of SAGBI	10
6 Specialty Crop Suitability Index	10
6.1 Annual Crops	11
6.2 Perennial Crops	14
6.3 Potential of Nutrient Loads to Groundwater	16
6.4 The Influence of Specialty Crops on Infiltration Rates	16

7	Final Groundwater Recharge Suitability Index	17
8	Surface Water Suitability	20
9	Per Acre Metrics for Groundwater Recharge Potential by Soil and Specialty Crop Types	25
9.1	Per-Acre Groundwater Mounding Effect Estimates.....	25
10	References.....	30
	Figures	32

LIST OF TABLES

Table 1. Parameter Ranges for Hydraulic Conductivity Indexes.....	7
Table 2. Reclassified Modified SAGBI	10
Table 3. Suitability Factors for Annual Crops.....	12
Table 4. Annual Crop Ranking for Groundwater Recharge Suitability.....	12
Table 5. Suitability Factors for Perennial Crops.....	14
Table 6. Perennial Crop Ranking for Groundwater Recharge Suitability.....	15
Table 7. Dry Conditions - Acreage Summary for Final Recharge Suitability Index	18
Table 8. Wet Conditions - Acreage Summary for Final Recharge Suitability Index	18
Table 9. Crop Acreage Summary for Final Recharge Suitability Index.....	19
Table 10. Irrigation and Reclamation District Surface Water Availability	22
Table 11. Per-Acre Mounding Estimates	28

LIST OF FIGURES

All figures are shown at the end of this report except Figures 1, 2, 18, and 25.

Figure 1. Simplified Flowchart for Generation of Recharge Suitability Index.....	4
Figure 2. Flowchart for Generation of Hydrogeologic Recharge Suitability Index.....	6
Figure 3. Horizontal Hydraulic Conductivity of Shallow Aquifer Materials	
Figure 4. Vertical Hydraulic Conductivity of Shallow Aquifer Materials	
Figure 5. Horizontal Hydraulic Conductivity Recharge Suitability Index	
Figure 6. Vertical Hydraulic Conductivity Recharge Suitability Index	
Figure 7. Combined Hydraulic Conductivity Recharge Suitability Index	
Figure 8. Recent Wet Period Depth to Groundwater Spring 2012	
Figure 9. Recent Dry Period Depth to Groundwater Fall 2016	

Figure 10. Wet Condition Unsaturated Thickness Recharge Suitability Index	
Figure 11. Dry Condition Unsaturated Thickness Recharge Suitability Index	
Figure 12. Wet Condition Surface Hydrogeologic Recharge Suitability Index	
Figure 13. Dry Condition Surface Hydrogeologic Recharge Suitability Index	
Figure 14. Modified SAGBI	
Figure 15. 2014 SACOG Crop Map	
Figure 16. Specialty Crop Suitability Index	
Figure 17. Specific Specialty Crop Suitability Index	
Figure 18. Flowchart for Generation of Final Recharge Suitability Index.....	17
Figure 19. Dry Condition Surface + Subsurface Suitability Index	
Figure 20. Wet Condition Surface + Subsurface Suitability Index	
Figure 21. Dry Condition Surface + Subsurface Suitability Index by Field	
Figure 22. Wet Condition Surface + Subsurface Suitability Index by Field	
Figure 23. Dry Condition Final Groundwater Recharge Suitability Index	
Figure 24. Wet Condition Final Groundwater Recharge Suitability Index	
Figure 25. Generalized Groundwater Mounding from Recharge.....	26

LIST OF APPENDICES

- Appendix A: Flowchart – Groundwater Recharge Suitability Index
- Appendix B: Specialty Crop Recharge Suitability

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
K _c	Crop Coefficient
N	Nitrogen
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 REVIEW AND SUMMARY

The purpose of Task 2 was 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 was to find and compile quantitative and qualitative information on the availability of water recharge from an irrigation water supply and conveyance perspective.

1.4 TASK 3 PURPOSE

Task 3 work focuses on evaluating groundwater recharge suitability relative to subsurface characteristics, surface soil properties, and crop type, and includes the following components:

1. Identification and description of recharge suitability factors and criteria used to assess infiltration.
2. Application of groundwater suitability index
3. Evaluation of specialty crops' influence on infiltration rates.
4. Development of per acre metrics for groundwater recharge potential by soil and specialty crop types.
5. Evaluation of nutrient load to groundwater potential from surface flooding on specialty crops

The main objective of this work is to apply an index and overlay method, using GIS, to determine a cumulative recharge suitability score for each field in the SACOG area. The results are supplemented and supported by narrative and/or qualitative information on the suitability of crops, soil, and hydrogeologic regions for recharge, and the availability and supply of irrigation water throughout the Study Area.

2 TASK 3 SUMMARY

Subsurface (hydrogeologic), surface and crop suitability recharge suitability indices were developed and applied to the SACOG region to evaluate poor, fair and good potential for recharge. The subsurface index indicated that areas that have the greatest potential for recharge from a hydrogeologic perspective are in the southeast portion of the SACOG region in

the Cosumnes and South American Subbasins. There are also limited areas in western Yolo Subbasin, the North American Subbasin, North Yuba and South Yuba Subbasins, and in the Sutter and East Butte Subbasins near the Sutter Buttes that have good potential for recharge. These areas shrink under wet conditions and swell under dry conditions.

Applying the Soil Agricultural Groundwater Banking Index (SAGBI) to the SACOG region, good and fair areas were indicated along the eastern side of the study area as well as some on the western side. However, the central portion of the SACOG area from north to south was indicated as a poor area for recharge considering soils. Combining subsurface and surface indices narrowed the areas with good recharge potential. Areas with both good surface and subsurface suitability are primarily in the central and southern portions of Sacramento County, central portion of Yolo County, along the Sutter Buttes, and in the western portions of Placer and Yuba Counties.

Specialty crops in the SACOG region were evaluated for recharge suitability considering degree of tolerance to saturation, dormant period length, and nitrogen requirement. Apples, grapes, pears and plums/dried plums were the highest rated for recharge potential, while almonds, kiwi fruit, pistachios, pomegranates and walnuts were rated fair. Idle (fallow) land was also considered good for recharge since specialty crops can potentially be established on it.

Good ratings for hydrogeologic, soil and crop suitability converge in the southern portion of Sacramento County, central portion of Yolo County, along the Sutter Buttes, and near the intersection of Yuba, Placer, and Sutter counties. The total acreage of good ratings in the final recharge index is 32,179 during wet conditions and 42,345 acres during dry conditions. Approximately 37% of the fields with good ratings are idle while the remainder are primarily almonds, walnuts, grapes, plums, prunes, or apricots. Throughout the study area, specialty crop fields with good overall potential for recharge are limited and scattered compared to the total specialty crop acreage.

Surface water suitability was not included in this evaluation at this time because of the scarcity of information available on surface water availability.

3 OVERVIEW OF APPROACH

Overall groundwater recharge suitability was assessed using a combination of the following indices:

- Hydrogeologic (Subsurface) Recharge Suitability Index for Wet and Dry Conditions (Section 4)
- Surface Soil Recharge Suitability Index (Section 5)
- Crop Suitability Index (Section 6)

Individual indices were combined into a final recharge suitability index which was assigned integer values of 1, 2, and 3, designating poor, fair, and good recharge suitability, respectively. A summary of how the final index was generated is provided below and shown in Figure 1. A detailed flowchart of index generation is provided in Appendix A.

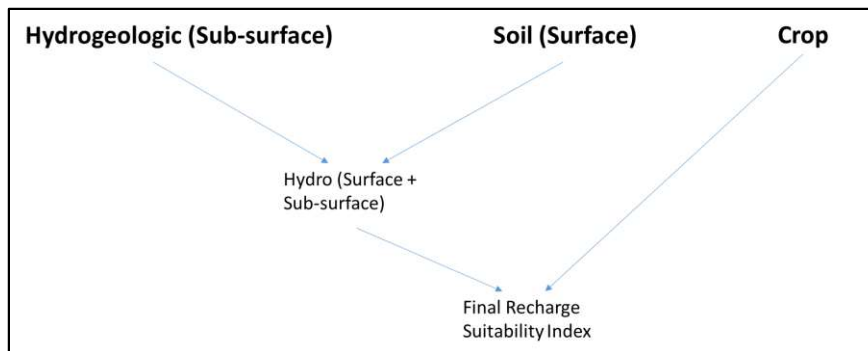


Figure 1. Simplified Flowchart for Generation of Recharge Suitability Index.

Hydrogeologic (Subsurface): The subsurface index utilized vertical and horizontal hydraulic conductivity data and depth to groundwater (DTW) measurements as discussed in the Task 1 Report. Two sets of DTW measurements for wet conditions (2012 data) and dry conditions (2016 data) were utilized. The hydraulic conductivity and DTW suitability factors were ranked individually and combined as discussed in Section 4 below. The index integers in the combined subsurface grid have values of 1, 2, and 3 representing poor, fair, and good recharge suitability.

Surface: Surface soil recharge suitability was assessed using the Soil Agricultural Groundwater Banking Index (SAGBI), O’Geen et al. (2015). This index uses five factors to determine the suitability of surface soils for recharge and assumes soils have been modified from deep tillage as discussed in Section 5. The index integer values in this grid have values of 1, 2, and 3 representing poor, fair, and good recharge suitability.

Crop Suitability: The suitability of specialty crops grown in the SACOG region as identified in Land IQ’s 2014 Department of Water Resources (DWR) crop layer were ranked according to their estimated suitability for recharge. Each specialty crop field was assigned a value based on the crop suitability ranking as is discussed in Section 6.

Final Recharge Suitability Index: The subsurface and surface grids were overlaid and areas with a good rating on both indices were assigned a good rating in the resulting combined grid. Any areas with either a poor surface or subsurface rating were assigned a poor rating. All other areas were rated as fair. The combined surface + subsurface grid was spatially averaged for each field and ranked into the poor, fair, or good categories based on the average value. Each field was then rated based on crop suitability. Any fields with either a poor crop or a poor rating from the combined surface + subsurface index were placed into the (1) poor category. Fields in the (3) good category had a good rating from the combined surface + subsurface index and either a good or fair crop. All other fields were placed in the (2) fair category.

Sections 4 through 7 below provide more detailed information on how the groundwater recharge suitability index was generated.

4 HYDROGEOLOGIC (SUBSURFACE) RECHARGE SUITABILITY INDEX

As noted in the Task 1 Report (Todd, 2017), the counties that make up SACOG overlie a large part of the Sacramento Valley Groundwater Basin and a small part of the San Joaquin Groundwater Basin. The subbasins of these groundwater basins within the SACOG counties have been used as the area of evaluation for the development of the hydrogeologic recharge suitability index. The hydrogeology of these groundwater basins and subbasins was described in the Task 1 Report (Todd, 2017).

Three key hydrogeologic components were identified in the Task 1 Report:

- Relative horizontal aquifer permeability (groundwater flow potential)
- Relative vertical aquifer permeability
- Relative unsaturated zone thickness

Available data on these aquifer characteristics were reviewed from multiple available sources and previously completed studies, including DWR, the United States Geological Survey (USGS), groundwater management plans (GWMPs), DWR Bulletin 118, geologic maps, and other previously completed studies. Task 1 of this project identified horizontal and vertical permeability (hydraulic conductivity) information from the Central Valley Hydrologic Model (CVHM, Faunt, 2009). Depth to groundwater datasets were also developed (Todd, 2017). The findings of Task 1 included recommendations for how these information and data should be applied to the development of a hydrogeologic recharge suitability index:

1. Develop indexed geographic coverages of vertical and horizontal hydraulic conductivity for application to the combined recharge suitability index.
 - a. Hydraulic conductivity values should be divided into reasonable increments and assigned integer values to facilitate combination with other indexed recharge feasibility parameters.
 - b. Vertical hydraulic conductivity should be more highly weighted than horizontal hydraulic conductivity by a factor of 3 to 1.
 - c. There is no need to include a separate coverage representing restrictive geologic materials as expressed in surficial geology in the recharge feasibility index; the affected areas are represented in the horizontal hydraulic conductivity coverage.
2. Develop indexed geographic coverages of unsaturated aquifer thickness from the depth to groundwater datasets presented in this report.
 - a. Separate unsaturated thickness coverage should be prepared for wet and dry conditions.
 - b. These individual datasets should then be developed into separate wet condition and dry condition versions of the combined recharge feasibility index. This will allow SACOG to evaluate the range of groundwater elevation conditions when reviewing recharge feasibility for specific locations.

- c. There is no need to include separate indexed coverage of fold and fault related horizontal flow restrictions; these features are represented in the depth to groundwater/unsaturated zone thickness coverages.

The following sections describe application of the information developed in Task 1 to the construction of a hydrogeologic recharge suitability index. A simplified flowchart of how the hydrogeologic components were combined into the suitability index is provided in Figure 2.

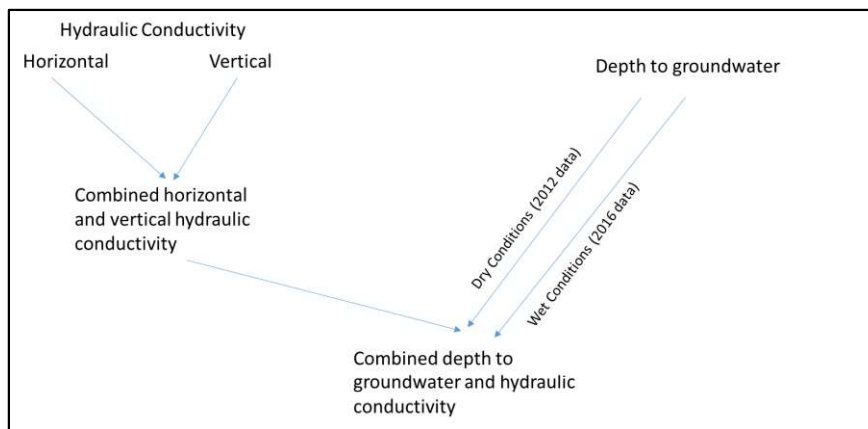


Figure 2. Flowchart for Generation of Hydrogeologic Recharge Suitability Index.

4.1 HYDRAULIC CONDUCTIVITY RECHARGE SUITABILITY INDEX

Hydraulic conductivity is a measure of the capacity of a porous media to transmit water. Groundwater aquifers generally have higher capacity to transmit water horizontally than vertically, so hydraulic conductivity is separated into horizontal and vertical components when modeling natural systems. When water enters a groundwater system, the rate at which it moves laterally is governed by horizontal hydraulic conductivity and the rate at which it moves vertically is governed by the vertical hydraulic conductivity. Water recharged in a discrete location will infiltrate more rapidly in areas with higher vertical hydraulic conductivity, making vertical hydraulic conductivity an important factor in managed recharge feasibility. When large volumes of water are recharged in discrete locations, there is a tendency for groundwater mounds to develop beneath the recharge areas. This can lead to decreased recharge rates or rejection of recharge water. However, water moves laterally away from a recharge source in areas with higher horizontal hydraulic conductivity. Therefore, it is important to also consider relative horizontal hydraulic conductivity when selecting recharge locations.

Horizontal and vertical hydraulic conductivity values for the shallow aquifer materials in the evaluation area were developed from the CVHM in Task 1 (Todd, 2017). These horizontal and vertical hydraulic conductivity values are shown on Figures 3 and 4, respectively.

The hydraulic conductivity values for the shallow aquifer materials were divided into reasonable increments and assigned integer index values, as recommended in the Task 1 Report and repeated above. The horizontal and vertical conductivity values present within the evaluation area were evaluated and each was divided into three ranges representing recharge potential of poor, fair, and good. This division considered both relative values within the evaluation area and general hydrogeologic principals relating to flow and transport of water in the subsurface.

Integer values of 1, 2, and 3 were applied to these ranges representing poor, fair, and good recharge potential, respectively. The ranges were assigned integer values so that these recharge suitability components could be used in combination with similarly indexed values for other components. The ranges of values used to divide the vertical and horizontal conductivity values into indexes are shown in Table 1 below and distribution of the indexes are shown on Figures 5 and 6.

Table 1. Parameter Ranges for Hydraulic Conductivity Indexes

Parameter	Value Range	Index	Index Integer Value
Horizontal Hydraulic Conductivity	Less than 75 ft/day	Poor	1
	75 to 300 ft/day	Fair	2
	Greater than 300 ft/day	Good	3
Vertical Hydraulic Conductivity	Less than 0.01 ft/day	Poor	1
	0.01 to 0.03 ft/day	Fair	2
	Greater than 0.03 ft/day	Good	3

ft = feet

The horizontal and vertical hydraulic conductivity indexes were combined into a single conductivity index. The index values from the two datasets were added together after applying a weighting factor of three to the vertical hydraulic conductivity index. In each cell of the CVHM within the evaluation area, the vertical hydraulic conductivity index value was multiplied by three and the product was added to the horizontal hydraulic conductivity index value for that cell. This resulted in a new indexed dataset with integer values ranging from 4 to 12. This range was divided into equal increments (4 to 6, 7 to 9, and 10 to 12) designated as poor, fair, and good and assigned a new index integer value of 1, 2, and 3. A new grid dataset (raster) was created using Geographic Information System (GIS) software from ESRI (ArcMap). This grid dataset represents combined hydraulic conductivity recharge suitability throughout the evaluation area. The combined hydraulic conductivity index distribution is shown on Figure 7.

4.2 UNSATURATED ZONE THICKNESS RECHARGE SUITABILITY INDEX

The thickness of the unsaturated zone is equivalent to depth to water, which fluctuates with shallow groundwater elevations over space and time. Groundwater recharge feasibility is directly proportional to the thickness of the unsaturated zone; the thicker the unsaturated zone, the more space there is for newly recharged water. Groundwater elevation and depth to water surfaces for wet conditions (spring 2012) and dry conditions (fall 2016) in the evaluation area were generated as part of Task 1 (Todd, 2017). The depth to water coverages for wet and dry conditions are shown on Figures 8 and 9, respectively. The wet and dry condition depth to water/unsaturated zone thickness values present within the evaluation area were assessed and divided into three ranges representing recharge potential of poor, fair, and good. This division considered both relative values within the evaluation area and general hydrogeologic principals relating to groundwater recharge feasibility. The unsaturated zone thickness ranges follow:

Poor = Less than 20 feet (ft) to groundwater

Fair = 20 to 80 ft to groundwater

Good = Greater than 80 ft to groundwater

Integer values of 1, 2, and 3 were applied to these ranges representing poor, fair, and good recharge potential, respectively. The ranges also were assigned integer values to facilitate combination with other indexed recharge suitability components. New grid datasets (rasters) were created using ESRI GIS software tools to represent unsaturated zone thickness suitability throughout the evaluation area. Wet and dry condition recharge suitability index coverages are shown on Figures 10 and 11, respectively.

4.3 COMBINED HYDROGEOLOGIC RECHARGE SUITABILITY (SUBSURFACE) INDEX

The hydraulic conductivity and unsaturated thickness recharge suitability indexes were combined into a single index representing the hydrogeologic suitability throughout the evaluation area. Individual hydrogeologic suitability coverages were created for wet and dry conditions, as recommended in the Task 1 Report (Todd, 2017). These suitability index coverages were constructed by combining the hydraulic conductivity index with the wet and dry condition unsaturated zone thickness index coverages using GIS software tools. The GIS grid dataset representing the combined hydraulic conductivity index was added to each of the unsaturated thickness GIS grid datasets and then all of the resulting values were divided by two (averaged) using raster calculation tools. This process was similar to the calculation steps described for the combination of the vertical and horizontal hydraulic conductivity coverages, but both datasets were equally weighted in this step. This resulted in a dataset with some fractional values. These values were divided into 3 increments (1 to 1.5, 2, and 2.5 to 3) designated as poor, fair, and good and assigned new index integer values of 1, 2, and 3. Maps showing the distribution of the combined hydrogeologic recharge suitability index coverages for wet and dry conditions are presented as Figures 12 and 13.

