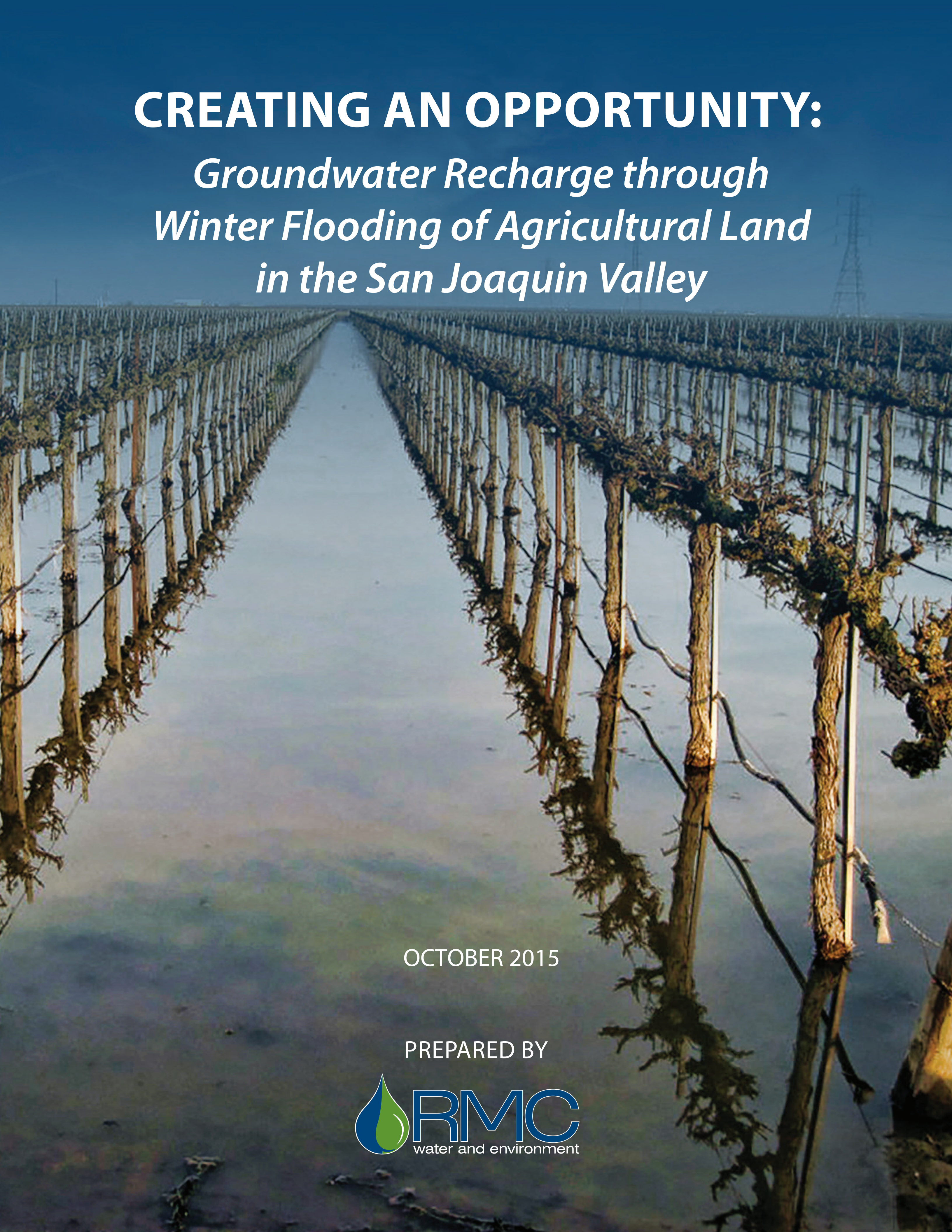
CREATING AN OPPORTUNITY:

Groundwater Recharge through Winter Flooding of Agricultural Land in the San Joaquin Valley



OCTOBER 2015

PREPARED BY

RMC
water and environment

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RMC Project Team

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Abstract

As California completes a fourth year of drought, groundwater levels have continued to decline significantly in many groundwater basins throughout the state. This condition highlights the need for increasing groundwater recharge opportunities during wet periods to support strategies for moving towards sustainable groundwater management. Given the cost and limited availability of suitable lands to dedicate for effective recharge basins and infrequent excess water availability for recharge in the San Joaquin Valley, new ideas have risen to use agricultural lands for recharging excess winter water.

This study evaluates the potential benefits of recharging groundwater through flooding of agricultural lands using excess winter river flows, focusing on a portion of the east side of the San Joaquin Valley in Merced, Madera, and Fresno counties. While the excess winter flows are not available every year, an average of 80,000 to 130,000 Acre-Feet Per Year (AF/year) can be diverted through the existing available capacities in the diversion turn-outs, conveyance, and distribution canals for delivery to farms. The recharge program benefits three major components of the hydrologic system in San Joaquin Valley: (i) Approximately 40% of recharge water would directly increase regional groundwater storage in the project area, (ii) approximately 43% of recharge water benefits streamflows by increasing the baseflows, and (iii) approximately 17% of recharge water benefits groundwater storage in areas outside the project area, but in the San Joaquin Valley.

The winter recharge water benefits groundwater storage in the project area by approximately 31,000 to 52,000 AF/year, with the balance of recharge benefiting the surface water system and groundwater basins adjacent to the recharge area. Due to variations in the hydrologic and hydrogelogic conditions across the three counties, the benefits to local groundwater storage are not uniform, with a higher percentage of the recharge contributing to the groundwater replenishment in the southern portion of the project area. When compared to the approximate estimated annual overdraft of 250,000 AF/year in the same area, the proposed recharge method would reduce overdraft by 12% to 20%. Given the low cost of implementation of such a recharge effort, this is a very efficient manner of helping the sustainability of groundwater in the project area.

Expansion of such an approach across a broader geographic area, including excess winter flows from other major watersheds in the valley, such as the San Joaquin, Tuolumne and Stanislaus rivers, would provide significant contribution towards addressing the estimated annual overdraft of 1,200,000 AF/year in the San Joaquin Valley and achieving sustainable groundwater management.

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Acronyms and Abbreviations

AF	acre-feet
AID	Alta Irrigation District
Baseline	Existing Conditions Baseline
C2VSim	California Central Valley Groundwater-Surface Water Simulation Model
cfs	cubic feet per second
CID	Consolidated Irrigation District
CVP	Central Valley Project
DSA	depletion study areas
DWR	California Department of Water Resources
FERC	Federal Energy Commission
FID	Fresno Irrigation District
ft	feet
GIS	geographic information system
GUI	graphical user interface
KRCD	Kings River Conservation District
KRWA	Kings River Water Association
MCL	maximum contaminant level
mg/l	micrograms per liter
NRCS	Natural Resources Conservation Service
SGMA	Sustainable Groundwater Management Act
SMCL	secondary maximum contaminant level
TAF	thousand acre-feet
TDS	total dissolved solids
UCD	University of California at Davis
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey

1. Introduction

Groundwater is a vital resource for California's urban, rural, and agricultural water users, and for the health of many of the state's natural habitats and ecosystems. In an average year, groundwater meets about 40% of the state's water demand and up to 60% or more during droughts (DWR, 2014). In some basins, groundwater provides 100% of the supply, especially during droughts, when groundwater provides a buffer against economic and environmental harm from water scarcity.

California's growing reliance on groundwater has resulted in a number of adverse consequences, including reduction in the amount of groundwater in storage, saltwater intrusion or other water quality degradation, increased energy costs due to pumping from greater depths, facilities costs such as well deepening or replacement, streamflow depletion, environmental degradation, and land subsidence.

Such consequences increase the impact of drought. In a May 2014 publication, University of California, Davis (UCD) researchers have estimated that the current drought has resulted in a $738 million reduction in gross farm revenue, as well as regional value-added losses of $856 million (Howitt, Medellin-Azuara, Lund, & MacEwan, 2014). And, climate change has been shown to substantially increase the overall likelihood of extreme California droughts (Williams, et al., 2015).

As California completes a fourth year of drought, the California Department of Water Resources (2014) noted that:

- Based on well completion reports received from January 2014 through September 2014, more than 350 new water supply wells are reported in Fresno and Tulare counties, and more than 200 water supply wells are reported in Merced County. More than 100 new water supply wells are reported in Butte, Kern, Kings, Shasta, and Stanislaus counties.
- Groundwater levels have decreased in many basins throughout the state from spring 2013 through fall 2014, and more notably since spring 2010. Basins with notable decreases in groundwater levels are in the Sacramento River, San Joaquin River, Tulare Lake, San Francisco Bay, Central Coast, and South Coast hydrologic regions.
- Subsidence is occurring in many groundwater basins in the state, especially in the southern San Joaquin River and Tulare Lake hydrologic regions. Due to ongoing decline of groundwater levels, areas with a higher potential for future subsidence are in the southern San Joaquin, Antelope, Coachella, and western Sacramento valleys.
- A multi-agency research project led by NASA estimated that peak summer acreage of Central Valley land idled (due to drought impacts, normal agronomic practices, crop markets, etc.) in 2014 was 1.7 million acres, almost 700,000 acres more than in 2011, a recent wet year.

The state legislature has also recognized the major issues related to the current use of groundwater through the passage of the Sustainable Groundwater Management Act (SGMA), signed by Governor Edmund G. Brown, Jr. on September 16, 2014 which included the provisions of Senate Bill (SB) 1168, Assembly Bill (AB) 1739, and SB 1319. The SGMA requires the formation of locally-controlled Groundwater Sustainability Agencies which must develop Groundwater Sustainability Plans to achieve sustainable groundwater conditions in groundwater basins or subbasins that DWR designates as medium or high priority. The legislative intent of the SGMA is to achieve all of the following:

- To provide for the sustainable management of groundwater basins.
- To enhance local management of groundwater consistent with 1) rights to use or store groundwater and 2) Section 2 of Article X of the California Constitution.
- To establish minimum standards for sustainable groundwater management.
- To provide local groundwater agencies with the authority and the technical and financial assistance necessary to sustainably manage groundwater.
- To avoid or minimize subsidence.
- To improve data collection and understanding about groundwater.
- To increase groundwater storage and remove impediments to recharge.
- To manage groundwater basins through the actions of local governmental agencies to the greatest extent feasible, while minimizing state intervention.

Increasing recharge to the aquifer system will be a critical water management strategy in many regions. Groundwater recharge is practiced in many areas of California, through direct recharge or in-lieu recharge. Direct recharge includes the spreading of surface water or recycled water in recharge basins and direct injection of water into the aquifer. In-lieu recharge involves the delivery of surface water or recycled water that reduces the extraction of groundwater. These methods often involve significant dedicated infrastructure and can be costly.

Another opportunity for groundwater recharge is the practice of recharging groundwater through on-farm capture of excess winter flows. The concept is to divert excess flows onto large acreages of active agricultural land for direct recharge of the groundwater basin. Water would be applied during the non-irrigation season, in excess of dormant-period evapotranspiration needs to allow downward percolation into the aquifer system. This report presents the results of a study on the potential benefits of this practice in a portion of the San Joaquin Valley.

This study evaluates two winter time scenarios: a short interval from December to February (Winter) and an extended interval from November to March (Extended Winter). The study estimated the availability of winter surface water supplies in excess of existing demands, assessed the capacity of existing water delivery infrastructure to carry excess water to cropland, and considered crop compatibility with flooding active farmland and land suitability for recharge to the aquifer system. By utilizing agricultural lands and existing infrastructure facilities to divert and convey water to these lands, implementation and operation costs would be small, significantly lower than construction and operation of other artificial recharge methods, allowing for cost-effective recharge of large volumes of infrequently available water. The results of this study include estimates of the potential volume of water that could be recharged through on-farm capture of excess winter flows during the two winter intervals, as well as details on which crops are most compatible with this practice.

1.1 Project Area

The project area for this effort is a portion of the San Joaquin Valley within Merced, Madera, and Fresno counties on the east side of the valley. Figure 1 shows the location of the project area, which has been defined based on the reporting units in the California Central Valley Groundwater-Surface Water Simulation Model (C2VSim), to simulate and report surface water and groundwater under potential project conditions (see Section 3). The project area includes five groundwater subbasins within the San Joaquin Valley Basin, as defined by the California Department of Water Resources (DWR) Bulletin 118: Merced, Chowchilla, Madera, and Kings Subbasins (DWR, 2003).

The project area includes over 50 water purveyors (Figure 3), although approximately 40% of the land is covered by five irrigation districts: Merced Irrigation District, Madera Irrigation District, Fresno Irrigation District, Consolidated Irrigation District, and Alta Irrigation District. Approximately 40% of the project area is not organized within a water district.

1.1 Key Assumptions

Several key assumptions regarding grower participation, water rights, infrastructure capacity, and use of recharged water were necessary to estimate the potential recharge resulting from on-farm capture of flood waters.

Grower Participation

Groundwater recharge through winter flooding of agricultural land will require the voluntary participation of growers and water purveyors. The purpose of the regional study was to provide a preliminary estimate of a feasible volume of groundwater recharge from on-farm capture of excess winter flows. Therefore, it was not possible to identify willing participants. The general areas identified in this study for groundwater recharge through winter flooding of agricultural land are conceptual and are not intended to identify specific land parcels, rather general areas that are suitable for winter flooding. It is not currently known which growers may ultimately agree to participate in such a program.

Water Rights

A water rights analysis of available recharge water was beyond the scope of this study. Therefore, an assumption was made that excess flows (see Sections 3 and 4.3) are available for diversion and use by the water purveyors. The effort was limited to water used within the service area of existing water rights holders, diverted at existing diversions, and applied in areas currently receiving surface water.

Infrastructure

A general evaluation of existing conveyance and distribution facilities was made for this study to identify the capacity to convey the recharge water. It is assumed that no new conveyance and/or distribution facilities (beyond field-level work necessary to pond and infiltrate water) would be needed. There may be locations where infrastructure could be expanded to meet multiple benefits, including groundwater recharge through winter flooding of agricultural land, but such expansions were not evaluated in this effort.

Additionally, it was assumed that existing infrastructure was generally available for conveying wintertime flows. It is possible that maintenance needs, flood protection needs, or staffing limitations would reduce or prevent the usage of some existing infrastructure for conveying wintertime flows.

Use of Recharged Water

The analysis did not include the recovery and use of the recharged water. The applied water was assumed to recharge the aquifer for future uses in the region. This is consistent with the operation of spreading basins in the region; these spreading basins recharge the groundwater system through ponding and percolating surface water in dedicated facilities generally for the benefit of regional groundwater users.