5 SURFACE SOIL RECHARGE SUITABILITY INDEX

Surface soil suitability was assessed using the Soil Agricultural Groundwater Banking Index (SAGBI), O'Geen et al. (2015). This index uses five factors to determine the suitability of surface soils, as they are described by soil survey (USDA-NRCS, 2014) to a depth of five to six feet, for recharge while preserving groundwater quality, soil quality, and productive crops. These factors and their weights in the final SAGBI rank are as follows:

1. Deep percolation (27.5%)
2. Root zone residence time (27.5%)
3. Topography (20%)
4. Chemical limitations (20%)
5. Soil surface conditions (5%)

A brief description of how SAGBI was developed follows; however, for a more detailed description, O'Geen et al. (2015) should be consulted.

5.1 DEEP PERCOLATION

Deep percolation represents the rate of water transmission through the soil profile into the aquifer below. This factor is particularly important for recharge because floodwaters for diversion or water from winter rains may only be available for a short time and thus need to be transmitted through the soil profile quickly. This factor was determined for each soil using the saturated hydraulic conductivity (K_{sat}) value of the most limiting soil layer in the soil profile. Soils with low K_{sat} values such as cemented layers, claypans, or strongly contrasting particle sizes limit downward percolation.

5.2 ROOT ZONE RESIDENCE TIME

In general, prolonged saturated periods are detrimental to crop health because they deprive roots of oxygen. Root zone residence time was included as a recharge suitability factor for this reason, and was determined by using the harmonic mean of the K_{sat} of all layers of the soil profile, soil drainage class, and shrink-swell properties. The harmonic mean is typically used when reporting the average value for rates and tends to be lower than a standard average. Poorly drained soils and soils with high shrink-swell received the lowest scores (O'Geen et al., 2015).

5.3 TOPOGRAPHY

Distributing water evenly on sloping land is difficult, whereas level land distributes water evenly and minimizes erosion by runoff. Slope classes from the soil survey were ranked to express topographic limitations with lower slope being better suited for recharge.

5.4 CHEMICAL LIMITATIONS

This factor was focused on salinity because it is included in soil survey descriptions. Other potential chemical limitations such as pesticides and nitrate (NO_3^-) (potential groundwater contaminants) could not be evaluated because they vary across time and landscapes. Electrical conductivity, the measure of soil salinity, was used to develop a score for this factor.

5.5 SURFACE CONDITIONS

The purpose of including this factor was to express the susceptibility of some soils to changes in physical conditions when they are flooded. Prolonged standing water can detrimentally impact soil structure by breaking down aggregates, which leads to soil crusts (that impede infiltration) and compaction. The surface conditions score was developed using the soil erodibility factor and the sodium adsorption ratio (SAR). SAR values greater than 13 indicate the soil has a high relative percentage of sodium compared to other soil salts and is thus prone to crusting due to sodium induced dispersion of soil particles. The soil erodibility factor is from the USDA-NRCS Revised Universal Soil Loss Equation (RUSLE) and estimates the potential soil susceptibility to erosion, disaggregation and physical crust formation.

5.6 SAGBI FINAL RANKS

The SAGBI score was calculated for each soil type in the Central Valley using the weighted geometric mean of the five factors. Each factor was weighted based on its significance to groundwater banking based on expert opinion (O'Geen et al., 2015). For this analysis, a modified SAGBI index was utilized which assumes that orchard and vineyard crops have been modified by deep tillage to a depth of 6 feet. Deep tillage, which is not reflected in the soil survey, is a standard practice on orchards and vineyards to destroy restrictive layers that impede root penetration (O'Geen et al., 2015). Deep tillage is accounted for in the modified SAGBI score by replacing the saturated conductivity value for the most restrictive layer with a depth-weighted average of saturated conductivity for the whole soil profile. The modified SAGBI scores were ranked for recharge suitability as excellent, good, moderately good, moderately poor, poor or very poor.

5.7 APPLICATION OF SAGBI

In order to be consistent with the subsurface index and to reflect the broad nature of the groundwater analysis, modified SAGBI ranks were condensed into 3 classes as indicated in Table 2. The modified SAGBI index, reclassified in this way, was applied to the SACOG area as shown in Figure 14.

Table 2. Reclassified Modified SAGBI

Modified SAGBI Classification ^a	Reclassified Modified SAGBI
6 – Excellent	3 - Good
5 – Good	
4 – Moderately Good	2 - Fair
3 – Moderately Poor	
2 – Poor	1 - Poor
1 – Very Poor	

Notes:

^aO'Geen et al. 2015

6 SPECIALTY CROP SUITABILITY INDEX

Crops in the Study Area were determined using Land IQ's DWR 2014 crop mapping data (Land IQ, 2016) shown in Figure 15. Crop types are categorized using the DWR Crop Legend Modified for Remote Sensing. The SACOG region has both specialty and non-specialty crops; however, only specialty crops were evaluated for recharge suitability in this analysis. It should be noted that the cropping factor is a dynamic in that the crops grown on a field could be changed. In contrast, the surface and subsurface factors are static and the combined index of these two factors (described in Section 7 and shown by field in Figures 21 and 22) represents all potential areas that would be suitable for groundwater recharge given that a well-suited crop could be established.

The suitability of each specialty crop in the SACOG area was determined by evaluating factors pertinent to recharge suitability. The factors evaluated for annual crops were different than those for perennial crops. Each factor was scored using numeric or qualitative data from literature sources and expert opinion. Both sources were used because literature sources alone may not reflect the true impact of recharge water on crops. While there are studies on the impacts of prolonged natural flooding on crop health, there is little research to date on intentional flooding for recharge. This is an important distinction, for the following reasons.

First, literature values quantifying the impact of natural flooding on crops are typically generated from sites with fine-textured soils (RMC, 2015). These soils, and the crops grown on them, would be the most negatively impacted by prolonged flooding and saturation, and would also be poorly suited for recharge because of low percolation and high root zone residence time. In contrast, flooding for the purposes of recharge would intentionally be conducted on coarse-textured soils that transmit water more readily and would not suffer the impacts to soil and crop quality that fine-textured soils would experience. Second, natural flooding results in uncontrolled duration and/or frequency of ponded water, whereas intentional recharge could be controlled to limit saturated periods according to crop tolerances. Third, crops that are considered for recharge were historically flood irrigated and were likely over-irrigated during the growing season to mitigate for poor irrigation efficiency. Thus, these crops have historically handled flooded conditions to some extent, but more management would be required during low ET winter months when applied water is removed more slowly.

Since current recharge studies are on-going and preliminary, expert opinions compiled and documented in various surveys were used as an additional source of information. O'Geen et al. (2015) compiled survey results of tree crop vulnerability to saturated conditions. Additionally, RMC (2015) compiled information on potential recharge periods for perennial crops from literature sources. Bachand et al. (2012) reported a pilot study that focused on flooding of crops including onions, tomatoes, potatoes and wine grapes. In addition, regional experts were consulted on the potential of annual crop rotations for recharge.

6.1 ANNUAL CROPS

Three suitability factors were scored for each annual crop. Rules for scoring are shown in Table 3 and more detailed crop information is provided in Appendix B. For each crop, the scores for the three factors were added together, then converted to a rating of poor, fair or good. Cumulative factor scores of 1, 2 or 3 were converted to a rating of poor; factor scores of 4, 5 or 6 were converted to a rating of fair, and factor scores of 7, 8 or 9 were converted to a rating of good. Because this evaluation focuses on winter recharge, crops with summer fallow periods scored "not possible" and were automatically given a poor rating, as were crops with a "not possible" score in management. Any crops that received a "not possible" score for any factor were automatically given a "poor" rating.

Table 3. Suitability Factors for Annual Crops

Suitability Factor	Criteria	Score
<u>Fallow period</u> – winter fallow periods accommodate winter recharge. Summer fallow periods and winter cropping preclude winter recharge. Winter fallow periods that required field prep would have some potential for winter recharge depending on crop rotation.	Winter; field requires no fall preparation	Good
	Winter, but field requires preparation such as bedding for spring planting	Fair
	Summer	Not possible
<u>Nitrogen (N) fertilizer requirement</u> – A high N fertilizer requirement makes crops poor candidates for recharge because of the high potential of pushing soil N into underlying aquifers and degrading groundwater quality.	Low annual fertilizer requirement less than 100 lb/ac	Good
	Moderate annual fertilizer requirement over 100 but less than 150 lb/ac	Fair
	High annual fertilizer requirement of 150 lb/ac or over	Poor
<u>Management</u>	Same crop every year with no uncertainty in field preparation, pesticide application, or spring management.	Good
	Rotated crop; late spring planting that would not interfere with winter recharge	Fair
	Rotated crop; early spring planting	Poor
	Crop grown in pots or very small plots	Not possible

Table 4 lists each annual specialty crop in the SACOG region with its corresponding rank for suitability for groundwater recharge. Any crop that scored not possible for any factor was assigned to the poor suitability class. It is important to note that this ranking is subjective and based on limited scientific literature and professional opinion. With more research providing updated data, these ratings would likely change.

Table 4. Annual Crop Ranking for Groundwater Recharge Suitability

Specialty Crop - Annuals	Rating
Beans (Dry)	Fair
Carrots	Poor
Flowers/nursery/Christmas trees	Poor
Lettuce/Leafy Greens	Poor
Melons, Squash and Cucumbers	Good

Specialty Crop - Annuals	Rating
Onions and Garlic	Poor
Peppers	Poor
Potatoes and Sweet Potatoes	Poor
Strawberries	Poor
Tomatoes	Fair

Table 3 shows that most annual crops in the SACOG region are poor candidates for recharge. This result is largely because of seasonality, the scale at which these crops are grown, and crop rotations that introduce uncertainty into the preparatory work need on winter fallowed fields and spring planting plans.

Melons, squash and cucumbers were rated “good” because they are short season summer crops with a low nitrogen (N) requirement. However, their suitability in practice would highly depend on the crops with which they are rotated, and if the rotation is annual or in a double-cropping scenario. If they were double-cropped, the fallow season in between summer and winter plantings would be very short, and even in an annual rotation, the fallow period might be in the spring or fall but not in the winter (Miyao, pers. comm.).

Though beans and tomatoes are rated fair, the uncertainty associated with the rotations of these crops would call their general suitability into question. For example, beans can be grown as an annual crop or as a cover crop intercropped between the rows of young orchards, which would not be reflected in the crop mapping data. In addition, beans are rotated with other crops that are subject to rotation management decisions that are sometimes not made in time to accommodate winter recharge. Bachand et al. (2012) reported low recharge rates on tomato crops in season. However, tomato fields in the SACOG region may not be suitable because: 1) growing beds are formed in the winter, so the fields are ready for planting in the spring; and 2) tomatoes are sometimes double cropped, making the fallow period very short (Mountjoy, pers. comm.; Dahlke, pers. comm.; Miyao, pers. comm.). Tomatoes may only be rotated once every three to five years if subsurface drip is used as the irrigation method (Vinchesi, pers. comm.).

Management considerations that would likely decrease the suitability of annual specialty crops include, but are not limited to, the following (Squires 2017, pers. comm.):

- Rotation decisions can depend on rent structure and markets, making it difficult for growers to predict with certainty what crop will be planted on a certain field in the spring. Without this information, recharge water would be undesirable because different crops require different field preparatory work, soil moisture, etc.
- Sometimes annual crops, such as tomatoes and wheat, are double-cropped, which would leave little time for recharge outside of the growing season, and would make it difficult to predict when recharge water could be applied.
- Pre-emergent or early season pesticide application in some crops would prevent water application before planting.

- Though this evaluation focuses on winter recharge, some annuals have been irrigated for recharge in-season in the southern part of the Central Valley (Bachand et al., 2012). However, some annual crops (such as melons) have great tolerance for drought and are not irrigated in season in the SACOG region, and have little tolerance for high water levels.
- Tolerance to saturation is unknown for many annual crops.

6.2 PERENNIAL CROPS

Perennial crops were evaluated on their suitability for groundwater recharge using the factors in Table 5. More detailed crop information is provided in Appendix B. For each crop, the scores for the three factors were added together, then converted to a rating of poor, fair or good. Cumulative factor scores of 1, 2 or 3 were converted to a rating of poor; factor scores of 4, 5 or 6 were converted to a rating of fair, and factor scores of 7, 8 or 9 were converted to a rating of good. Because this evaluation focuses on winter recharge, crops with no dormant period were scored “not possible” and automatically received a “poor” rating, as were crops with no tolerance to saturation. Any crops that received a “not possible” score for any factor were automatically given a “poor” rating.

Table 5. Suitability Factors for Perennial Crops

Suitability Factor	Criteria	Score
<u>Saturation Tolerance</u> – the greater the saturation tolerance, the less potential to harm crops through root oxygen deprivation.	Good tolerance - before and after budbreak	Good
	Moderate tolerance – before budbreak but not after budbreak; either one for 48 hours or more	Fair
	Low tolerance – 48 hours or less	Poor
	No tolerance	Not possible
<u>N fertilizer requirement</u> – A high N fertilizer requirement makes crops poor candidates for recharge because of the high potential of pushing soil N into underlying aquifers and degrading groundwater quality.	Low annual fertilizer requirement less than 100 lb/ac	Good
	Moderate annual fertilizer requirement over 100 but less than 150 lb/ac	Fair
	High annual fertilizer requirement of 150 lb/ac or over	Poor
<u>Dormancy Duration</u> – The longer a tree crop is dormant, the longer the timeframe for possible winter recharge	Maximum chill hours required of 1,500 or more	Good
	Required chill hours between 500 and 1,500	Fair
	Required chill hours of 500 or lower	Poor
	No dormancy	Not possible

Perennial crop resistance to diseases common under saturated conditions and carried by flood water, primarily phytophthora root and crown rot (*Phytophthora* spp.), is also an important suitability factor; however, this evaluation did not consider susceptibility to phytophthora because conditions that favor its development are the same for all trees. Periods of 24 hours or more of saturated soil favor *Phytophthora* infections (UC Davis, 2015). Conversely, good soil drainage and more frequent but shorter irrigations (e.g. pulse irrigation) reduce the risk of root and crown rot. It is assumed that recharge irrigation would be managed to prevent or reduce the introduction and proliferation of the phytophthora fungus. Management practices include protecting crowns of trees from prolonged standing water, pulsing irrigations to avoid prolonged periods of standing water, planting on berms, and avoiding introduction of infested plant material. Though rootstocks and varieties differ in their susceptibility to phytophthora, crop data does not allow for determining which varieties and rootstocks are planted in specific orchards.

Ratings for each perennial specialty crop are shown in Table 6. Crops that scored “not possible” in any category were deselected from the overall groundwater recharge suitability index.

Table 6. Perennial Crop Ranking for Groundwater Recharge Suitability

Specialty Crop	Rating	Notes
Almonds	Fair	High acreage
Apples	Good	Low acreage; likely grown on sloped land
Bush Berries	Poor	Very low acreage
Cherries	Poor	No tolerance to saturation
Citrus	Poor	No dormant period
Dates	Poor	No dormant period
Grapes	Good	High acreage
Kiwi fruit	Fair	Low acreage
Olives	Poor	No dormant period
Peaches/Nectarines	Poor	No tolerance to saturation
Pears	Good	Low acreage; likely grown on sloped land
Pistachios	Fair	Low acreage
Plums, Dried Plums	Good	High acreage
Pomegranates	Fair	Low acreage
Walnuts	Fair	High acreage

Table 6 shows that apples, grapes, pears and plums/dried plums are likely good candidates for winter recharge considering the factors used in this evaluation. While apples and pears have low acreage and are likely grown on sloping land that precludes recharge irrigation application, grapes and plums/dried plums are grown in relatively large acreages and would have more potential for winter recharge in the SACOG region. Crops with “fair” ratings include almonds, kiwi fruit, pistachios, pomegranates and walnuts. Again, some of these crops are grown in very

small acreages in the SACOG region (kiwi fruit and pomegranates) while the others (almonds, walnuts) are preferred crop choices.

The crop suitability index as applied to the SACOG region is shown in Figure 16 and the specific crop types for the good and fair rated areas are shown in Figure 17.

Because of the large acreage of almonds in the SACOG region and throughout the state, UC Davis has initiated studies on the potential of these crops for recharge; however, data is not available from these studies to date to determine the suitability of these crops (Dahlke, pers. comm.). Pistachios are also being studied because they have tolerance to saturation. Other organizations are studying recharge on walnuts as well (Mountjoy, pers. comm.). These studies must be conducted for multiple years before winter recharge suitability and its potential impacts on crop, soil and groundwater quality can begin to be understood.

6.3 POTENTIAL OF NUTRIENT LOADS TO GROUNDWATER

There is little information on the potential of nutrient leaching to groundwater in the context of winter recharge. The main published study took place at Terranova Ranch in Fresno, CA and found that recharge increased nitrate loads to groundwater when applied on a soil with high residual nitrate, while it removes nitrate accumulated near the surface soil (Ariyama, 2015).

Modeling scenarios suggests that over time, if N is managed well, the legacy N leaching diminishes as the vadose zone is flushed with clean recharge water (Bachand et al., 2017; Ariyama, 2015). Legacy N is affected by the crop grown with a low N application crop like grapes having lower legacy N transport compared to higher N application crops like almonds and tomatoes (Bachand et al., 2017). Grower management practices can also cause differences in legacy N on fields with similar crops (Bachand et al., 2017).

The 2012 Terranova Ranch study found that flood flows applied to fields flushed the root zone and upper vadose zone of nitrate and salts, leading to much lower EC and nitrate concentrations to a depth of 8 feet when compared to fields in which more limited flood flows were applied or for which drip irrigation with groundwater was the sole water source (Bachand et al., 2012). In addition, a site mass balance model indicated approximately 40 feet of water would be needed to displace the approximately 2.25 lbs/ft² of legacy salts and approximately 0.04 lbs/ft² of N into groundwater. The impacted groundwater would then require an additional 40-60 feet of water to dilute salt and nitrate concentrations back to initial levels (Bachand et al., 2016; Ariyama, 2015).

6.4 THE INFLUENCE OF SPECIALTY CROPS ON INFILTRATION RATES

There has been little information published on the infiltration rates associated with specialty crops or with conversion of non-specialty crops to specialty crops. Infiltration rates for select crops (wine grapes, alfalfa, fallow) have been measured in a study conducted at Terranova Ranch in Fresno County California which represents the primary source of information (Bachand et al., 2012; Bachand et al., 2014). Terranova Ranch conducted recharge in 2012 at a recharge rate of about 15 CFS diversion rate from the James Bypass (limited by conveyance capacity and typical in capacity to other recent farm recharge efforts). Infiltration rates measured during this study averaged 4.2 in/day for all fields with rates decreasing asymptotically over time to about 2-2.5 in/day after 20 days. Rates did not differ significantly between the different crops and soils

tested. At a 2.5 in/day infiltration rate, 100 acres are required to infiltrate 10 CFS of captured flood flows (Bachand et al., 2012). For a field of approximately 70 acres, this relationship corresponds to pumping water onto the field at 3,500 gpm (Bachand et al., 2016). Deep tillage was also thought to have improved infiltration rates in some fields.

Infiltration rates of 2 in/day were also estimated on 67 acres of engineered recharge basins near the James Bypass receiving stormflow (Bachand et al., 2012).

7 FINAL GROUNDWATER RECHARGE SUITABILITY INDEX

The final groundwater recharge suitability index was generated using the hydrogeologic (subsurface), surface soil, and crop suitability indices described in Sections 4 – 6. The final index was generated for both dry (fall 2016) and wet (spring 2012) conditions using the respective DTW measurements for those years. The procedure used to create the index is described below and a simplified flow chart is shown in Figure 18. A more detailed flow chart is provided in Appendix A.