Figure 1: Project Area

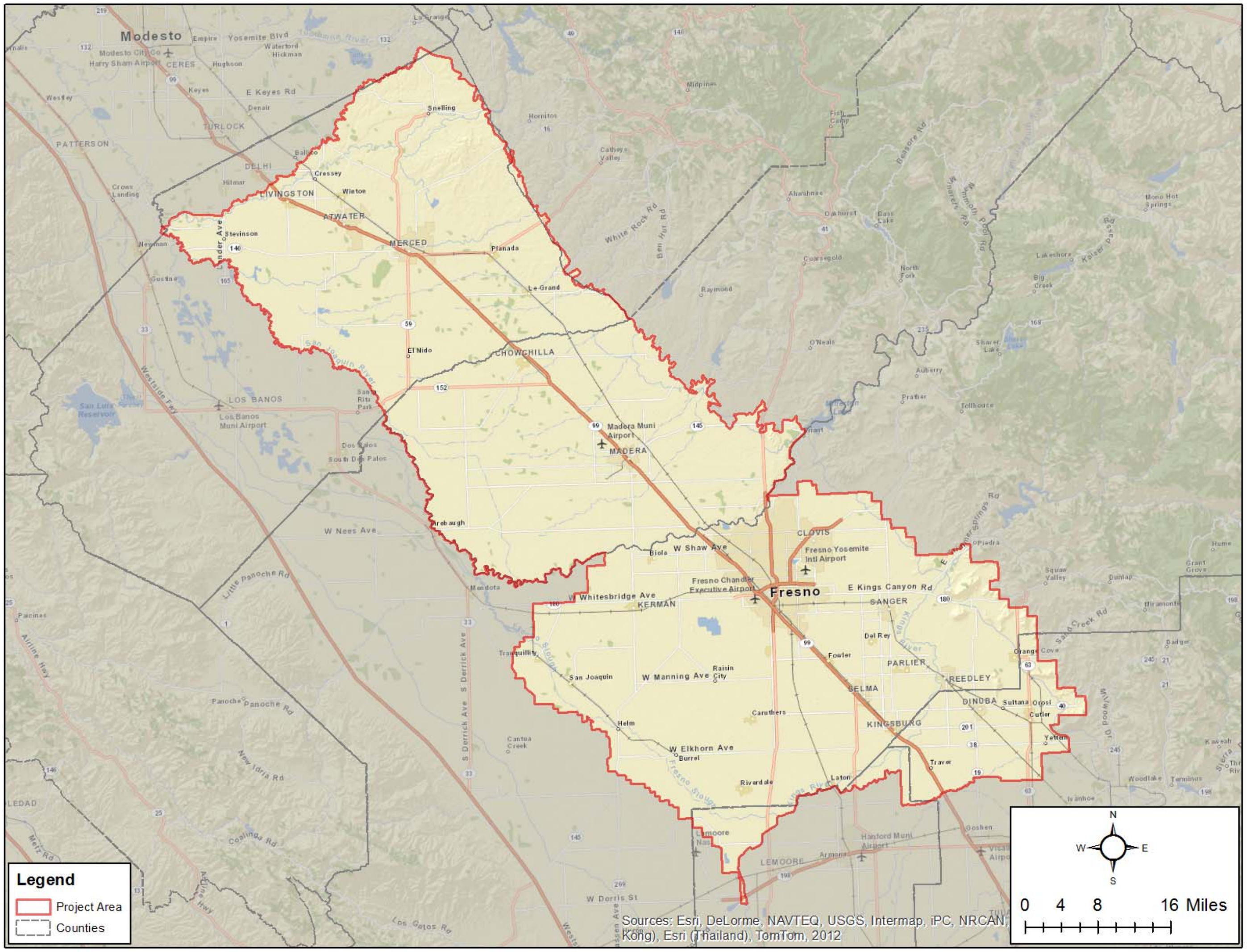


Figure 2: Groundwater Subbasins within the Project Area

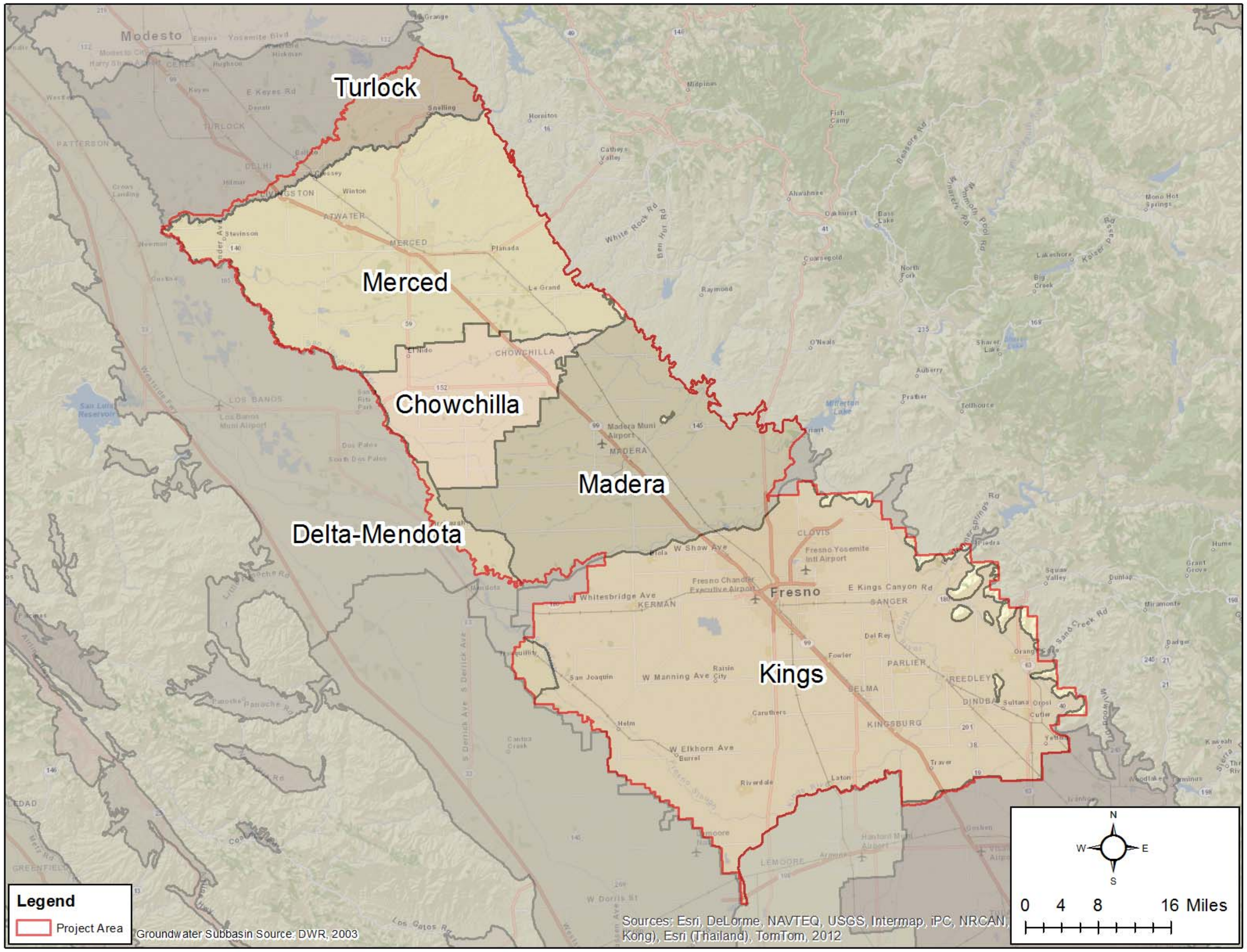
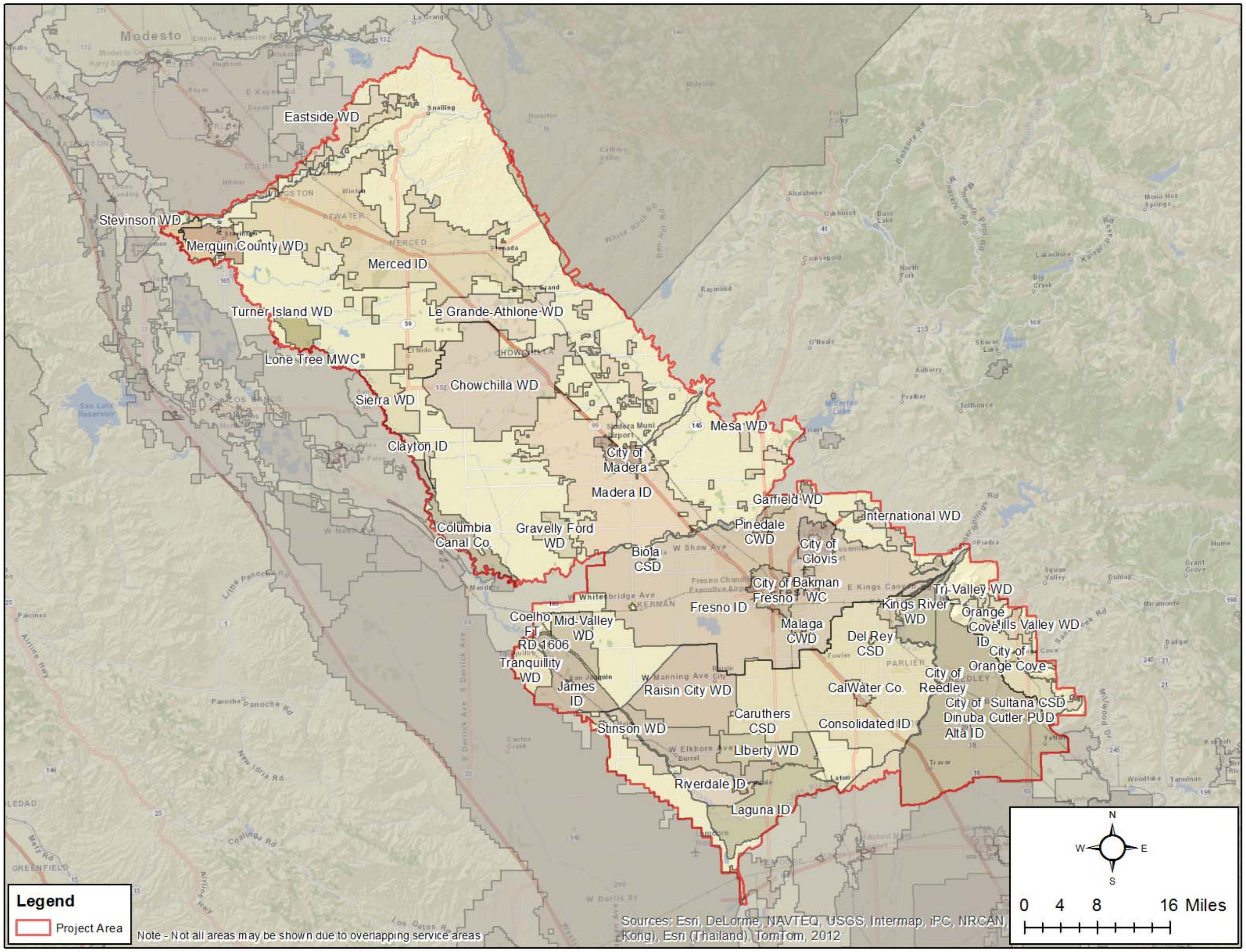


Figure 3: Water Purveyors within the Project Area


Eastside WD
Stevinson WD
Merquin County WD
Merced ID
Turner Island WD
Le Grande-Athlone WD
Lone Tree MWC
Chowchilla WD
Sierra WD
Clayton ID
Mesa WD
City of Madera
Madera ID
Garfield WD
International WD
Pinedale CWD
City of Clovis
Columbia Canal Co.
Gravelly Ford WD
Biola CSD
City of Bakman
Fresno WC
Tri-Valley WD
Kings River WD
Fresno ID
Coelho FT RD 1606
Mid-Valley WD
Malaga CWD
Orange Cove ID
Hills Valley WD
Del Rey CSD
City of Orange Cove
Tranquillity WD
James ID
Raisin City WD
CalWater Co.
City of Reedley
City of Dinuba
Sultana CSD
Cutler PUD
Alta ID
Caruthers CSD
Consolidated ID
Stinson WD
Liberty WD
Riverdale ID
Laguna ID
Legend
Project Area
Note - Not all areas may be shown due to overlapping service areas
Sources: Esri, DeLorme, NAVTEQ, USGS, Intermap, iPC, NRCAN, Kong), Esri (Thailand), TomTom, 2012
N
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2. Modeling Input Development

A multi-step process was used to estimate the potential recharge in the project area from on-farm capture of excess winter flows. First, an analysis of the suitability of different areas for recharge was performed. This analysis used spatial data representing different components that affect the ability of land to recharge water to the underlying aquifer and resulted in a map of areas with higher or lower suitability for recharge. Crop compatibility with on-farm capture of excess flows was evaluated to determine which crops to include in the analysis. And, the availability of surface water flows above minimum flow requirements and within the available distribution capacity was analyzed, providing an estimate of the amount of water that could be recharged based on historical hydrology. These components were incorporated into a model scenario using the California Central Valley Groundwater-Surface Water Simulation Model (C2VSim), to simulate the long-term migration of the recharged water and the amount of water that remains in storage.

The following sections discuss the analyses performed in more detail.

2.1 Land Recharge Suitability

The land recharge suitability analysis was performed using a geographic information system (GIS) overlay technique. In this technique, relevant characteristics of subsurface conditions are collected, each characteristic is ranked based on suitability for recharge, the ranking for each characteristic is weighted based on its relative importance for recharge, and finally, the weighted rankings are combined to develop a final score for recharge suitability.

The following five characteristics were ranked and then combined to assess the suitability of lands for recharge:

1. Soil type
2. Deep ripping of soils
3. Subsurface materials, at three depth intervals
    - 0 – 50 feet below ground surface
    - 50 – 100 feet below ground surface
    - 100 – 150 feet below ground surface
4. Corcoran Clay thickness
5. Depth to groundwater

Within each data set, the data were ranked based on the relationship to groundwater recharge through winter flooding of agricultural land, with higher rankings associated with data indicative of greater ability to transmit water from the surface to the aquifer system and lower rankings associated with data indicative of lower ability to transmit water from the surface to the aquifer system. Further, each overall data set was weighted based on its relative importance to groundwater recharge through winter flooding of agricultural land compared to the other characteristics. The following subsections summarize the ranking and weighting for the different characteristics.

Data Set Ranking

Rankings were developed for each data set on a scale from one to five, with one indicating the lowest level of suitability for recharge and five indicating the highest level of suitability for recharge.

Soil Type

Surface soils play an important role in the ability to recharge water. This includes the texture of the soil, with finer grained soils resulting in slower recharge, and the presence of hardpans or claypans, which can further inhibit recharge. The U.S. Department of Agriculture's (USDA) Hydrologic Soil Group classification was used to rank areas by the relative ability of the soils to infiltrate recharge water. The Hydrologic Soil Group refers to soils grouped according to their runoff potential. The soil properties that influence runoff potential are those that affect the minimum rate of water infiltration on bare soil during periods after prolonged wetting. These properties include depth to a seasonal high water table, the infiltration rate, and depth to a layer that significantly restricts the downward movement of water. The slope and the kind of plant cover are not considered but are separate factors in predicting runoff (U.S. Department of Agriculture, Natural Resources Conservation Service, 2008).

Soils are assigned to one of four groups (A, B, C, and D), defined as follows:

- **Group A.** Soils having a high infiltration rate (low runoff potential) when thoroughly wet. These consist mainly of deep, well-drained to excessively-drained sands or gravelly sands. These soils have a high rate of water transmission.
- **Group B.** Soils having a moderate infiltration rate when thoroughly wet. These consist chiefly of moderately-deep or deep, or moderately-well drained or well-drained soils that have moderately fine texture to moderately coarse texture. These soils have a moderate rate of water transmission.
- **Group C.** Soils having a slow infiltration rate when thoroughly wet. These consist chiefly of soils having a layer that impedes the downward movement of water or soils of moderately-fine texture or fine texture. These soils have a slow rate of water transmission.
- **Group D.** Soils having a very slow infiltration rate (high-runoff potential) when thoroughly wet. These consist chiefly of clays that have a high shrink-swell potential, soils that have a high water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow over nearly impervious material. These soils have a very slow rate of water transmission.

The description of soils typically includes the depth of rooting to be expected for perennial plants (Soil Survey Division Staff, 1993). This is an important factor for groundwater recharge through winter flooding of agricultural land as this method of recharge does not include excavation.

Figure 4 shows the USDA-Natural Resources Conservation Service (NRCS) hydrologic soil group classifications for the project area (U.S. Department of Agriculture, Natural Resources Conservation Service, 2008). Figure 5 shows the ranking for soils. The four categories were spread evenly from 5 to 1: A soils ranked 5, B soils ranked 3.7, C soils ranked 2.3, and D soils ranked 1. Limited areas with unsurveyed soils were assigned a rank of 3.