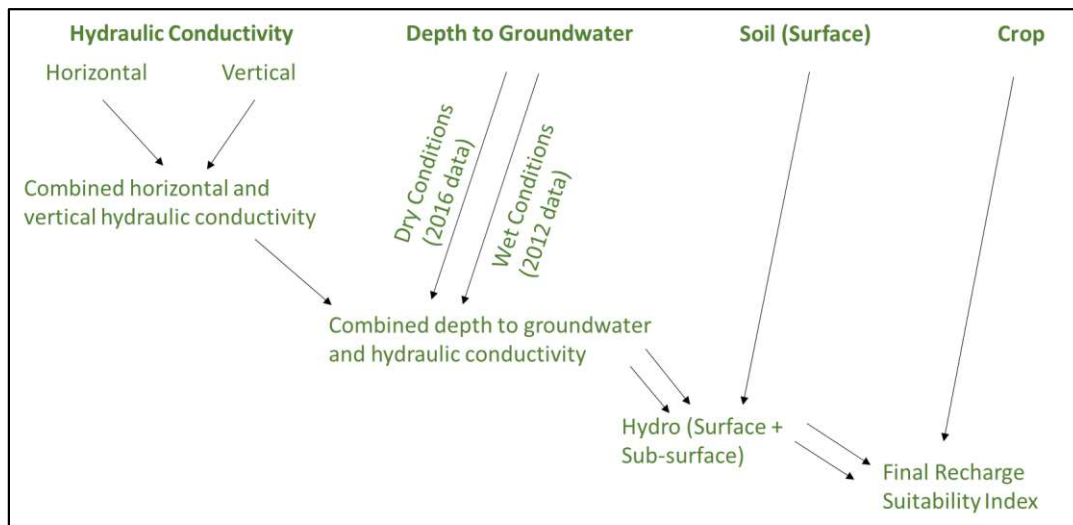


Figure 18. Flowchart for Generation of Final Recharge Suitability Index.

The surface and subsurface grids were overlaid and areas with a good rating on both indices were assigned a good rating on the combined grid. Any area with either a poor surface or poor subsurface rating was assigned a poor rating on the combined grid. All other combinations were placed in the fair category. The results of this application are shown in Figure 19 (dry condition) and Figure 20 (wet condition). The spatial average of the combined grid (surface + subsurface) for each field was calculated using the zonal statistics tool in ArcGIS. Fields with a spatial average of $1 \leq 1.5$ were placed into the poor category, $> 1.5 \leq 2.5$ in the fair category, and $> 2.5 - 3$ in the good category (Figures 21 and 22). Fields were then further ranked based on crop suitability. Any fields with either a poor crop or a poor rating from the combined surface + subsurface index were placed into the (1) poor category. Fields in the (3) good category had a good rating from

the combined surface and subsurface index and either a good or fair crop. Fields with any other combination of crop and surface/subsurface values were placed in the (2) fair category.

The final index with a rating for each specialty crop field in the SACOG region under dry and wet conditions is shown in Figures 23 and 24, respectively. A summary of the acreage associated with each ranking is shown in Table 7 for dry conditions and Table 8 for wet conditions.

Approximately 37% of the good suited fields in wet and dry conditions were idle, with the remainder being primarily walnuts, almonds, grapes, plums, prunes, and apricots (Table 9).

Table 7. Dry Conditions - Acreage Summary for Final Recharge Suitability Index

SAGBI + Subsurface Rating	Crop Rating	Dry Condition			
		Acres	# of Fields	Final Index	Total Acres
Specialty Crops					
3	3	25,914	1,197	3: Good	42,345
3	2	16,431	682		
2	3	72,274	2,563	2: Fair	121,217
2	2	48,943	1,982		
3	1	7,514	287	1: Poor	271,771
2	1	27,695	1,069		
1	3	155,142	4,154		
1	2	42,657	1,541		
1	1	38,763	1,070		
Non-Specialty Crops					
3	N/A	40,985	1,466	N/A	408,687
2	N/A	104,578	3,383		
1	N/A	263,125	5,251		
Fields Outside Extent of Surface or Subsurface Dataset					
NA	3	6,238	1,837	N/A	19,644
NA	2	2,014	181		
NA	1	1,170	426		
NA	Non-Specialty	10,222	1,804		

Notes:

Color shading corresponds to fields shown on Figure 23.

Table 8. Wet Conditions - Acreage Summary for Final Recharge Suitability Index

SAGBI + Subsurface Rating	Crop Rating	Wet Condition			
		Acres	# of Fields	Final Index	Total Acres
Specialty Crops					
3	3	20,428	1,008	3: Good	32,179
3	2	11,751	466		
2	3	69,810	2,506	2: Fair	118,917

SAGBI + Subsurface Rating	Crop Rating	Wet Condition			
		Acres	# of Fields	Final Index	Total Acres
2	2	49,107	1,961		
3	1	5,636	206		
2	1	25,616	1,017		
1	3	163,092	4,400	1: Poor	284,237
1	2	47,173	1,778		
1	1	42,720	1,203		
Non-Specialty Crops					
3	N/A	31,108	1,194		
2	N/A	103,414	3,356	N/A	408,687
1	N/A	274,165	5,550		
Fields Outside Extent of Surface or Subsurface Dataset					
NA	3	6,238	1,837		
NA	2	2,014	181		
NA	1	1,170	426	N/A	19,644
NA	Non-Specialty	10,222	1,804		

Notes:

Color shading corresponds to fields shown on Figure 24.

Table 9. Crop Acreage Summary for Final Recharge Suitability Index

Crop ^a	Crop Rating	Dry Condition Final Recharge Index				Wet Condition Final Recharge Index			
		Acres				Acres			
		Poor	Fair	Good	Total	Poor	Fair	Good	Total
Specialty									
Idle	3	101,909	43,390	16,024	161,322	106,985	42,349	11,988	161,322
Walnuts	2	26,866	30,323	8,329	65,518	29,520	30,387	5,612	65,518
Almonds	2	7,355	16,622	7,925	31,901	8,919	16,966	6,016	31,901
Grapes	3	27,511	16,467	6,075	50,054	28,904	15,560	5,590	50,054
Plums, Prunes and Apricots	3	13,295	10,562	3,301	27,158	14,356	10,348	2,455	27,158
Melons, Squash, Cucumbers	3	6,596	1,619	491	8,706	6,886	1,447	372	8,706
Pistachios	2	371	263	133	767	416	269	81	767
Pomegranates	2	41	30	36	108	41	30	36	108
Pears	3	5,165	182	12	5,360	5,257	90	12	5,360
Apples	3	666	54	11	731	704	16	11	731
Bush Berries	2	25	4	6	35	30	2	4	35
Kiwis	2	190	177	2	369	190	177	2	369
Beans (Dry)	2	7,809	1,524	0	9,333	8,057	1,276	0	9,333
Carrots	1	603	0	0	603	603	0	0	603
Cherries	1	1,772	0	0	1,772	1,772	0	0	1,772
Citrus	1	221	0	0	221	221	0	0	221
Dates	1	6	0	0	6	6	0	0	6
Nursery	1	707	0	0	707	707	0	0	707

Crop ^a	Crop Rating	Dry Condition Final Recharge Index Acres				Wet Condition Final Recharge Index Acres			
		Poor	Fair	Good	Total	Poor	Fair	Good	Total
Lettuce/Leafy Greens	1	102	0	0	102	102	0	0	102
Olives	1	4,333	0	0	4,333	4,333	0	0	4,333
Onions and Garlic	1	1,544	0	0	1,544	1,544	0	0	1,544
Peaches/Nectarines	1	10,490	0	0	10,490	10,490	0	0	10,490
Peppers	1	286	0	0	286	286	0	0	286
Potatoes and Sweet Potatoes	1	12	0	0	12	12	0	0	12
Strawberries	1	133	0	0	133	133	0	0	133
Tomatoes	1	53,763	0	0	53,763	53,763	0	0	53,763
<i>Total</i>		271,771	121,217	42,345	435,333	284,237	118,917	32,180	435,333
Non-Specialty or No Crop Rating									
Rice	0				176,721				176,721
Alfalfa and Alfalfa Mixtures	0				56,230				56,230
Mixed Pasture	0				47,719				47,719
Corn, Sorghum and Sudan	0				44,396				44,396
Sunflowers	0				28,111				28,111
Wheat	0				15,594				15,594
Safflower	0				10,453				10,453
Misc. Grain and Hay	0				8,747				8,747
Young Perennials	0				6,517				6,517
Misc. Grasses	0				5,125				5,125
Misc. Truck Crops	0				3,342				3,342
Wild Rice	0				2,232				2,232
Misc. Deciduous	0				1,954				1,954
Misc. Field Crops	0				984				984
Cotton	0				462				462
Misc. Subtropical Fruits	0				99				99
<i>Total</i>					408,687				408,687

Notes:

^a Fields outside coverage of hydrogeologic dataset not included in table.

8 SURFACE WATER SUITABILITY

Information was provided in the Task 2 Report on availability of surface water for select irrigation districts within the SACOG region which had specialty crops and groundwater recharge index values from the Task 3 Report. The acreage within these districts of each groundwater recharge suitability index class is summarized in Table 10. Some fields in the SACOG region were not associated with an irrigation district as indicated at the bottom of Table 10. For several districts specific surface water volume was not available, 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. Several districts did not have information available as indicated in the Task 2 Report; thus, the surface water factor was not incorporated into the final recharge suitability index.

There were seven irrigation districts which had greater than 1,000 acres of land in the good groundwater recharge suitability class. Four of these seven districts were estimated to have some quantity of surface water available. Overall, many of the districts researched had some quantity of surface water supply, but the reliability and timing of availability of this supply are less certain. Specialty crops fields where surface water is not currently used for irrigation may need to modify existing irrigation infrastructure to allow conveyance of recharge water onto fields.

Table 10. Irrigation and Reclamation District Surface Water Availability

Agency Name	Dry Condition – GW Recharge Index			Non-Specialty Crop Acres	Estimated Surface Water Availability (AFY)
	1: Poor	2: Fair	3: Good		
Reclamation Districts					
Reclamation District No 1001	7,585	6,678	684	10,755	0
Reclamation District No 784	1,848	1,151	541	993	0
Reclamation District No 10	3,425	4,778	340	687	0
Reclamation District No 777	5,613	2,496	255	1,998	0
Reclamation District No 1660	5,127	268	116	7,604	0
Reclamation District No 730	1,106	221	104	1,727	0
Reclamation District No 1000	889	453	87	13,075	0
Reclamation District No 2054	2,972	437	21	4,517	0
Reclamation District No 1500	22,054	444	15	34,333	0
Reclamation District No 2056	2,322	1,329	0	1,995	0
Reclamation District No 823	1,753	572	0	1,816	0
Reclamation District No 108	4,966	182	0	15,048	142,250 - Sac. River 1917 permit
Reclamation District No 2035	9,910	0	0	7,501	19,824
Reclamation District No 787	3,101	0	0	5,157	0
Reclamation District No 783	1,819	0	0	2,627	0
Reclamation District 1004	0	0	0	23	76,465
Reclamation District No 2068	0	0	0	42	70,941
Irrigation Districts					
YCFC & WCD	59,807	33,961	5,676	41,291	80,387
Galt Irrigation District	76	3,852	5,314	8,792	GW primary source
South Sutter Water District	6,499	7,450	3,401	34,952	74,877
Wheatland Water District	254	1,653	1,709	3,820	23,092
Tudor Mutual Water Company	1,305	240	1,209	153	pre-1914 water rights
Omochumne-Hartnell/ SCWA Overlap Service	18	1,774	1,032	1,180	--
Western Placer Irrigation District	1,096	877	1,014	1,233	no data; 0 CVP water
Omochumne-Hartnell Water District	4,112	1,812	768	3,923	100
Sacramento County Water Agency (SCWA)	2,085	1,886	652	3,612	76,000
Camp Far West Irrigation District	1,678	742	618	494	Bear River access
Dunnigan Water District	2,046	3,166	566	3,460	11,600

Agency Name	Dry Condition – GW Recharge Index			Non-Specialty Crop Acres	Estimated Surface Water Availability (AFY)
	1: Poor	Acres 2: Fair	3: Good		
Feather Water District	5,449	1,720	552	550	20,000
California American Water Company	293	1,190	471	1,164	11,831
Dry Creek Mutual Water Company	721	1,396	451	1,785	13,682
Sutter Community Service District	564	210	433	379	municipal
Butte Water District	5,803	2,395	377	4,246	133,000
South Yuba Water District	40	681	316	7,749	25,487
Brophy Water District	465	801	278	10,402	43,470
Plumas Mutual Water Company	1,788	1,334	242	781	pre-1914 water rights
Colusa County Water District	212	534	208	0	54,000
Elk Grove Water Service Retail/ SCWA WSA	38	286	203	140	--
Linda County Water District	42	40	158	304	0 - municipal
N. San Joaquin Water Conservation District	275	373	146	365	limited Mokelumne River access
Rio Linda/ Elverta Water District	14	174	141	228	municipal
Sutter Extension Water Districts	11,068	1,094	90	15,739	111,000
Natomas Central MWC	5,330	370	86	9,567	61,123
Tisdale Irrigation and Drainage Company	1,274	242	79	973	no data
Clay Water District	124	910	74	1,693	0
Hallwood Irrigation Company	763	662	74	7,714	78,000
Oswald WD	433	186	67	65	Feather River access
Sutter Community SD / Sutter Ext. WD	0	51	62	20	--
Nevada Irrigation District	206	309	17	2,425	239,000
Elk Grove Water District	17	65	12	0	2,935
Ramirez Water District	8	58	8	4,215	25101
Cordua Irrigation District	380	266	2	8,952	60,000
Meridian Farms Water Company	3,525	1,868	0	5,906	35,000
Browns Valley Irrigation District	43	688	0	3,732	47,574
Pleasant Grove Verona Municipal WD	2,607	663	0	4,369	municipal
Garden Highway Mutual Water Company	700	652	0	2,415	Feather River access
YCFC&W / UC Davis	88	365	0	584	--
Deseret Farms	610	312	0	518	no data
Newhall Land & Farming Company	695	158	0	3,303	no data

Agency Name	Dry Condition – GW Recharge Index			Non-Specialty Crop Acres	Estimated Surface Water Availability (AFY)
	1: Poor	2: Fair	3: Good		
SMUD Rancho Seco	45	12	0	0	1,600
California Water Service	0	2	0	10	0
Sutter Mutual Water Company	14,812	0	0	31,492	182,025
River Garden Farms Company	2,771	0	0	4,017	poor recharge suitability
Butte Slough Irrigation Company	2,638	0	0	3,737	poor recharge suitability
Pelger Mutual Water Company	1,668	0	0	1,995	poor recharge suitability
Hershey Land Company	157	0	0	619	poor recharge suitability
Biggs - West Gridley Water District	101	0	0	936	161,000
Placer County Water Agency	77	0	0	72	290,667
San Juan Water District	7	0	0	0	poor recharge suitability
Citrus Heights Water District	5	0	0	0	poor recharge suitability
Carmichael Water District	2	0	0	0	poor recharge suitability
Browns Valley ID/Cordua ID	0	0	0	419	no specialty crops
Fair Oaks Water District	0	0	0	7	no specialty crops
UC Davis	0	0	0	34	no specialty crops
No Associated Irrigation District	154,785	57,230	21,295	202,794	no data

Notes:

— Service overlap, see individual agency providers for surface water availability

9 PER ACRE METRICS FOR GROUNDWATER RECHARGE POTENTIAL BY SOIL AND SPECIALTY CROP TYPES

9.1 PER-ACRE GROUNDWATER MOUNDING EFFECT ESTIMATES

The effects of groundwater recharge can be described in terms of increased groundwater volume and decreased depth to groundwater. The volumetric component is straightforward; every unit of water that is successfully recharged to groundwater results in a directly proportional increase in total groundwater volume (assuming that this newly recharged water does not cause discharge promptly from the groundwater system). Changes in the depth to groundwater resulting from recharge in specific discrete locations are more difficult to predict. This is because the movement of water recharged in discrete locations is a function of application and subsurface parameters. These include:

- The extent of the area over which recharge is applied,
- The rate at which recharge water is applied,
- The rate at which recharge water infiltrates to groundwater,
- The storage coefficient of the aquifer (the volume of water that can be stored and released per unit volume of aquifer material),
- Background groundwater gradients, and
- Other local recharge and discharge.

It is not possible to accurately estimate real-world effects of discrete area recharge on groundwater elevations without a thorough representation of these parameters. However, simplified analytical methods are available for assessing generalized groundwater elevation changes.

Application of the Hantush equation (1967) is an industry standard approach for estimating the height of a groundwater recharge mound as a function of time and distance from the recharge area, as illustrated below in Figure 25. The Hantush equation is a two-dimensional approximation that assumes that the underlying aquifer is unconfined, homogeneous, isotropic, and effectively infinite in areal extent. The analysis does not account for travel time, lateral flow of recharge water through the unsaturated zone, a sloping groundwater table, aquifer boundaries (such as surface water bodies, bedrock, or faults), or aquifer stresses, such as pumping. Nonetheless, the Hantush equation is suitable for approximation of groundwater mounding beneath a hypothetical field that may be used for recharge.

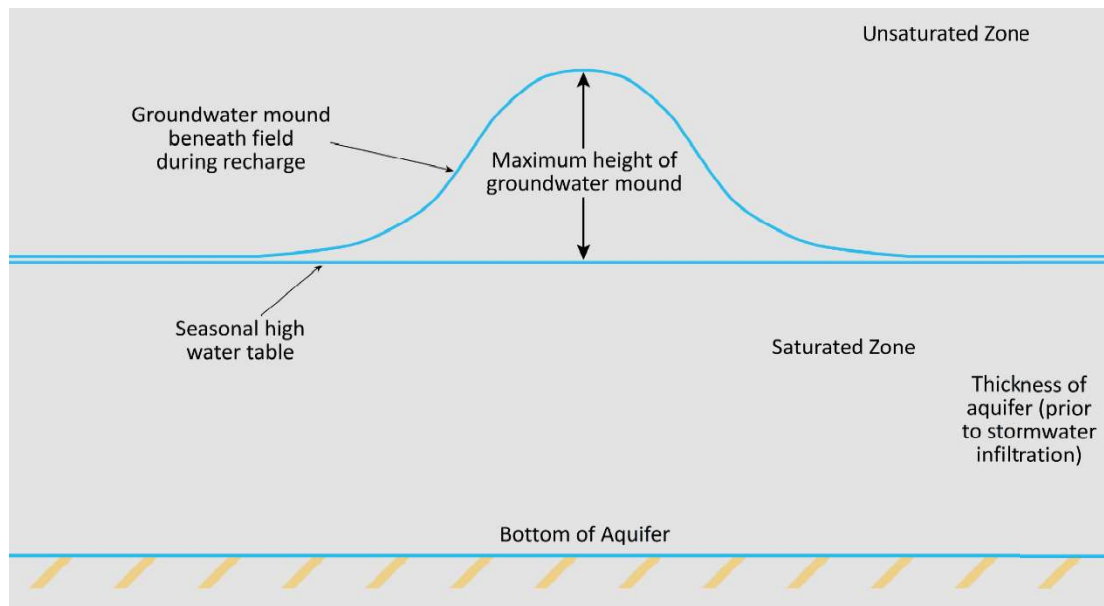


Figure 25. Generalized Groundwater Mounding from Recharge

The Hantush equation was solved using the mounding function for a one acre rectangular recharge area. An Excel macro developed by USGS (Carleton, 2010) was used to solve the following equation:

$$Z(r, t) = h_m^2 - h_i^2 = (V/2\pi K)(w(u_0) + (1 - e^{-u_0})/u_0)$$

where,

$Z(r, t) =$	Height of the mound above initial height of water table with respect to distance from center of recharge area over time
$h_m =$	Height of mound above aquifer base
$h_i =$	Initial height of water table above aquifer base
$V =$	Volume of recharge water expressed as $w\pi r^2$, where w is the vertical infiltration rate from a circular recharge area of radius, r
$K_H =$	Horizontal hydraulic conductivity of the aquifer
$w(u) =$	Theis well function for nonleaky aquifers
$u_0 =$	$R^2/4ntR$, where $n = Kb/Sn$ and $b = 0.5(h_i(0) + h(t))$, where S = Specific yield of the unsaturated zone, t = time since start of recharge, and b = constant of linearization

As shown in the Hantush equation, the development of a groundwater mound is largely dependent on the vertical infiltration rate (w), specific yield (S) of the unsaturated zone, and the horizontal hydraulic conductivity (K_H). The saturated aquifer thickness in the study area is very large, but for this analysis it was assumed that the recharge effects would be limited to the top 200 ft of saturated thickness.

A series of solutions to the Hantush equation were calculated to examine scenarios representing the range of possible combinations of hydrogeologic conditions present within the evaluation area. In each case, the recharge area was simulated as a one acre square. Five combinations of subsurface conditions were simulated representing hydrogeologic index conditions of Good, Fair to Good, Fair, Poor to Fair, and Poor. Calculations were completed for each of these scenarios at four different recharge rates representing the likely range of rates that specialty crops can tolerate: 0.5 ft/month, 1 ft/month, 1.5 ft/month, and 2 ft/month (within range of potential estimated applied recharge water, as described in Task 2 Report). It was assumed that these recharge rates are over and above evapotranspiration demands. All Hantush simulations were completed assuming a recharge period of 90 days. The results shown in Table 11 present the maximum height and the height at a radial distance of 2,000 ft for the groundwater mounds resulting from each hydrogeologic condition and application rate.

The estimated mound height under the recharge area varied from 0.009 ft to 0.923 ft. In general, the more permeable the subsurface the lower the mound. This relationship suggests that the mound from recharge in lower permeability areas will rise higher as the flow of water away from the field is slower. While groundwater mound heights are greater in less permeable material, the effects will take a longer time to propagate horizontally. The same volume of water is added to these scenarios, therefore the net volumetric benefit to the groundwater aquifer is the same.

Table 11. Per-Acre Mounding Estimates

Scenario	Horizontal Hydraulic Conductivity (ft/day)	Aquifer Storage Coefficient (unitless)	Initial Saturated Thickness (ft)	Distance	Estimated Groundwater Rise from Recharge Water at Varying Rates (feet)			
					0.5 ft/month	1.0 ft/month	1.5 ft/month	2.0 ft/month
Good	600	0.3	100	Center	0.009	0.018	0.027	0.036
				2,000 ft	0.004	0.008	0.012	0.016
Fair to Good	350	0.2	125	Center	0.012	0.025	0.037	0.05
				2,000 ft	0.006	0.011	0.017	0.023
Fair	150	0.15	150	Center	0.023	0.045	0.068	0.09
				2,000 ft	0.006	0.017	0.026	0.035
Poor to Fair	100	0.1	160	Center	0.032	0.064	0.096	0.128
				2,000 ft	0.013	0.026	0.038	0.051
Poor	10	0.05	180	Center	0.231	0.462	0.693	0.923
				2,000 ft	0.038	0.077	0.115	0.154

This mounding analysis provides a range of estimated groundwater mounding as a result of recharge on a single acre. The size and shape of groundwater mounds resulting from recharge will be affected by actual recharge area size and shape. The height and extents of groundwater mounds resulting from real-world recharge in agricultural fields would be cumulative and non-linear (i.e., the mound height of a two-acre area would not be twice that of a one-acre area). Additional analytical mounding estimates can be completed on a field-scale basis for individual specific locations once they have been identified. Alternatively, a simplified numerical groundwater model employing a non-linear change approach could be used to estimate the effects of recharging on multiple fields throughout the SACOG area.

10 REFERENCES

- Ariyama, J. 2015. N leaching and groundwater recharge modeling for the on-farm flood flow capture project in Fresno, California. M.S. Thesis. University of California, Davis. Davis, California
- Bachand, P. A. M.; Horwath, W. R.; Roy, S.; Choperena, J.; Cameron, D. 2012. Implications of using On-Farm Flood Flow Capture to recharge groundwater and mitigate flood risks along the Kings River, CA; Final Report; Grant Agreement No. 68-9104-0-128 between Bachand & Associates and the United States Department of Agriculture Natural Resources Conservation Service. Aquatic Commons; September 30, 2012. <http://aquaticcommons.org/11287/> (accessed Sept 10, 2014).
- Bachand, P.A.M., S.B. Roy, N. Stern, J. Choperena, D. Cameron and W.R. Horwath. 2016. On-farm flood capture could reduce groundwater overdraft in Kings River Basin. *California Agriculture* 70:200-207.
- Bachand, P.A.M., S.M. Bachand, H. Waterhouse, J. Rath, M. Ung, S. Roy, V. Kretsinger, B. Dalgish, W. Horwath, H. Dahlke, C. Creamer, J. Choperena, and D. Mountjoy. 2017. Technical report: Modelling nitrate leaching risk from specialty crop fields during on-farm managed floodwater recharge in the Kings groundwater basin and the potential for its management. Sustainable Conservation.
- California Department of Water Resources (DWR), 2003, California's Groundwater, Bulletin 118, Update 2003, October 2003.
- Carleton, G.B., 2010, Simulation of groundwater mounding beneath hypothetical stormwater infiltration basins: U.S. Geological Survey Scientific Investigations Report 2010-5102, 64 p.
- Dahlke, H. August 2017. Personal communication.
- Faunt, C.C. ed., 2009, Groundwater Availability of the Central Valley Aquifer: U.S. Geological Survey Professional Paper 1766, Available at <http://pubs.usgs.gov/pp/1766/>
- Hantush, M.S., 1967, Growth and Decay of Groundwater-Mounds in Response to Uniform Percolation, *Water Resources Research* vol. 3, no.1, pp 227-234.
- Land IQ. 2016. Statewide Crop Mapping, 2014.
- Mountjoy, D. Sustainable Conservation. August 2017. Personal communication.
- Miyao, G. August 2017. Personal communication. UCCE Farm Advisor for Yolo, Solano and Sacramento Counties.
- O'Geen, T., M. Saal, H. Dahlke, D. Doll, R. Elkins, A. Fulton, G. Fogg, T. Harter, J. Hopmans, C. Ingels, F. Niederholzer, S. Sandoval Solis, P. Verdegaal and M. Walkinshaw. 2015. Soil suitability index identifies potential areas for groundwater banking on agricultural lands. *California Agriculture* 69;75-84.

RMC Environment and Water. 2015. A New Opportunity, Groundwater Recharge through Winter Flooding of Agricultural Land in the San Joaquin Valley. California Water Foundation.

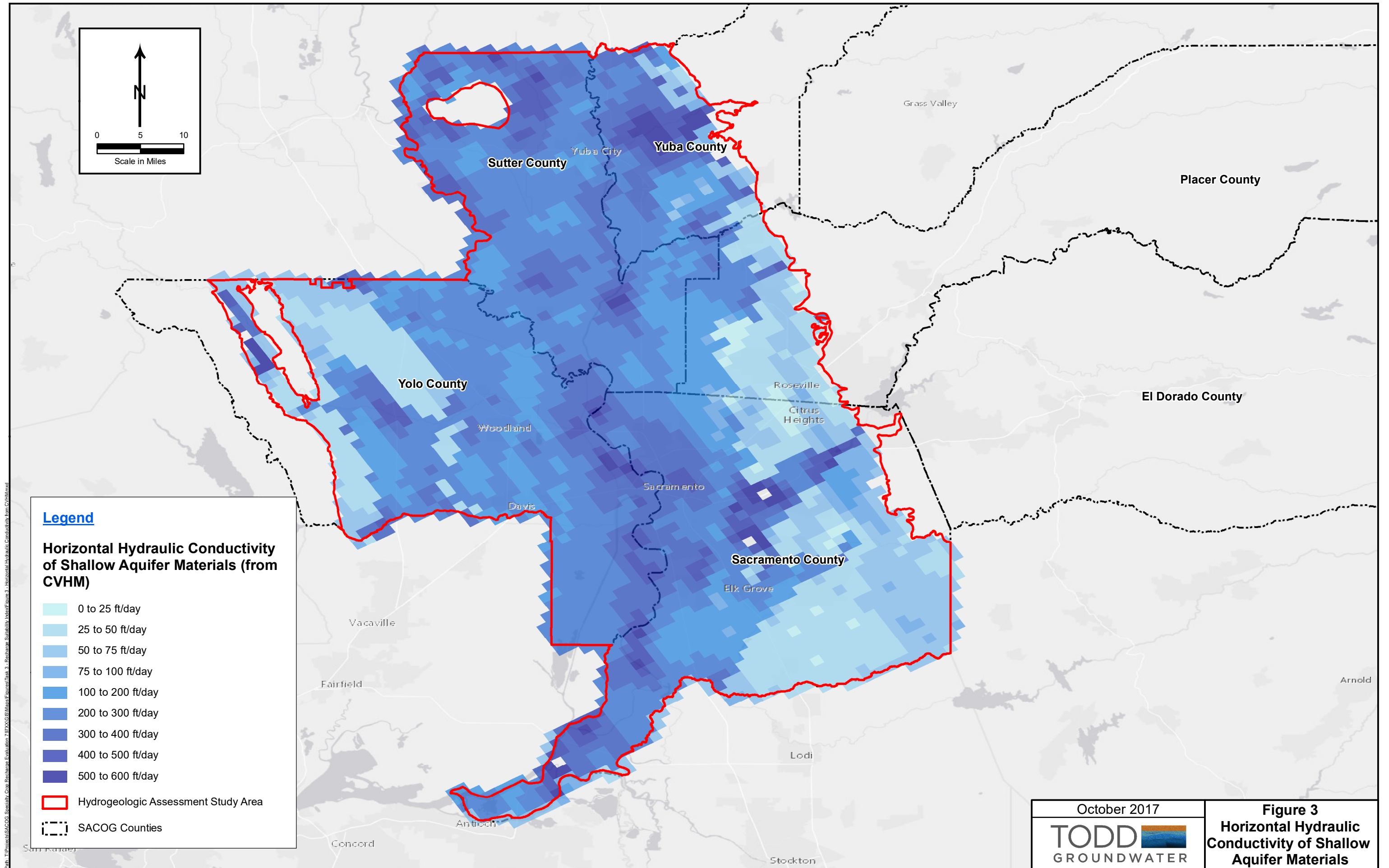
Squires, P. August 2017. Personal communication. Squires Ag Consulting.

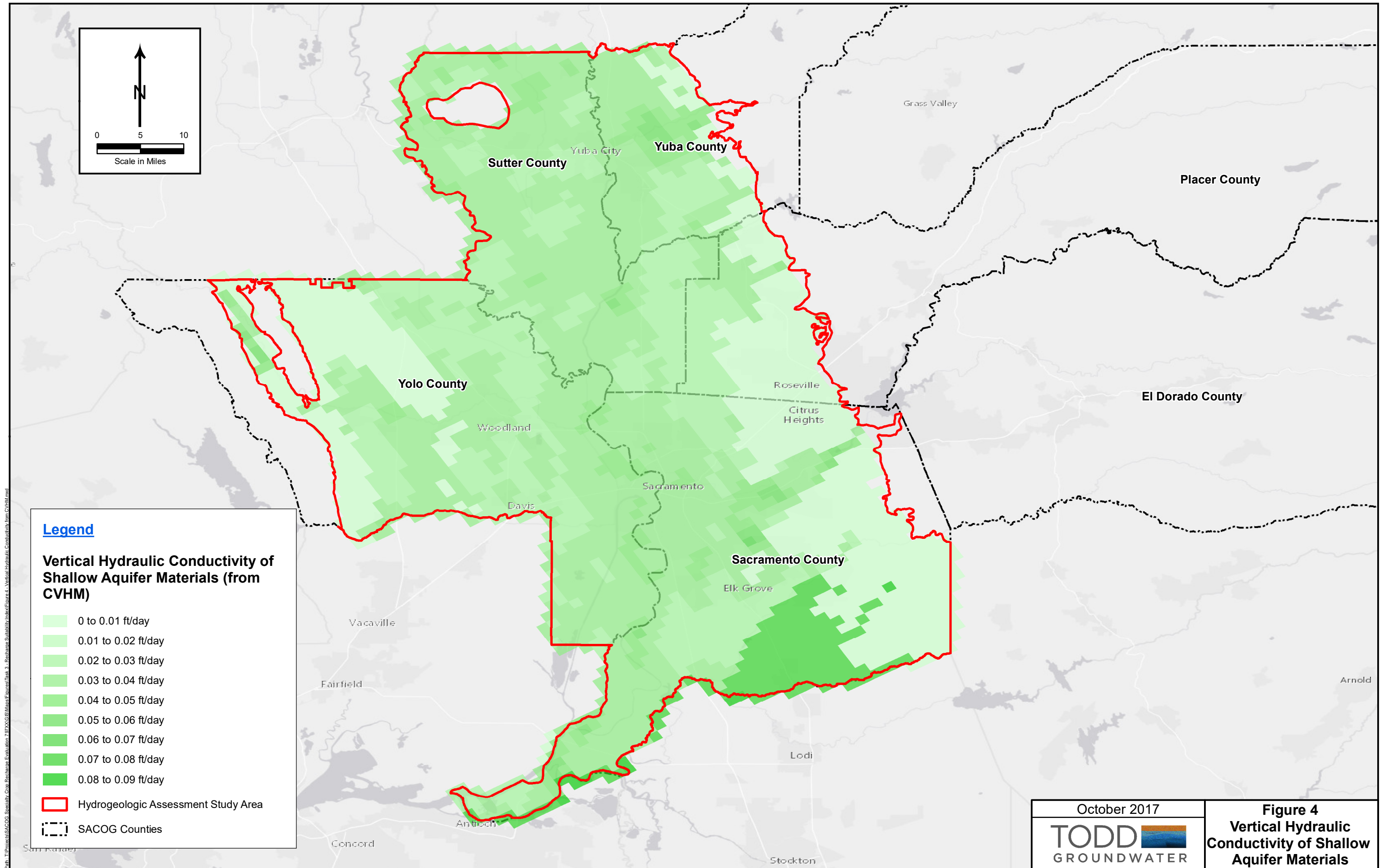
Todd Groundwater (Todd), 2017, Draft Regional Hydrogeologic Assessment for Recharge Feasibility, prepared for the Sacramento Area Council of Governments (SACOG), August 2017.

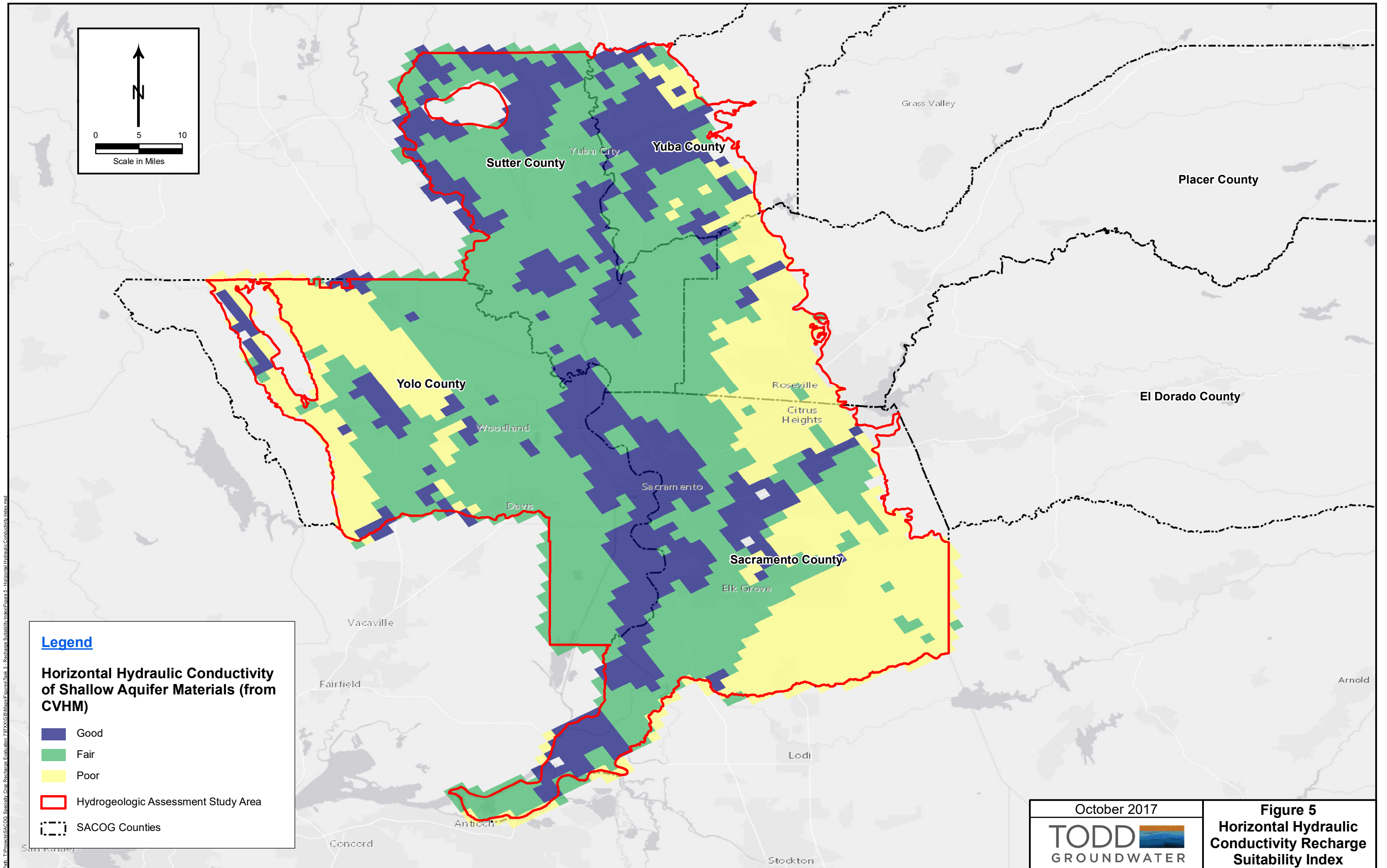
UC Davis. 2015. UC IPM Pest Management Guidelines, various. Example for apple: <http://ipm.ucanr.edu/PMG/r4100511.html>). Accessed August 30, 2017.