Figure 4: Hydrologic Soil Groups

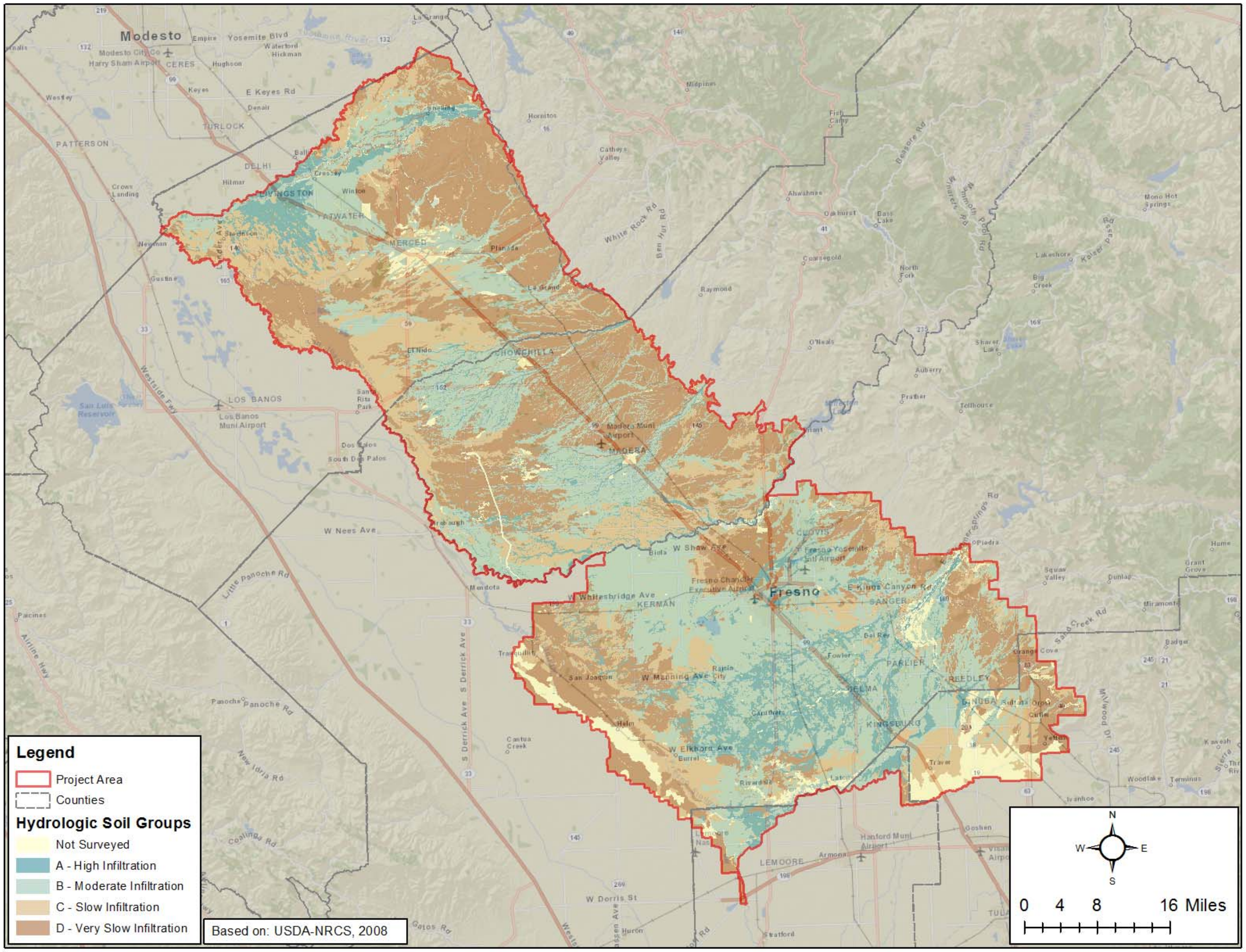
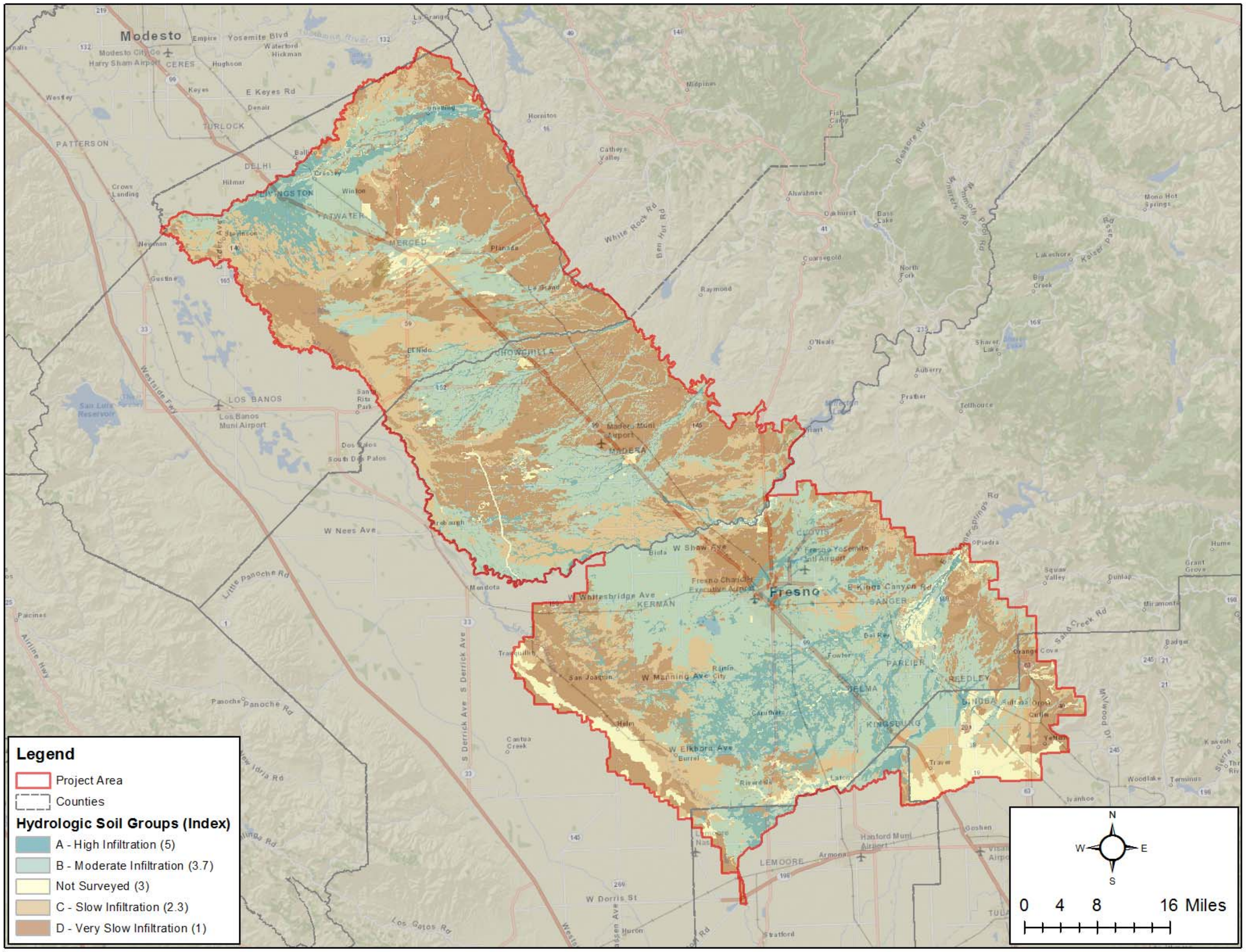


Figure 5: Ranked Hydrologic Soil Groups



Deep Ripping

Deep ripping is the mechanical manipulation of the soil to break up or pierce highly compacted, impermeable or slowly permeable subsurface soil layers, or other similar kinds of restrictive soil layers. Typically, this involves dragging a steel shank through the soil to a depth of about 6 feet. Deep ripping is usually performed in the San Joaquin Valley prior to planting permanent crops to increase rooting depth and drainage.

Deep ripping can improve the permeability of the soil beyond what is identified in the soil surveys. To account for this, a data set of deep ripped lands was included in the GIS overlay analysis. The data set was developed at the UCD under contract to the California Water Foundation and used land use and satellite imagery to identify areas likely to have been deep ripped prior to planting. These areas were assumed to be tree or vine crops planted on soils with a restrictive layer.

Figure 6 shows the deep ripped soils in the project area (O'Geen & Saal, 2013).

Figure 7 shows the ranking for deep ripped soils: 5 for deep ripped areas and 1 for areas not ripped.