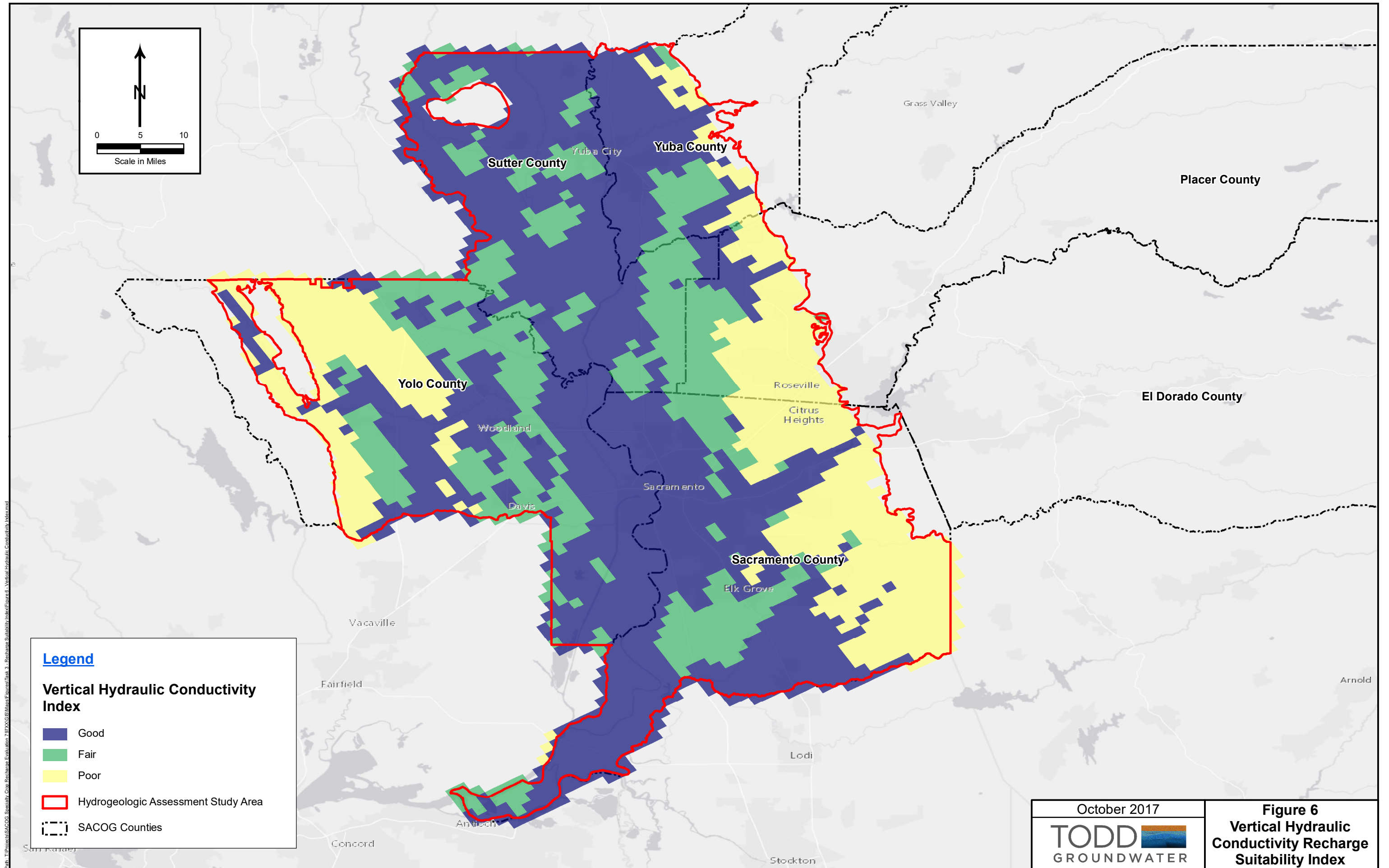
Vinchesi, A. August 2017. Personal communication. UCCE Vegetable Crops Advisor for Colusa, Sutter and Yuba Counties.

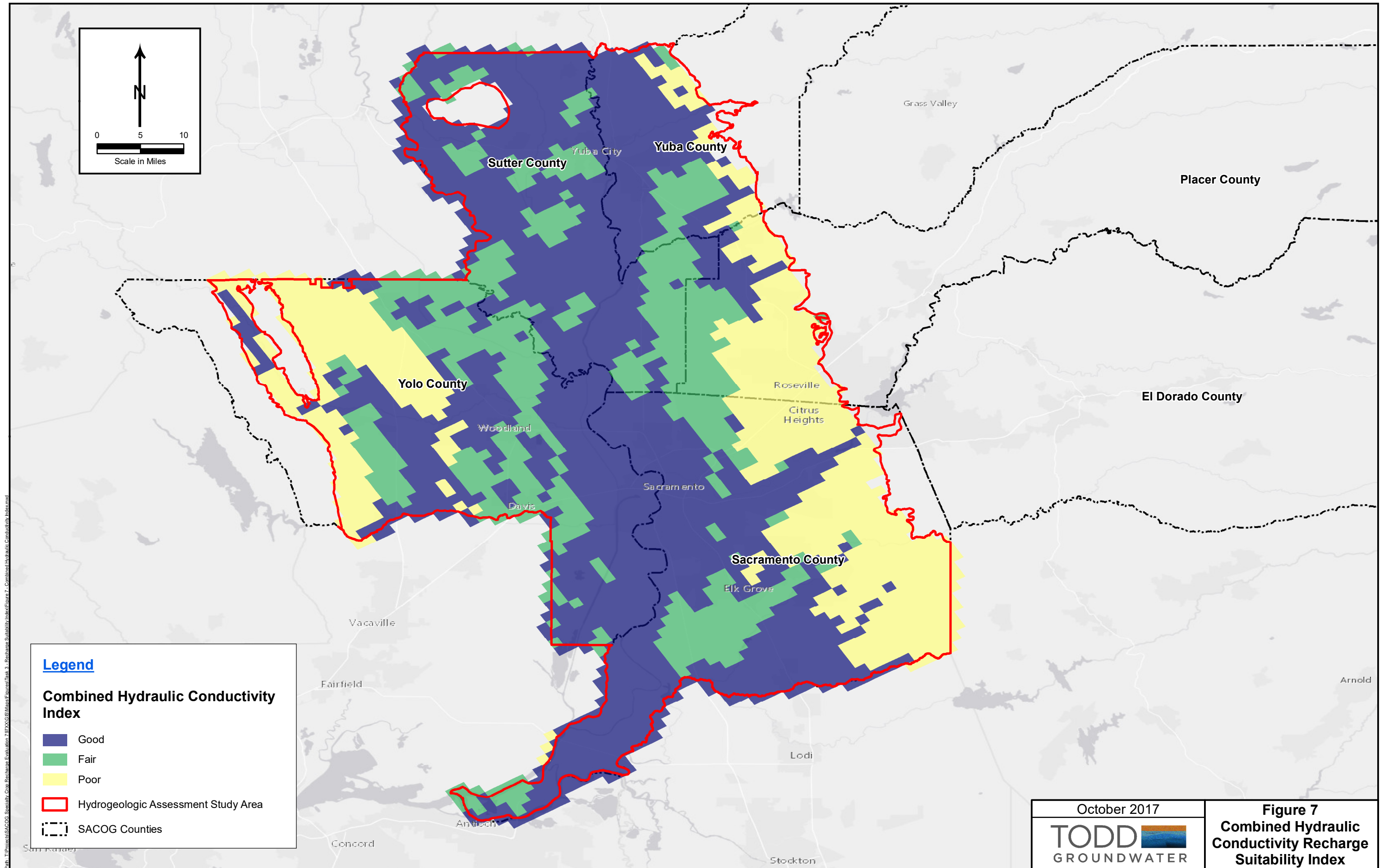
FIGURES

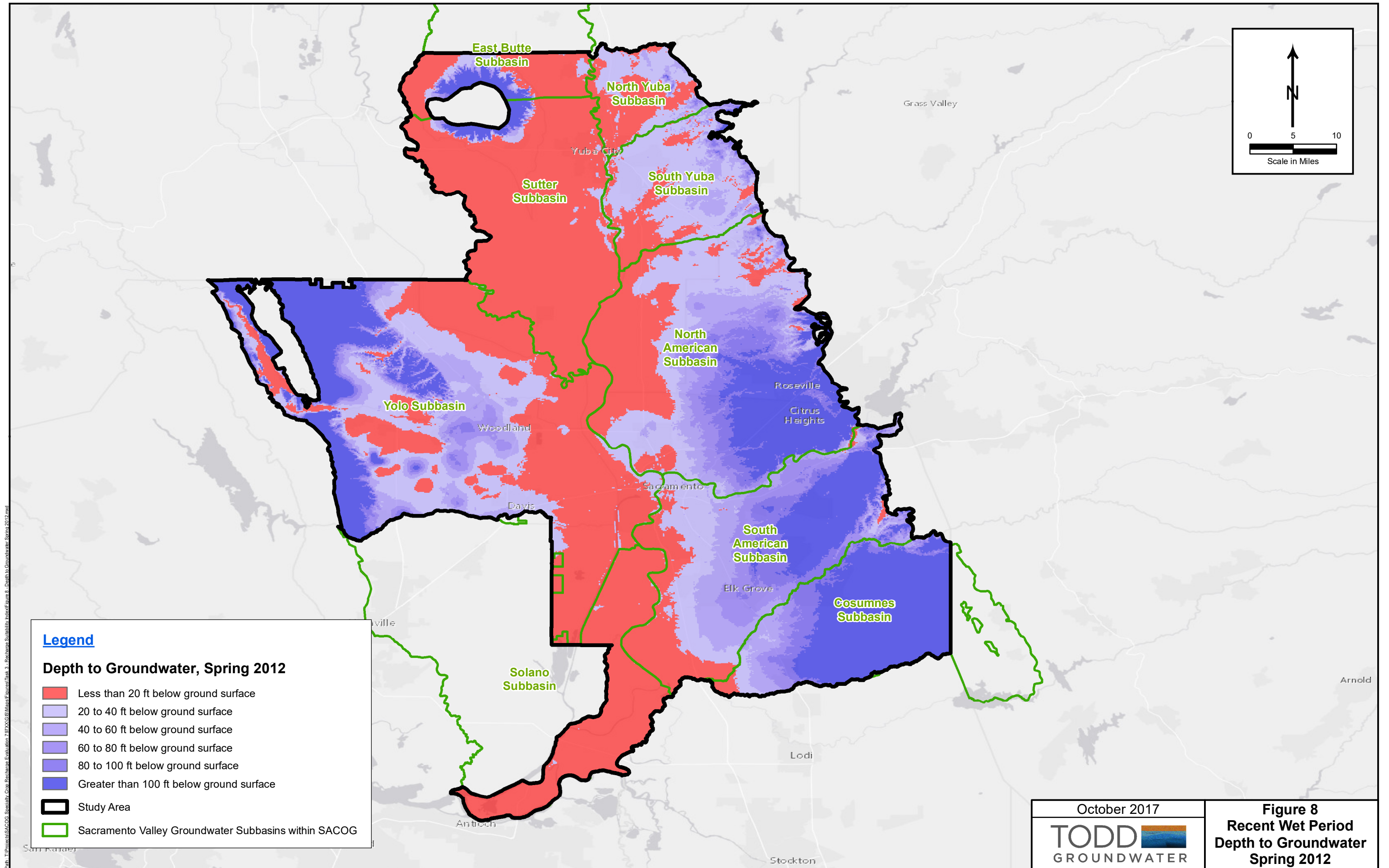


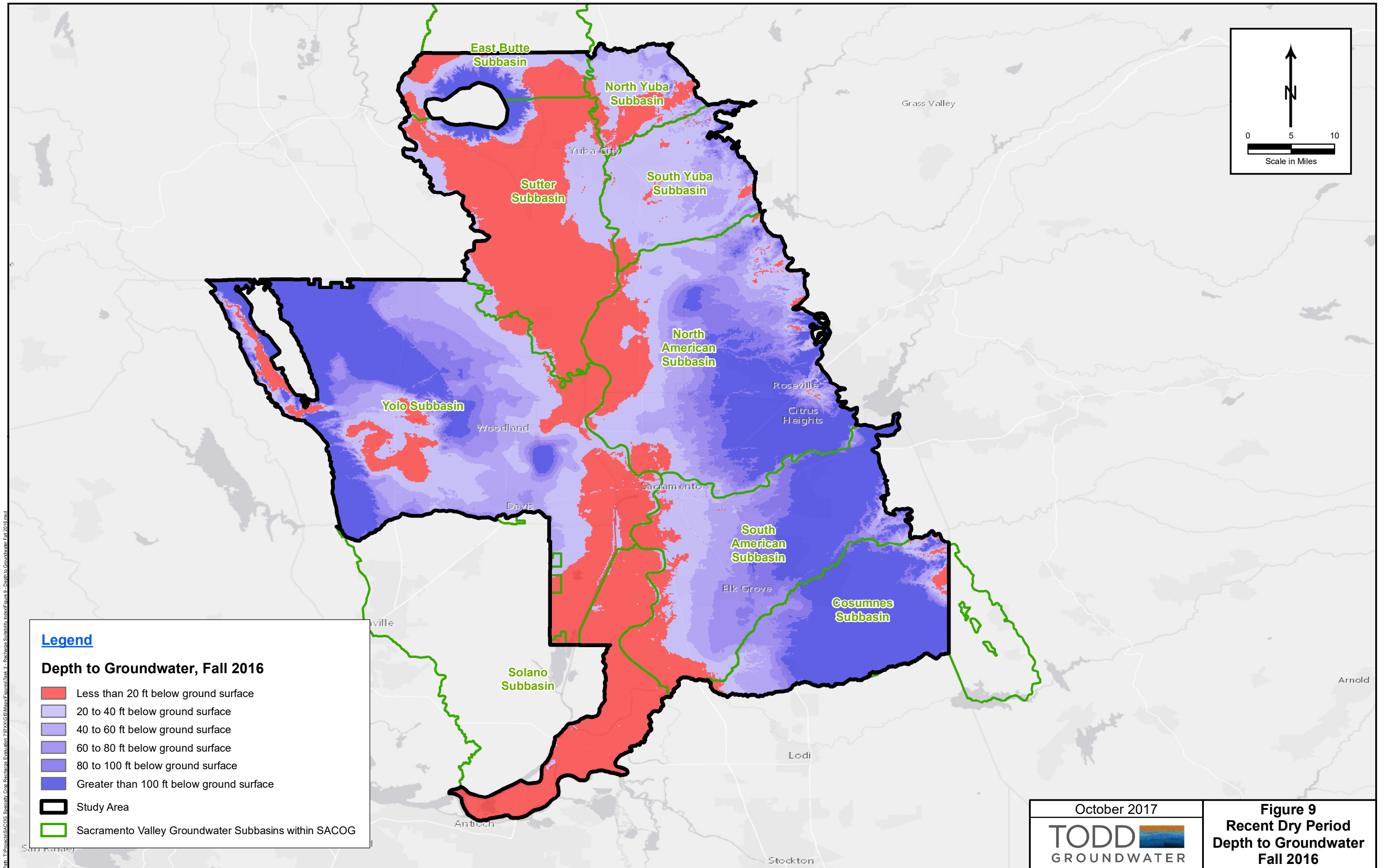


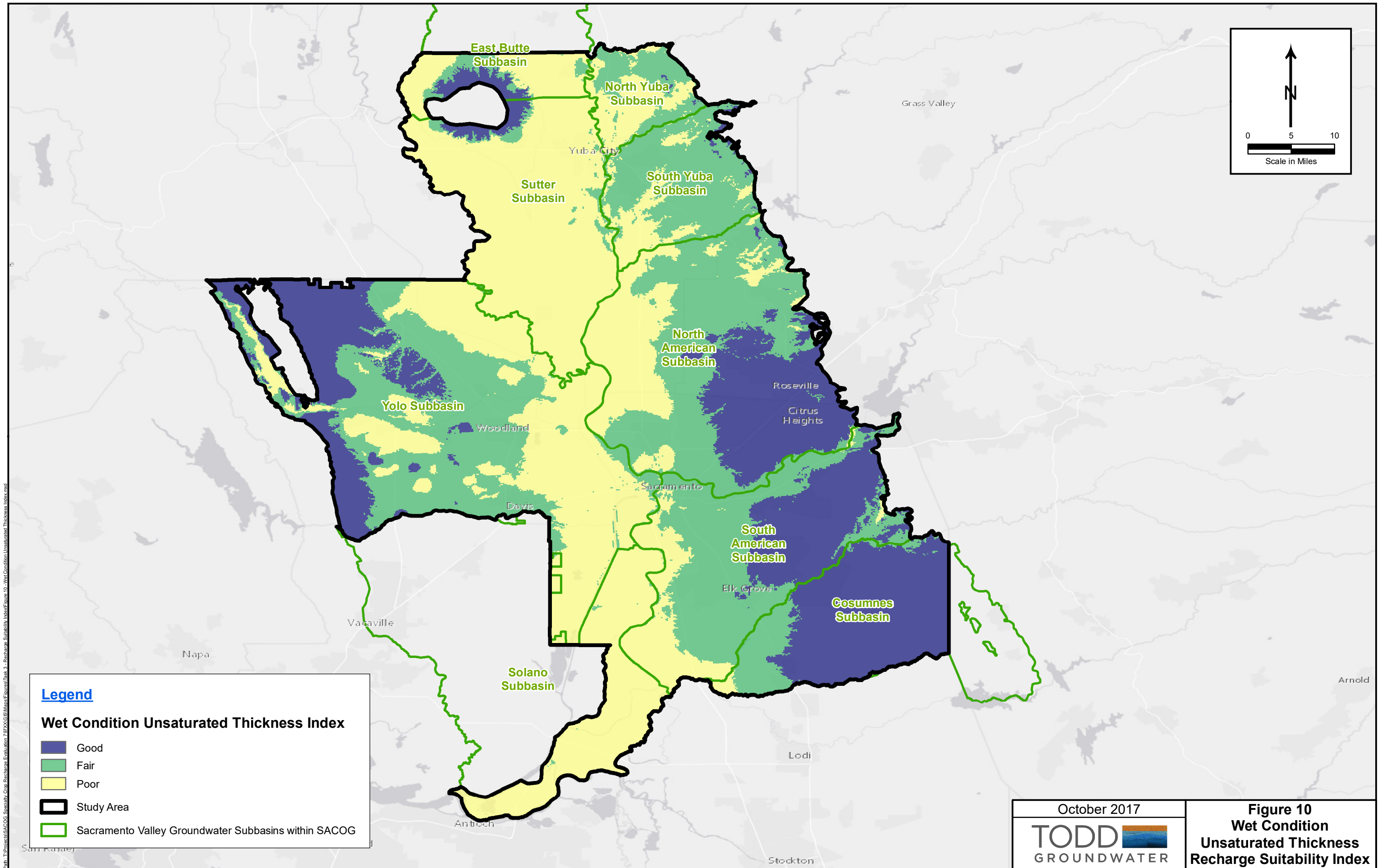


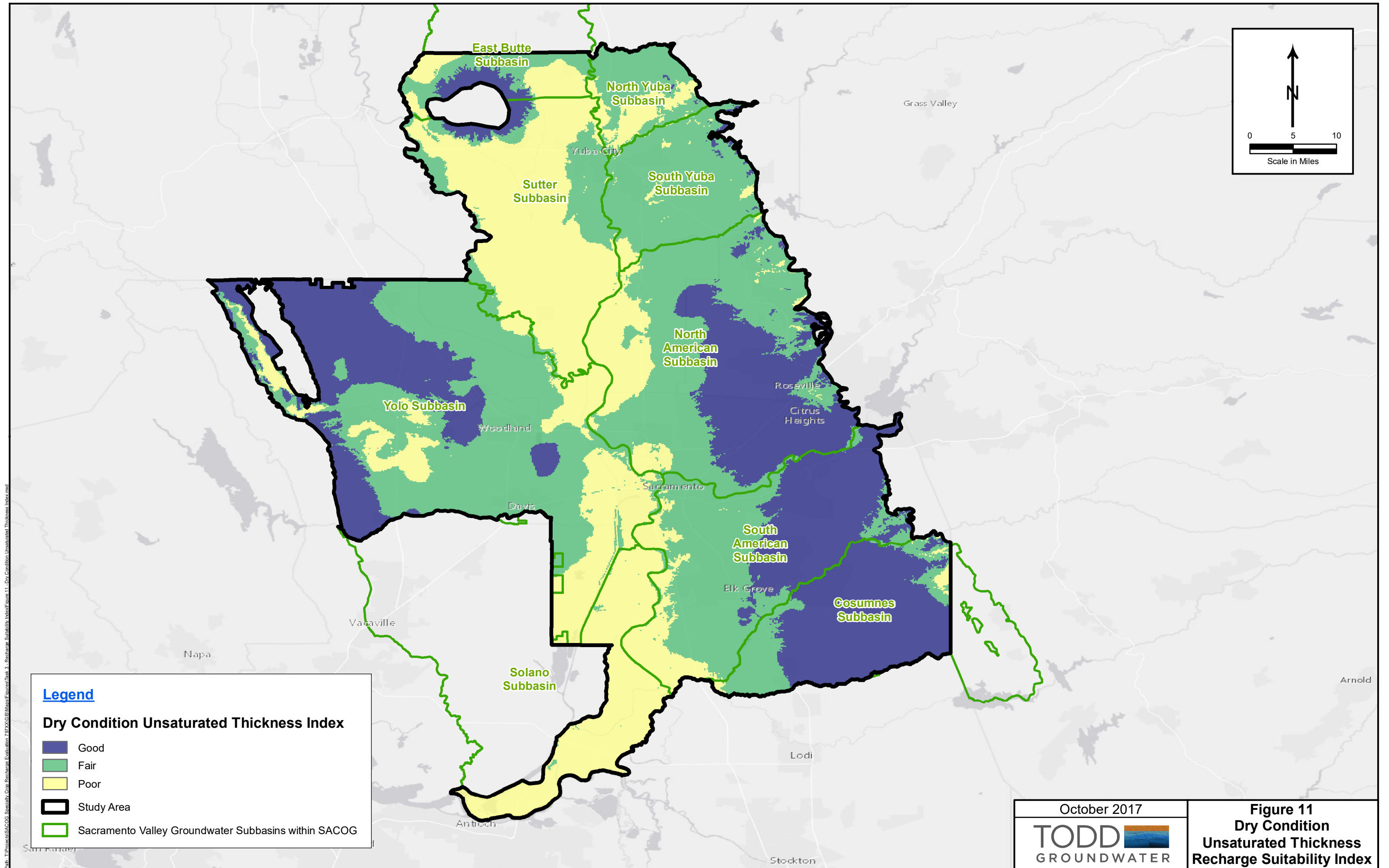


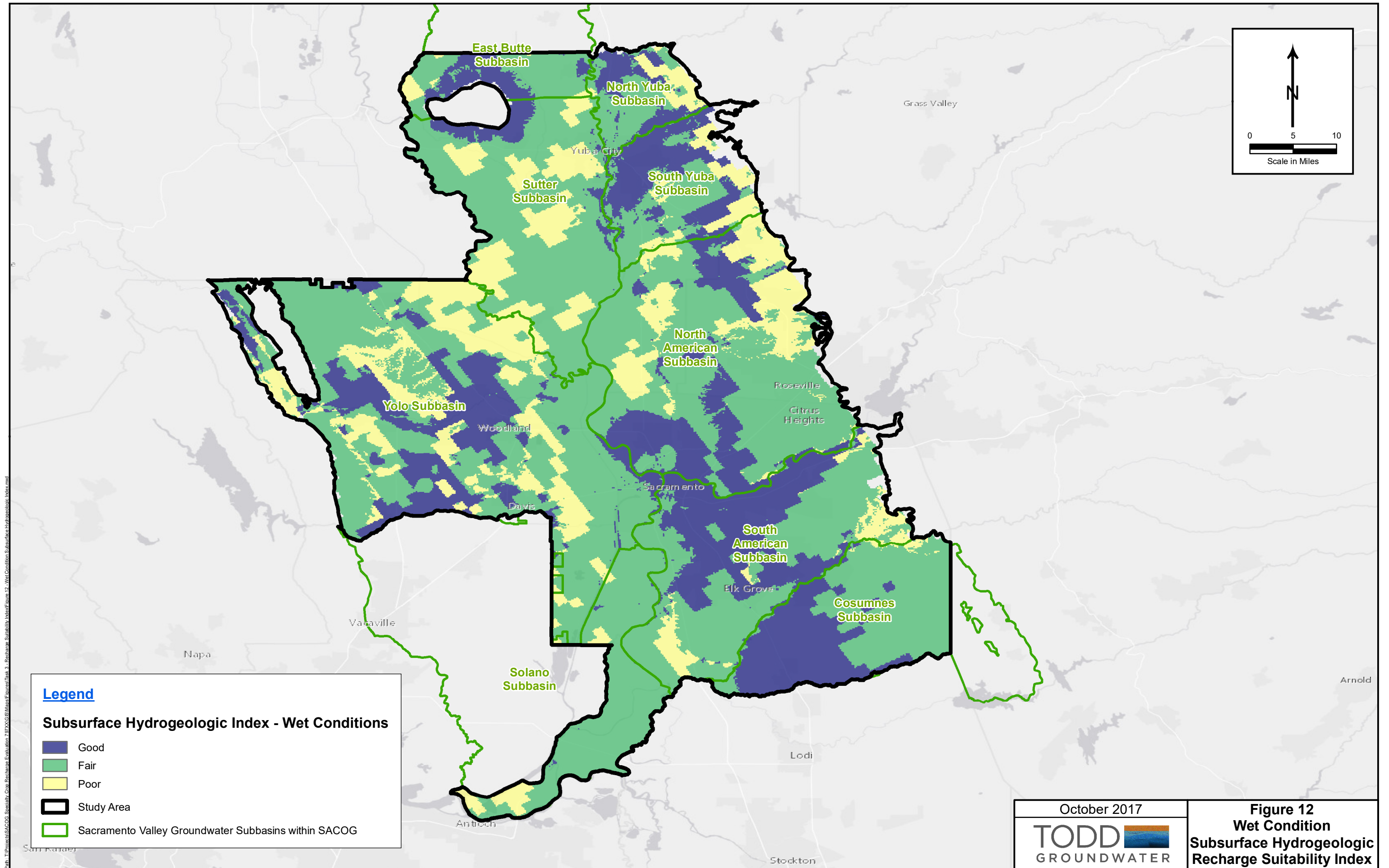




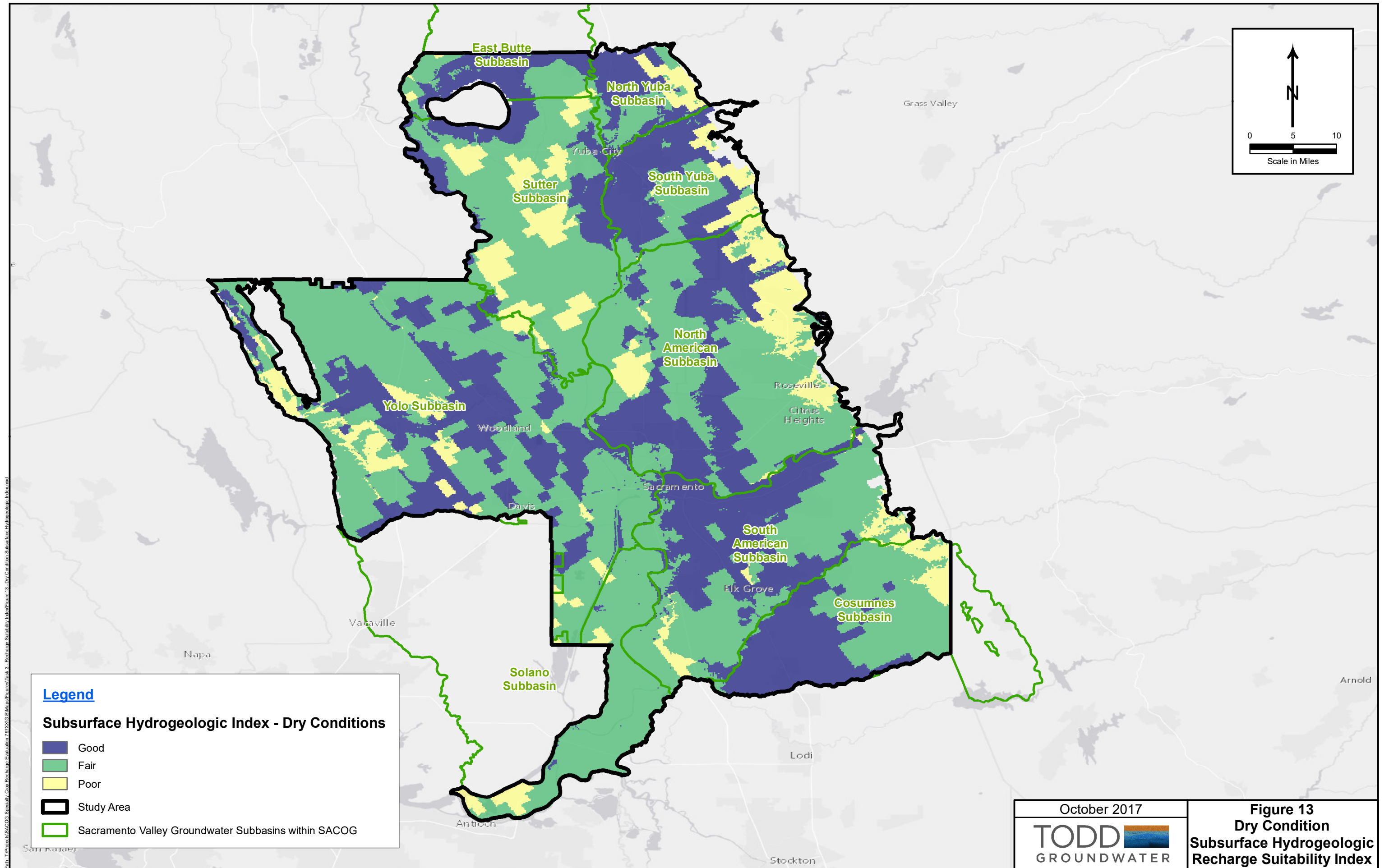








Path: T:\Projects\SACOG_Specialty_Cons_Recharge_Evaluation_787X\GIS\Maps\Figures\Figure 12 - Wet Condition Subsurface Hydrogeologic Index.mxd



Path: T:\Projects\SACOG_Specialty_Corp_Recharge_Evaluation_787X\GIS\Maps\Figures\Figure 13 - Dry Condition Subsurface Hydrogeologic Index.mxd

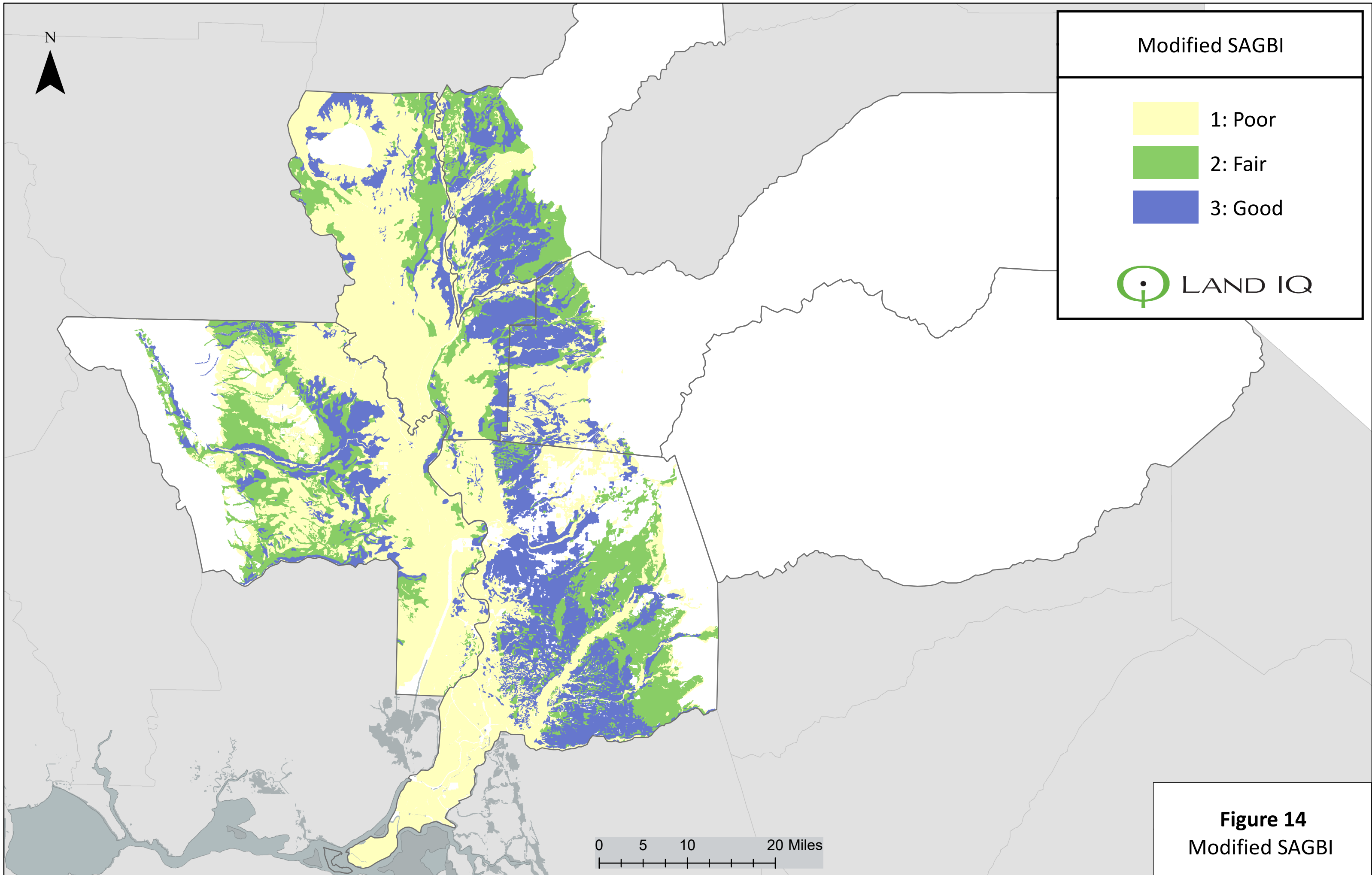
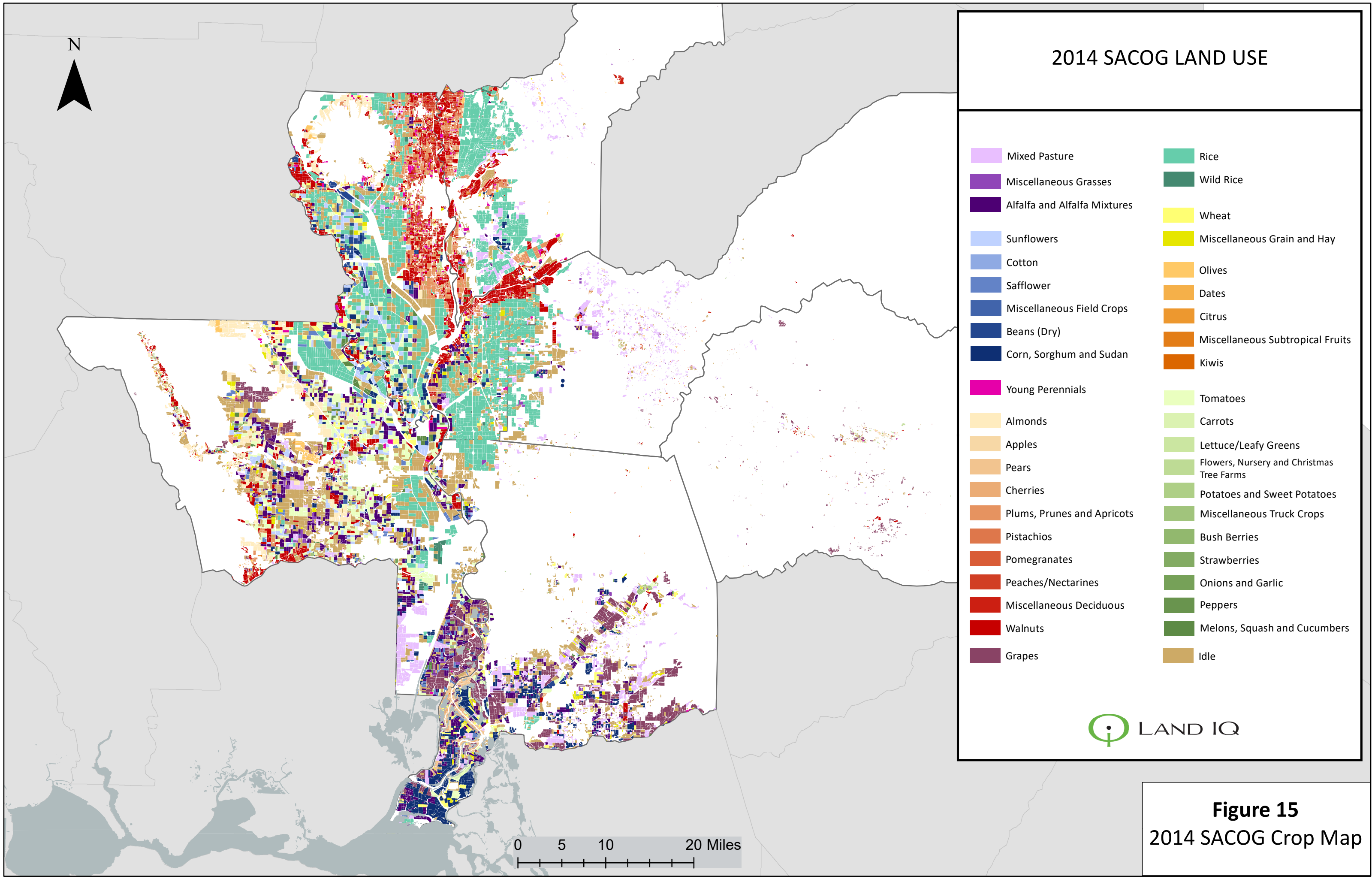
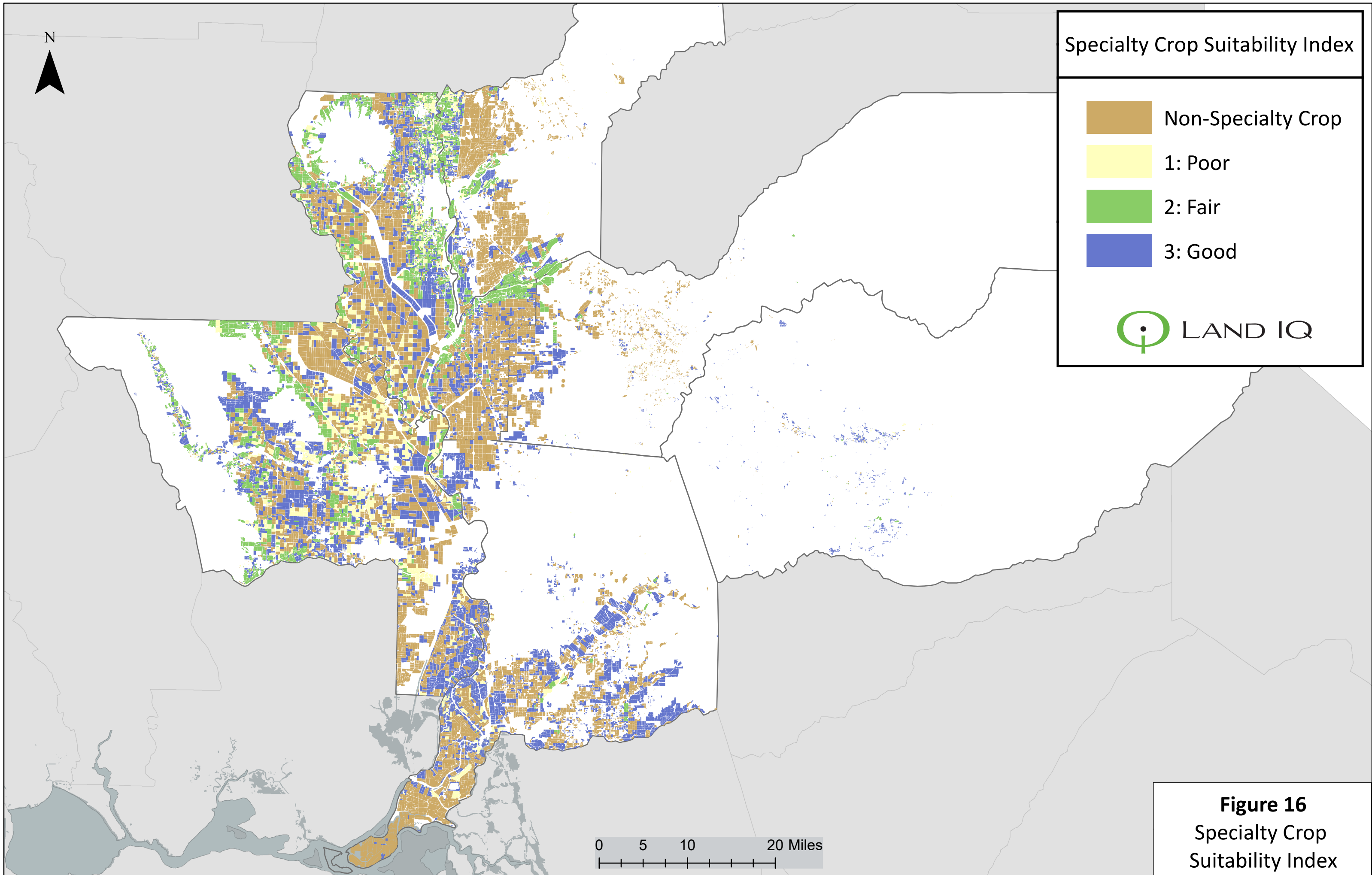
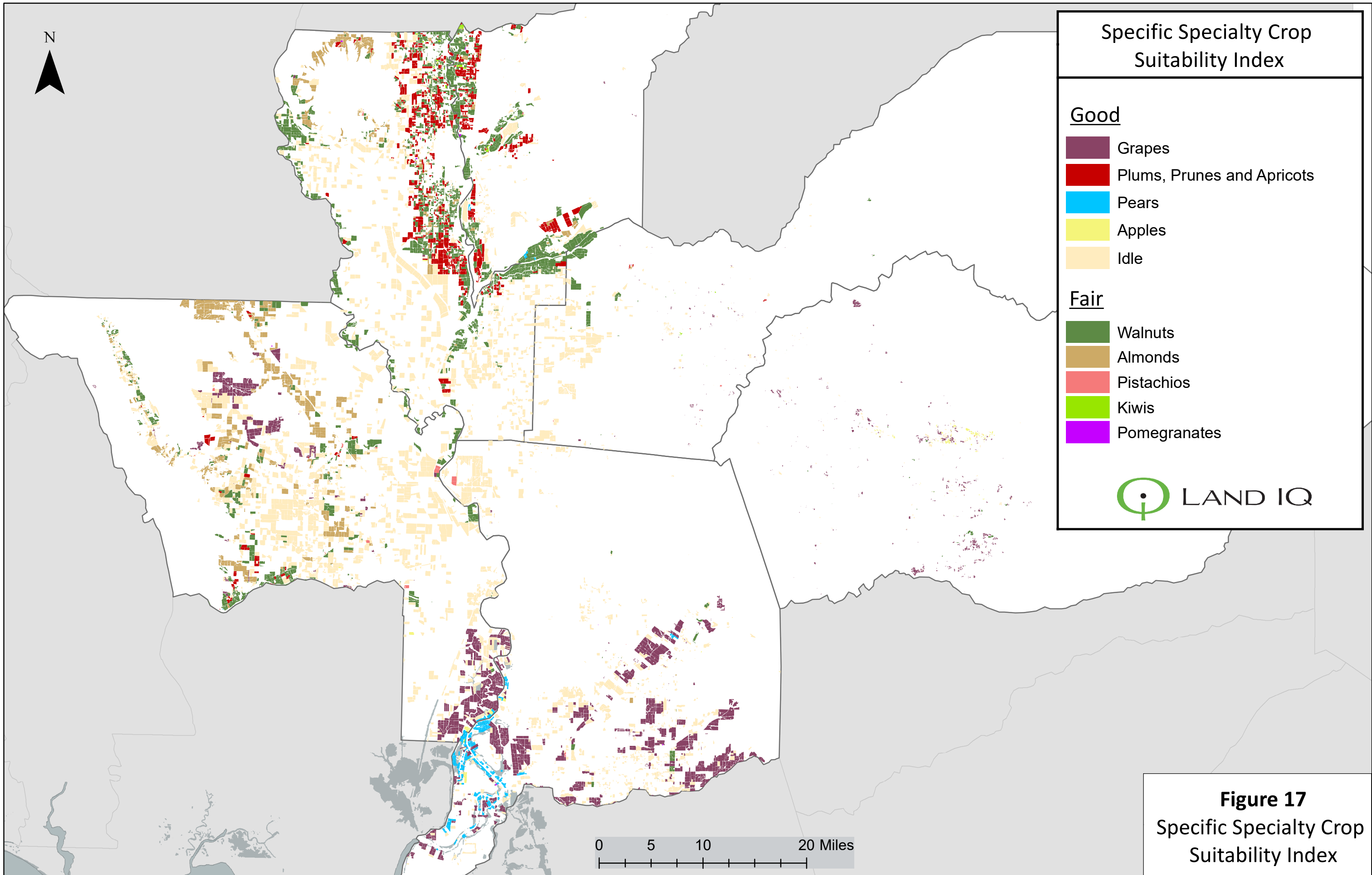
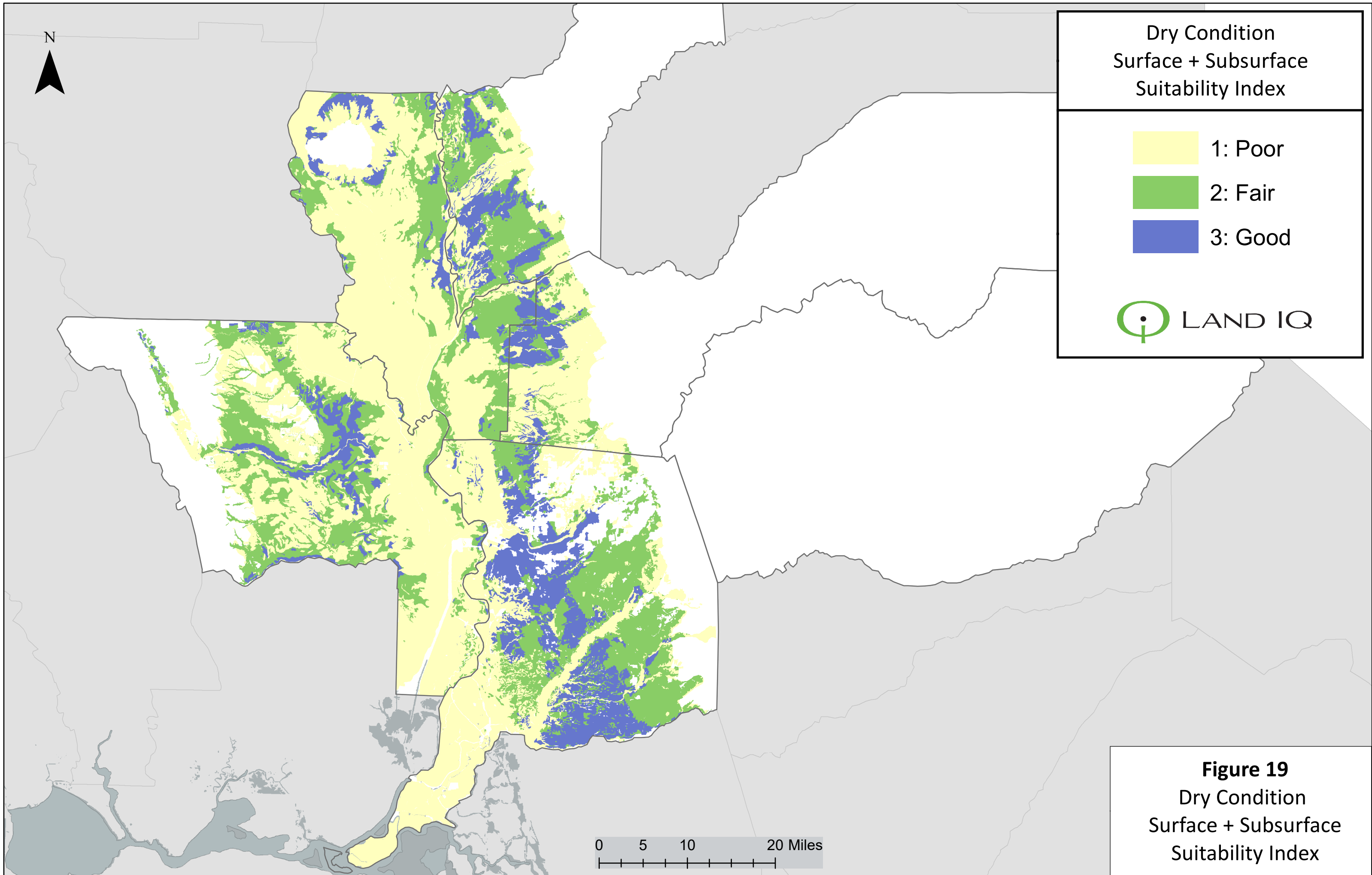