Figure 6: Deep Ripped Soils in the Project Area

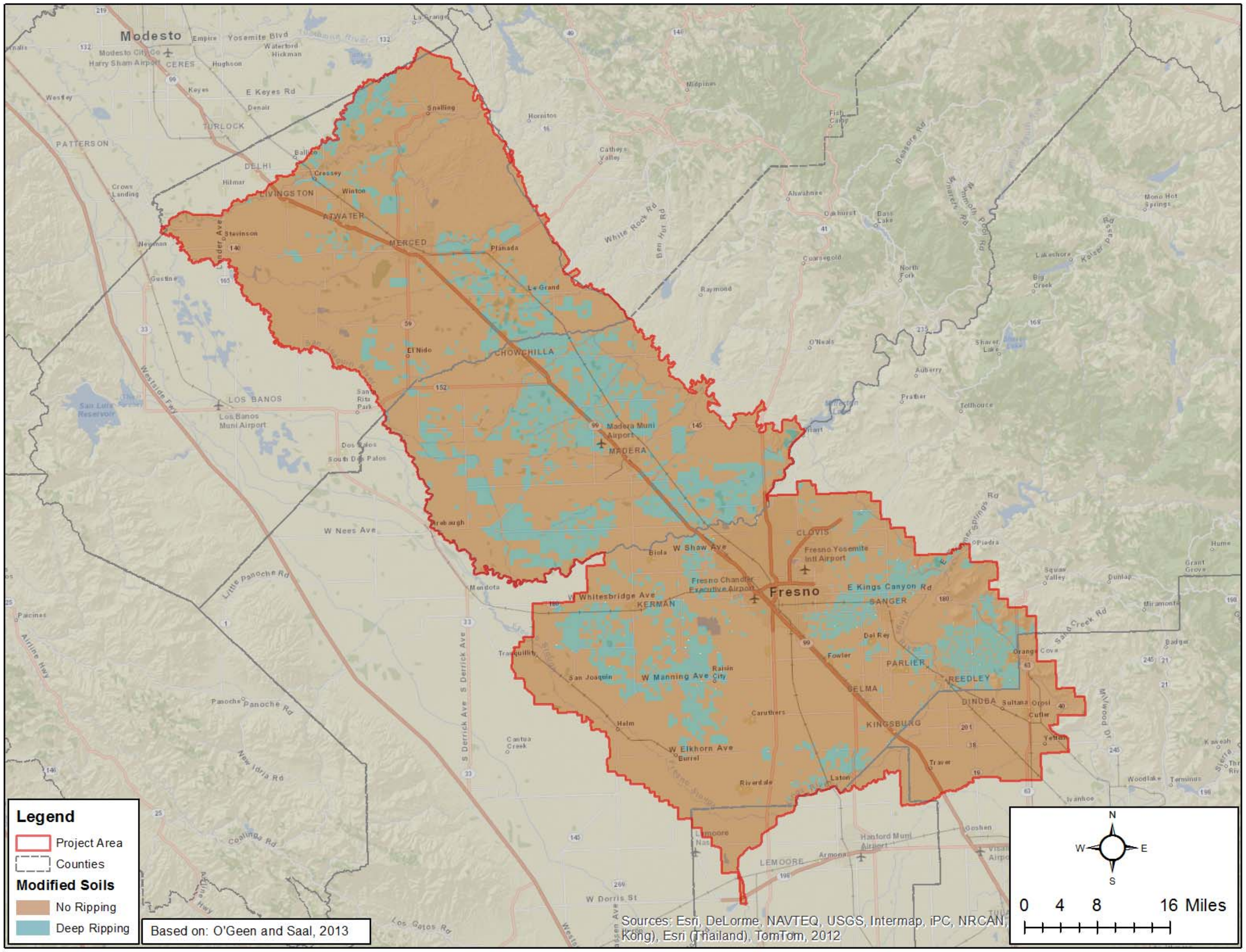
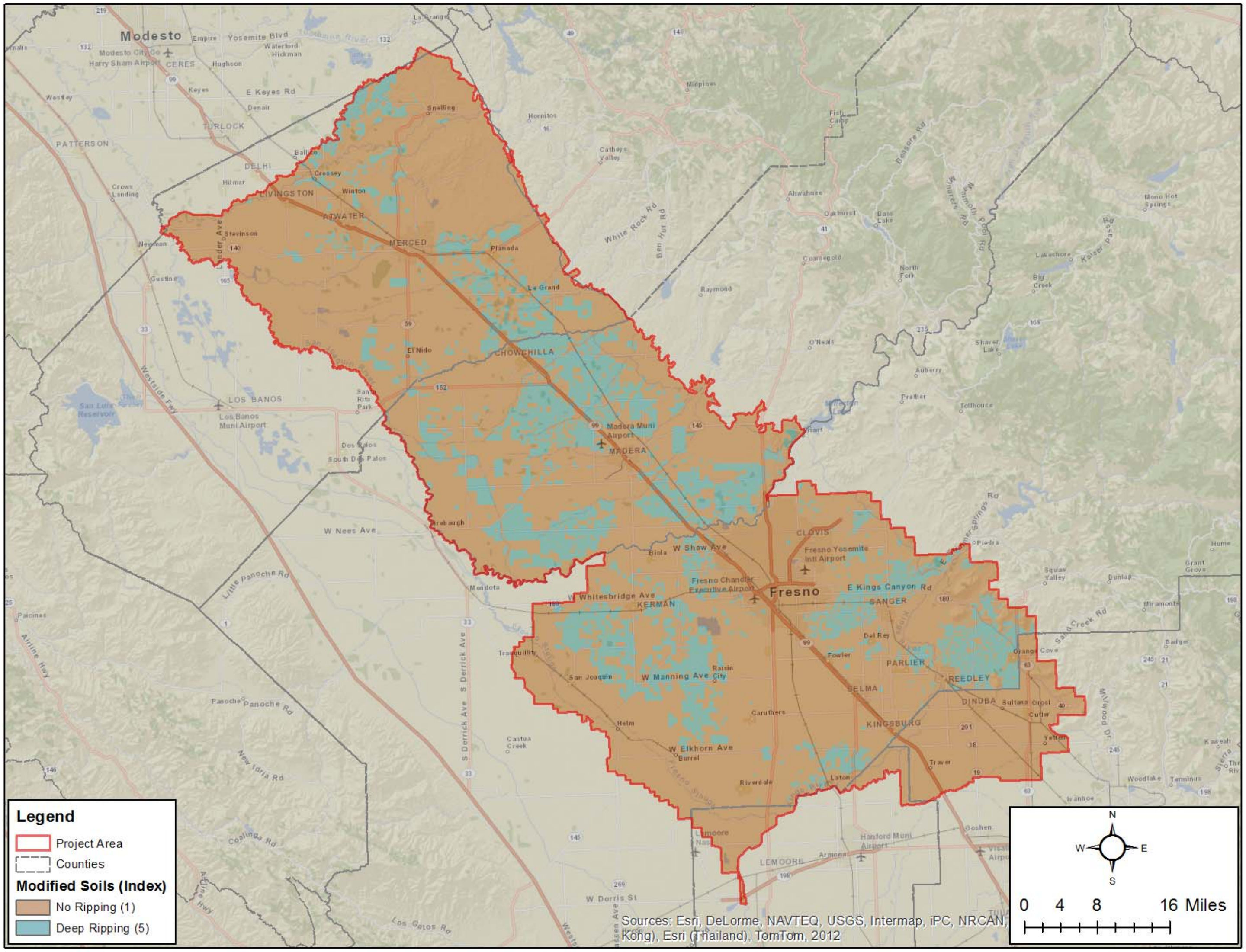


Figure 7: Ranked Deep Ripped Soils



Subsurface Materials

Subsurface permeability impacts the ability of water to migrate through the subsurface to the aquifer system. Texture of subsurface material can be used as a surrogate for permeability data, which is not available at the same level of detail. Coarser grained materials (e.g., gravels and sands) allow water to pass more easily than finer grained materials (e.g., clays and silts).

Texture data were pulled from a US Geological Survey (USGS) project that developed a three-dimensional texture model of the Central Valley using approximately 8,500 drillers' logs. These logs described lithology up to 3,100 feet below ground surface, simplified into a binary classification of coarse- and fine-grained materials. Statistical methods (i.e., kriging) were used to estimate the percent coarse across the San Joaquin Valley on a 1-mile spatial grid at 50-foot depth intervals from land surface down to 2,300 feet below land surface (Faunt, Belitz, & Hanson, 2010).