Figure 14
Modified SAGBI









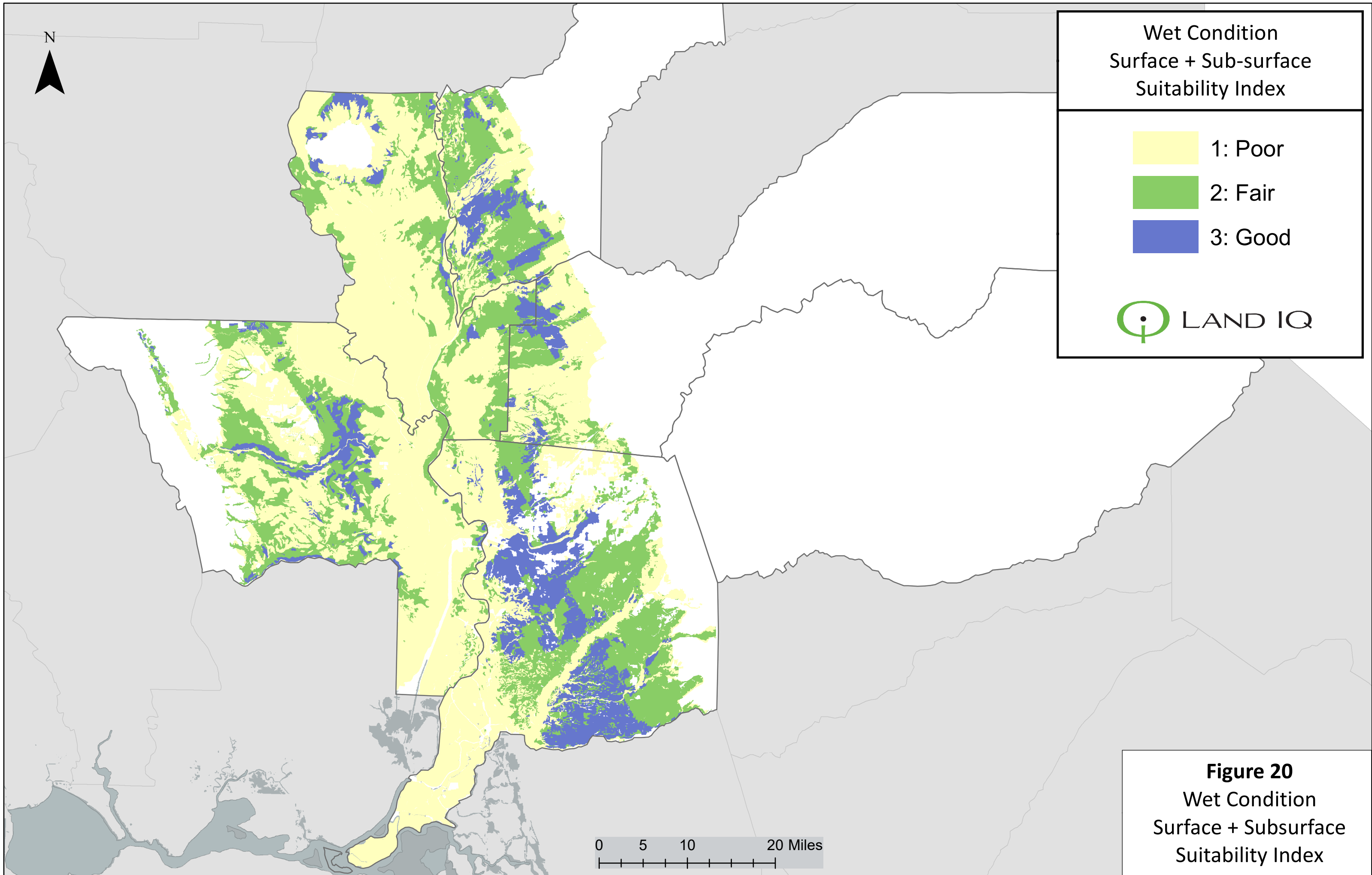
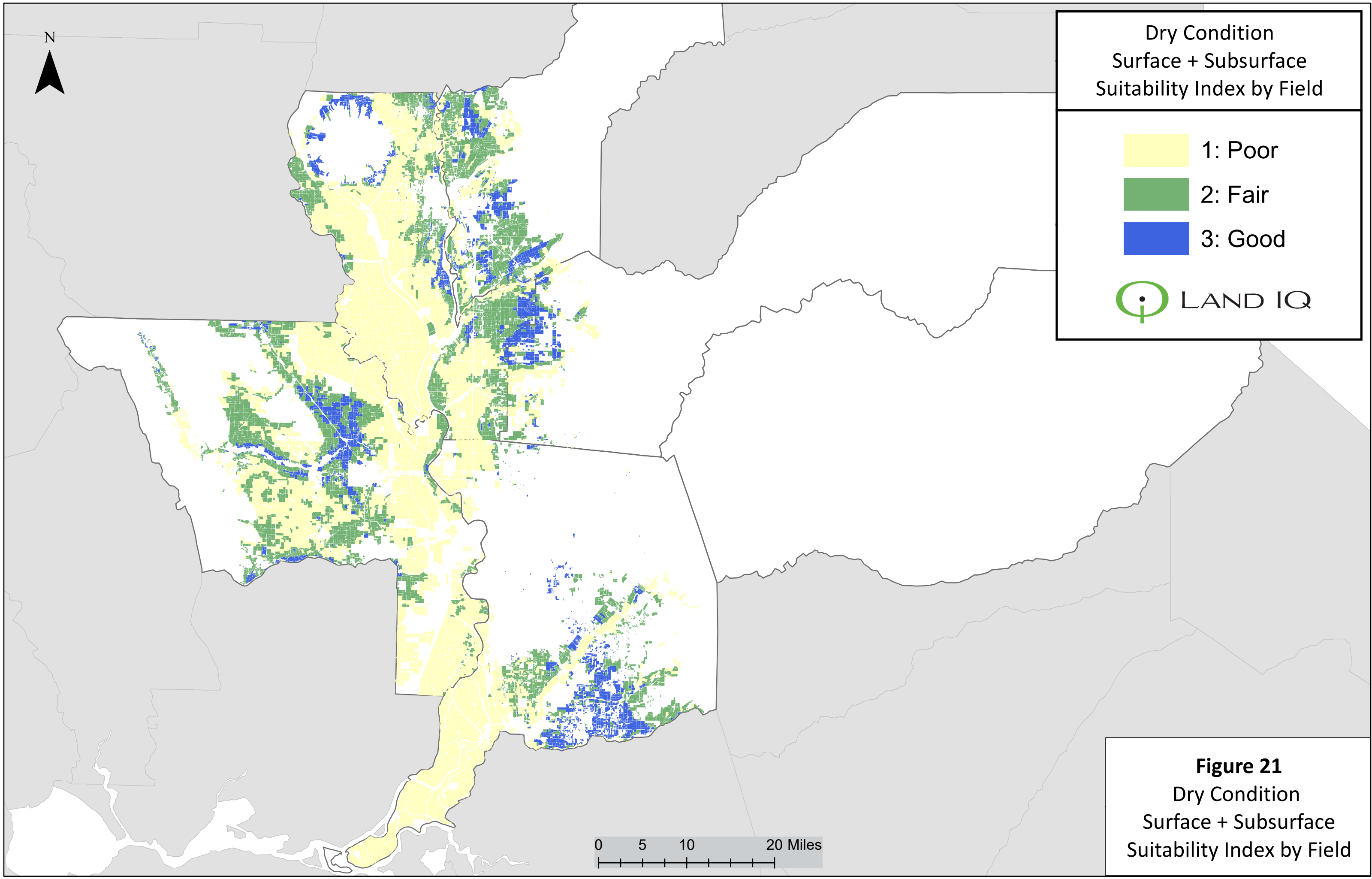
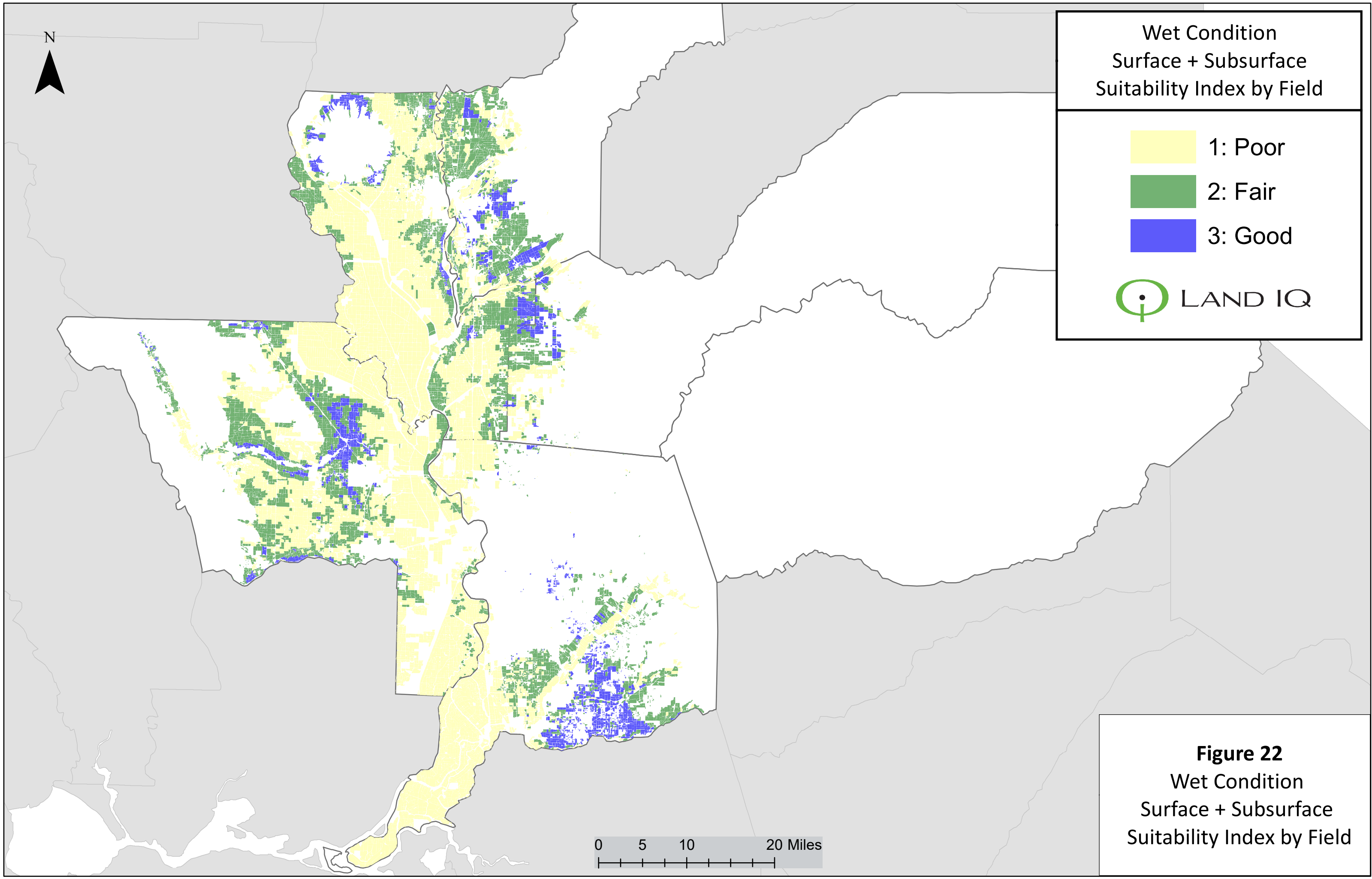
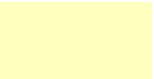


Figure 20
Wet Condition
Surface + Subsurface
Suitability Index





Wet Condition
Surface + Subsurface
Suitability Index by Field

	1: Poor
	2: Fair
	3: Good

 LAND IQ

Figure 22
Wet Condition
Surface + Subsurface
Suitability Index by Field

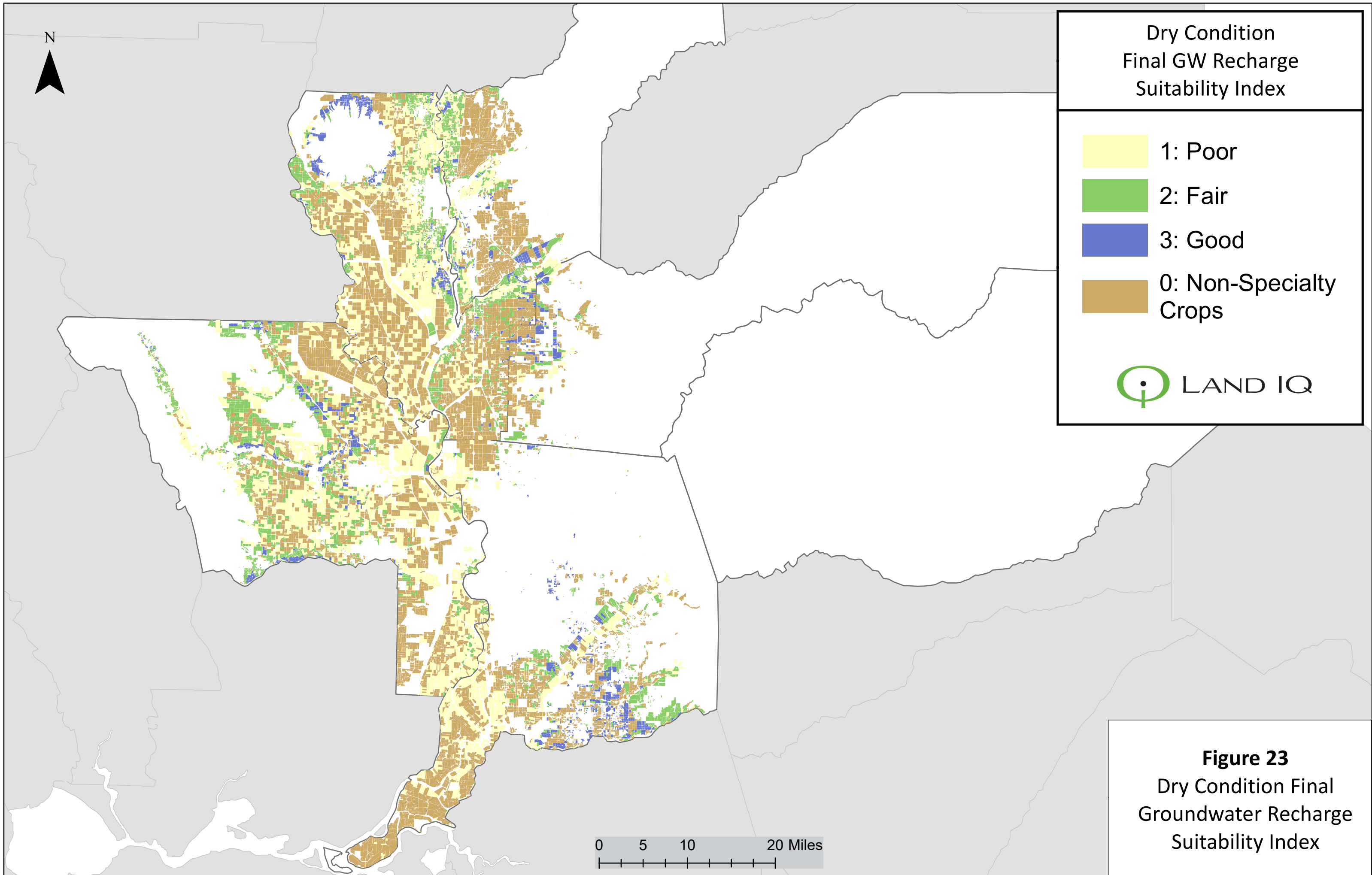
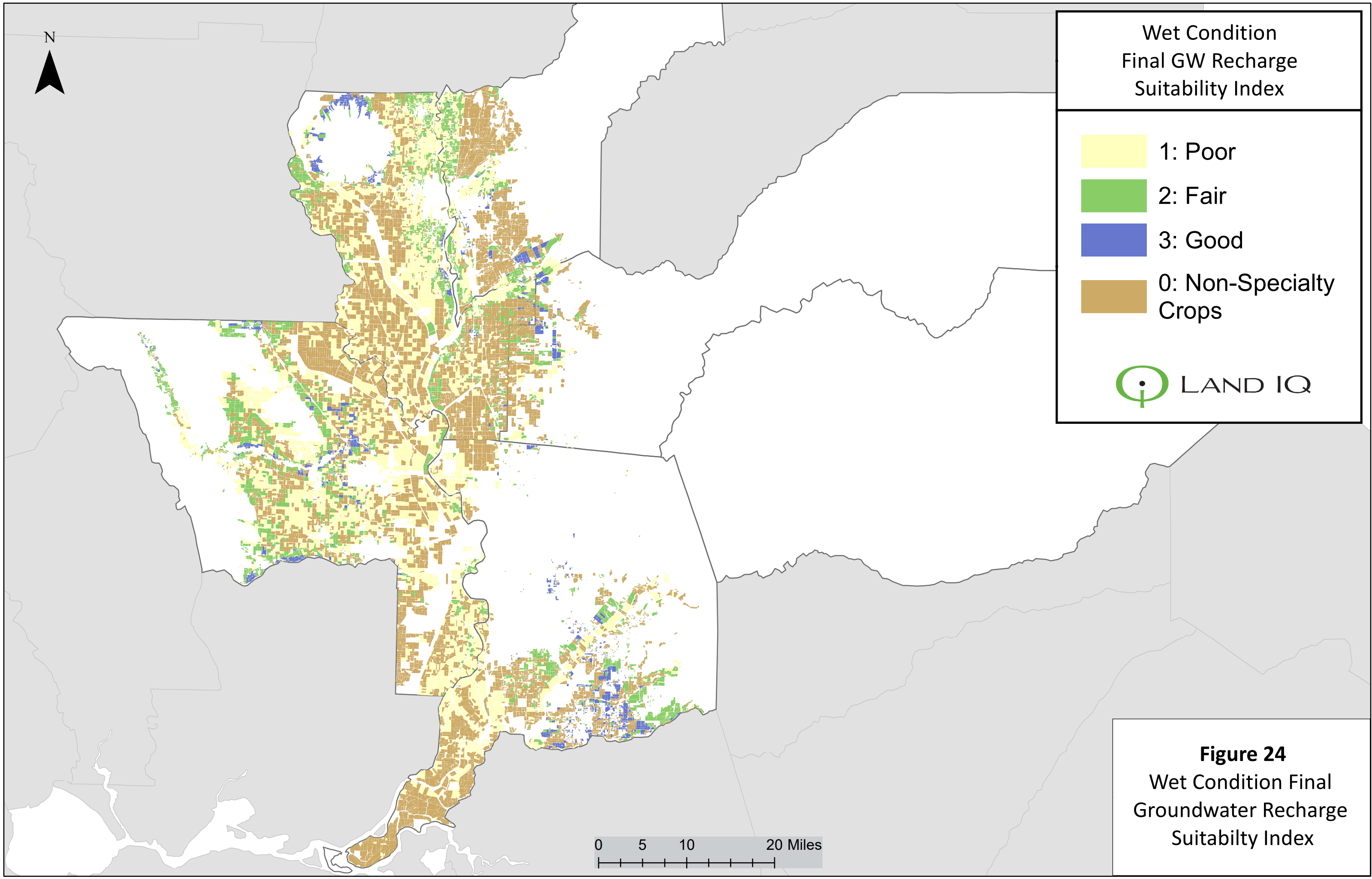


Figure 23
Dry Condition Final
Groundwater Recharge
Suitability Index



APPENDIX A

FLOWCHART - GROUNDWATER RECHARGE SUITABILITY INDEX

Groundwater Recharge Suitability Index

Hydrogeologic Sub-Surface

Horizontal Hydraulic Conductivity

- < 75 ft/day – **1 (poor)**
- 75 – 300 ft/day – **2 (fair)**
- > 300 ft/day – **3 (good)**

Figure 5

Combine horizontal and vertical hydraulic conductivity grids

Vertical Hydraulic Conductivity

- < 0.01 ft/day – **1 (poor)**
- 0.01 – 0.03 ft/day – **2 (fair)**
- > 0.03 ft/day – **3 (good)**

Figure 6

Horizontal Hydr. Cond.	Initial Grid Values	Vertical Hydr. Cond.		
		1	2	3
		--Combined Grid Values*--		
1	1	1	2	3
2	1	1	2	3
3	1	1	2	3

*Vertical hydr. cond. grid weighted/multiplied by 3, then added to horizontal grid value. The combined grid values ranging from 4-12 were assigned values of: 1-poor (4-6); 2-fair (7-9); and 3-good (10-12).

Figure 7

Combine conductivity and DTW grids

Depth to Groundwater (DTW)

- < 20 ft – **1 (poor)**
- 20 – 80 ft – **2 (fair)**
- > 80 ft – **3 (good)**

Figure 10

Dry Condition: uses dry season (fall 2016) DTW

Figure 11

Wet Condition: uses wet season (spring 2012) DTW

Combined Hydr. Cond.	Initial Grid Values	DTW		
		1	2	3
		--Combined Grid Values*--		
1	1	1	1	2
2	1	1	2	3
3	2	3	3	3

*DTW and hydr. cond. grids added together then divided by two (averaged). The combined grid values were assigned values of: 3-good (2.5-3); 2-fair (2); and 1-poor (1-1.5).

Figure 13

Wet Condition

Combine sub-surface and surface grids

Sub-Surface	Initial Grid Values	Modified SAGBI		
		1	2	3
		--Combined Grid Values--		
1	1	1	1	1
2	1	1	2	2
3	1	1	2	3

Figure 19

Dry Condition

Figure 20

Wet Condition

Grid to Polygon Conversion: Surface and sub-surface combined grid is spatially averaged by field, then the resulting values split in 3 increments

- $1 \leq 1.5$: **1 – Poor**
- $>1.5 \leq 2.5$: **2 – Fair**
- $> 2.5 - 3$: **3 – Good**

Figure 21

Dry Condition

Figure 23

Dry Condition Final Recharge Suitability Index

Figure 22

Wet Condition

Combined Surface and Sub-surface	Values	Crop Suitability		
		1	2	3
		--Final Index Values*--		
1	1	1	1	1
2	1	1	2	2
3	1	3	3	3

* Fields with non-specialty crops assigned 0 integer value and fields outside the extent of hydrogeologic data coverage assigned 9 integer value

Figure 24

Wet Condition Final Recharge Suitability Index

Surface Soil

Modified SAGBI*	Reclassified Modified SAGBI
6 – Excellent	3 - Good
5 – Good	
4 – Moderately Good	2 - Fair
3 – Moderately Poor	
2 – Poor	1 - Poor
1 – Very Poor	

* Assumes soil is modified by deep tillage

Figure 14

Specialty Crop Suitability

Specialty Crops Grown in SACOG Region	Value
Carrots Cherry Citrus Dates Garlic Lettuce Nursery Olives Onion Peach/Nectarine Peppers Potato Strawberry Sweet Potato Tomato	1 - Poor
Almond Beans (dry) Bush Berry Kiwi Pistachio Pomegranate Walnut	
Apple Apricot Cucumber Idle (Fallow)* Melon Pear Plum/Prune Squash Wine Grape	
	2 – Fair
	3 - Good

* Idle is not a specialty crop, but has potential for specialty crops to be established

Figures 15 - 17

Field recharge suitability assigned based on crop suitability and the combined surface and sub-surface index value

Surface Water Availability

Information is provided in the Task 2 Report on availability of surface water for irrigation districts within the SACOG region. Several districts did not have information available; thus, this factor was not incorporated into the final recharge suitability index.

APPENDIX B

SPECIALTY CROP RECHARGE SUITABILITY

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
Annuals								
Beans (Dry)	2116 lbs/acre	CDFA	--	N/A - recharge would occur during fallow period		--		0 - 125
Carrots	315 cwt/acre	CDFA	--	N/A - recharge would occur during fallow period		--		150
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
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
Onions and Garlic	garlic - 169 cwt/acre onion - 400-600 cwt/acre	CDFA	--	N/A - recharge would occur during fallow period		--		100-200
Peppers	415	CDFA	--	N/A - recharge would occur during fallow period		--		200
Potatoes and Sweet Potatoes	potatoes- 402 cwt/acre sweet potato-325 cwt/acre	CDFA	--	N/A - recharge would occur during fallow period		--		160-240
Strawberries	650 cwt/acre	CDFA	--	N/A - recharge would occur during fallow period		--		158
Tomatoes	processing - 44.8 tons/acre	CDFA	--	N/A - recharge would occur during fallow period		--		150 - 175
Perennials								
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	
			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	
			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 sensstive of <i>Prunus</i> species to flooded soil conditions		Schaffer et al., 1992 ³	0-40	
Bush Berries	197 cwt/acre	CDFA	--	Unknown		--	0.25 lbs N/plant/yr	
Cherries	2.53 tons/acre	CDFA	--	up to 48 hrs	no tolerance	O'Geen et al., 2015 ²	60	
Citrus	orange-608 cartons/acre	CDFA	--	no tolerance	no tolerance	O'Geen et al., 2015 ²	100	
Dates	3.6 cwt/acre	CDFA	Unknown	Unknown	Unknown	--	50-245	
Kiwis	6.88 tons/acre	CDFA	Unknown	Unknown	Unknown	--	150	
Olives	3.2 tons/acre	CDFA	--	Unknown	Unknown	O'Geen et al., 2015 ²	40-100	
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	
Pears	17.2 tons/acre	CDFA	<i>P. betulaefolia</i>	> 2 weeks	> 2 weeks	O'Geen et al., 2015 ²	120-150	
			<i>P. communis</i>	> 2 weeks	2 weeks	O'Geen et al., 2015 ²		
			<i>Cydonia oblonga</i>	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	
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	
	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	
Walnuts	1.81 tons/acre	CDFA	--	1 - 2 weeks	up to 48 hrs	O'Geen et al., 2015 ²	86-214	
Wine Grapes	6.83 tons/acre	CDFA	--	> 2 weeks	1 week	O'Geen et al., 2015 ²	0 - 40	
Fallow								
Idle	N/A	N/A	N/A	N/A	N/A	N/A	N/A	

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 data from several studies

⁴ <http://ucanr.edu/sites/Pomegranates/files/164437.pdf>

⁵ N recommendations vary based on yield goals and perennial crop age

⁶ <http://ucanr.edu/repository/cao/landingpage.cfm?article=ca.v070n01p9&fulltext=yes>

⁷ http://www.raintreenursery.com/Chill_Hours.html

⁸ <http://www.cultivatetoplate.com/what-are-chilling-hours-and-why-are-they-important/>

Crop	Source	Chill Hours	Source	Annual Crop Notes	Crop Suitability Ranking
Annuals					
Beans (Dry)	CDFA-FREP	N/A	N/A	seeds beds prepared in winter	2-Fair
Carrots	CDFA-FREP	N/A	N/A	fallow during summer	1-Poor
Flowers, Nursery and Christmas Tree Farms	--	N/A	N/A	variable fallow period and field prep	1-Poor
Lettuce/Leafy Greens	CDFA-FREP	N/A	N/A	fallow during summer	1-Poor
Melons, Squash, and Cucumbers	UC	N/A	N/A	fields typically level - no beds	3-Good
Onions and Garlic	CDFA-FREP	N/A	N/A	fallow during summer	1-Poor
Peppers	UC	N/A	N/A	seeds beds prepared in winter	1-Poor
Potatoes and Sweet Potatoes	CDFA-FREP	N/A	N/A	seed beds prepared in winter potatoes fallow during summer	1-Poor
Strawberries	UC	N/A	N/A	fields need prep in winter	1-Poor
Tomatoes	CDFA-FREP	N/A	N/A	seed beds prepared in winter	1-Poor
Perennials					
Almonds	CDFA-FREP	400-700 ⁶	UCANR ⁶	N/A	2-Fair
Apples	CDFA-FREP	300-1,200	Nursery ⁷	N/A	3-Good
Apricots	UCANR	350-1,000	UCANR ⁶	N/A	3-Good
Bush Berries	UC	blackberry - 200-500 raspberry- 700-800	Nursery ⁷	N/A	2-Fair
Cherries	O'Geen et al., 2015	600-1,400	UCANR ⁶	N/A	1-Poor
Citrus	O'Geen et al., 2015	0	CALSCE ⁸	N/A	1-Poor
Dates	UC	0	CALSCE ⁸	N/A	1-Poor
Kiwis	UC	400-800	UCANR ⁶	N/A	2-Fair
Olives	CDFA-FREP	0	CALSCE ⁸	N/A	1-Poor
Peach/Nectarines	CDFA-FREP	200-1,200	UCANR ⁶	N/A	1-Poor
Pears	CDFA-FREP	600-1,500	UCANR ⁶	N/A	3-Good
Pistachios	CDFA-FREP	800-1,000	UCANR ⁶	N/A	2-Fair
Plums/prunes	CDFA-FREP	700-1,800	UCANR ⁶	N/A	3-Good
Pomegranate	O'Geen et al., 2015	100-200	Nursery ⁷	N/A	2-Fair
Walnuts	CDFA-FREP	400-1,500	UCANR ⁶	N/A	2-Fair
Wine Grapes	CDFA-FREP	100-500	UCANR ⁶	N/A	3-Good
Fallow					
Idle	N/A	N/A	N/A	N/A	3-Good

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 data from several studies

⁴ <http://ucanr.edu/sites/Pomegranates/files/164437.pdf>

⁵ N recommendations vary based on yield goals and perennial crop age

⁶ <http://ucanr.edu/repository/cao/landingpage.cfm?article=ca.v070n01p9&fulltext=yes>

⁷ http://www.raintreenursery.com/Chill_Hours.html

⁸ <http://www.cultivatetoplate.com/what-are-chilling-hours-and-why-are-they-important/>