The percent coarse grains for the three upper depth intervals (0 – 50 ft, 50 – 100 ft, and 100 – 150 ft) are shown on Figure 8, Figure 10, and Figure 12, respectively. These percentages were grouped and then ranked from 1 to 5 as follows:

1: Areas with less than 20% coarse grain materials
2: Areas with 20 – 60% coarse grain materials
3: Areas with 40 – 60% coarse grain materials
4: Areas with 60 – 80% coarse grain materials
5: Areas with 80 – 100% coarse grain materials

Maps of these rankings are shown in the following figures:

- 0 to 50 ft: Figure 9
- 50 to 100 ft: Figure 11
- 100 to 150 ft: Figure 13

Figure 8: Texture of Subsurface Materials, 0 – 50 ft below ground surface

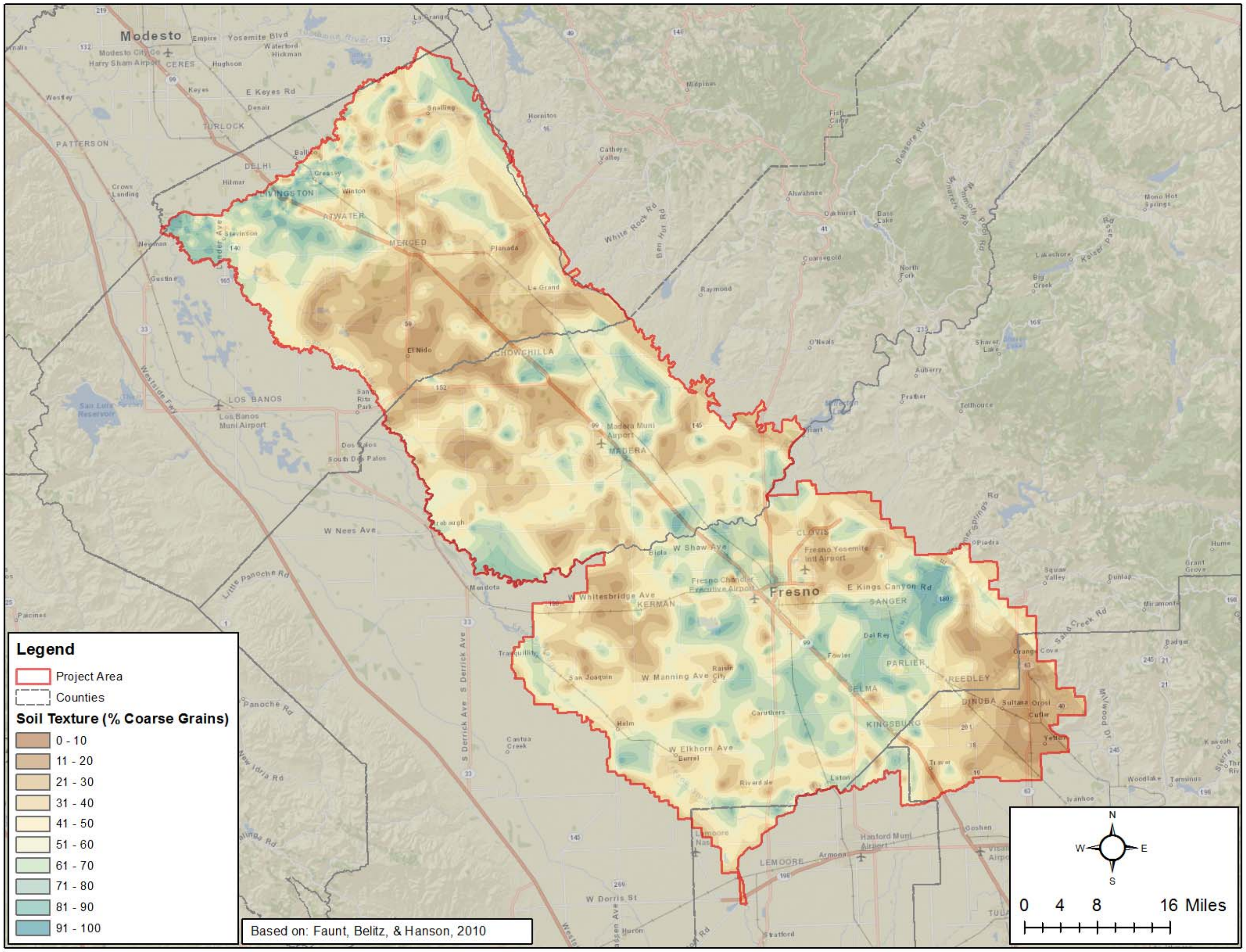


Figure 9: Ranked Texture of Subsurface Materials, 0 – 50 ft below ground surface

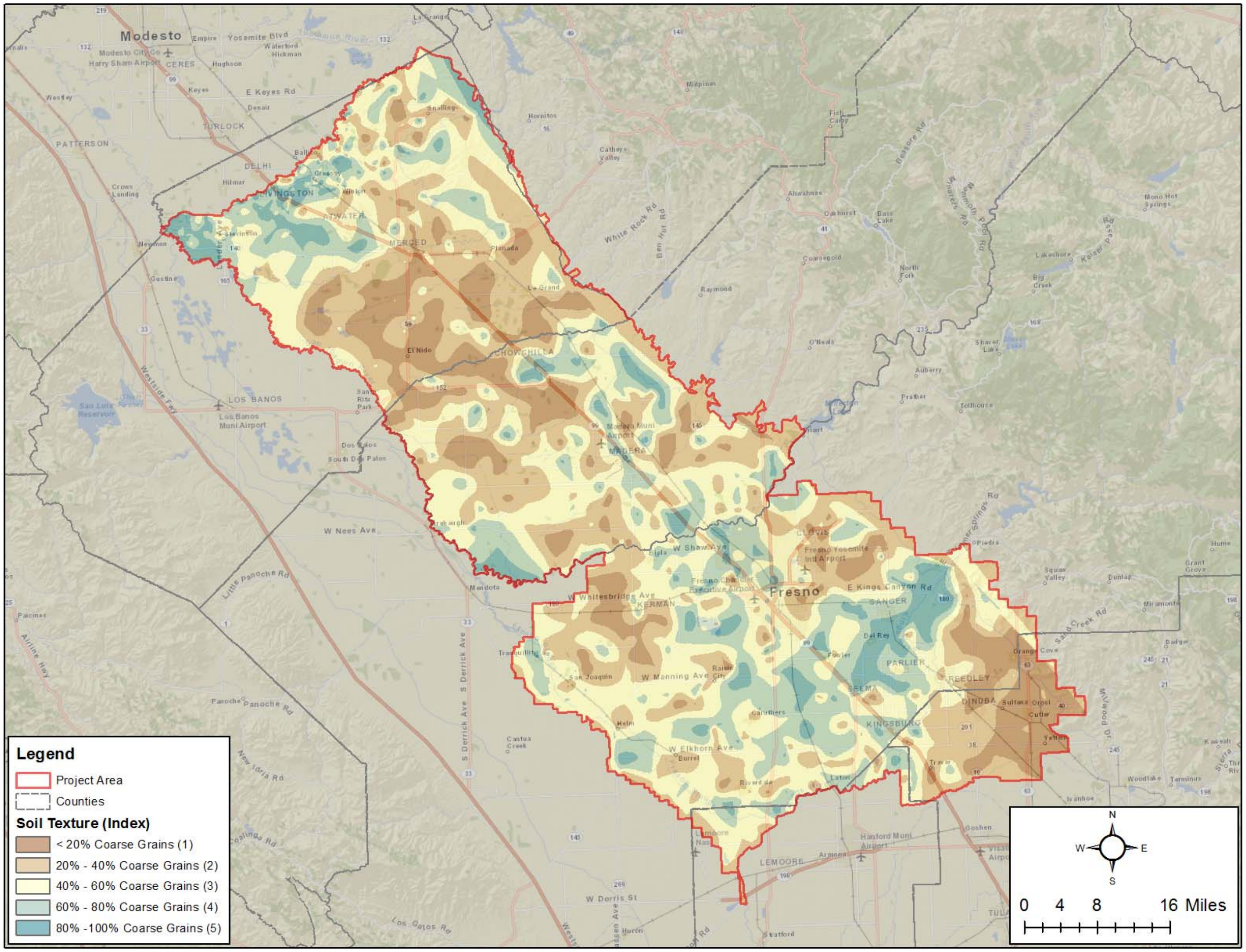


Figure 10: Texture of Subsurface Materials, 50 – 100 ft below ground surface

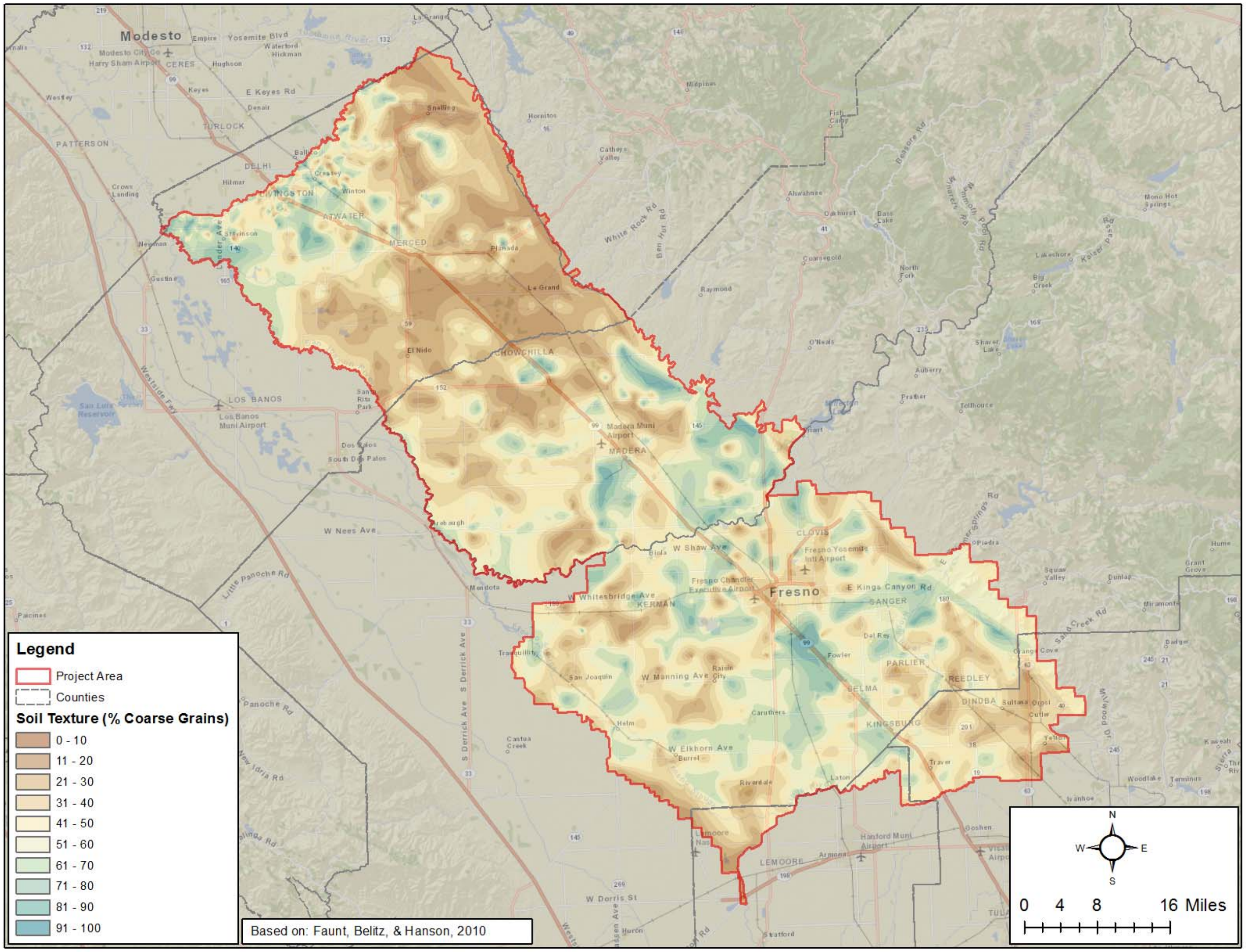


Figure 11: Ranked Texture of Subsurface Materials, 50 – 100 ft below ground surface

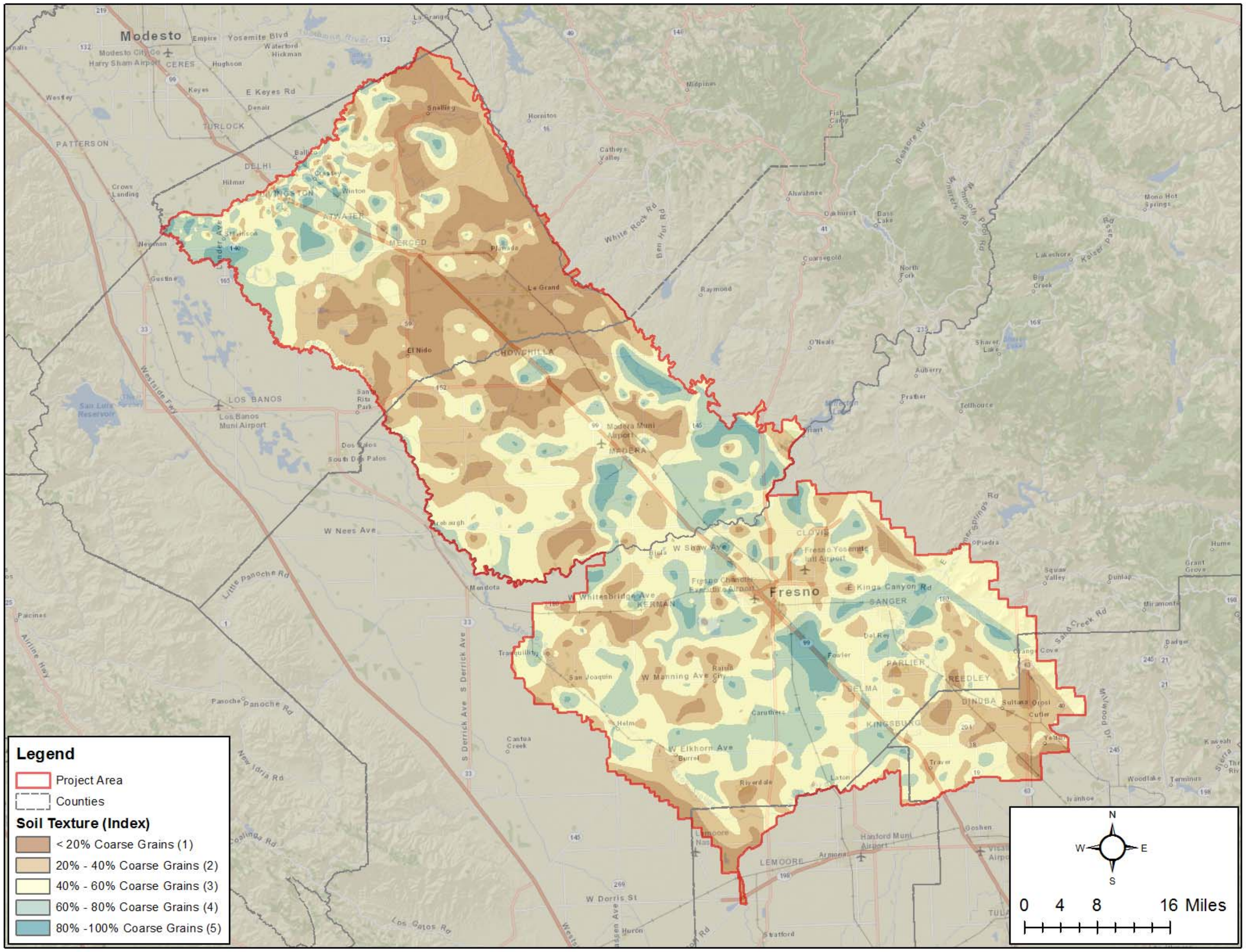


Figure 12: Texture of Subsurface Materials, 100 – 150 ft below ground surface

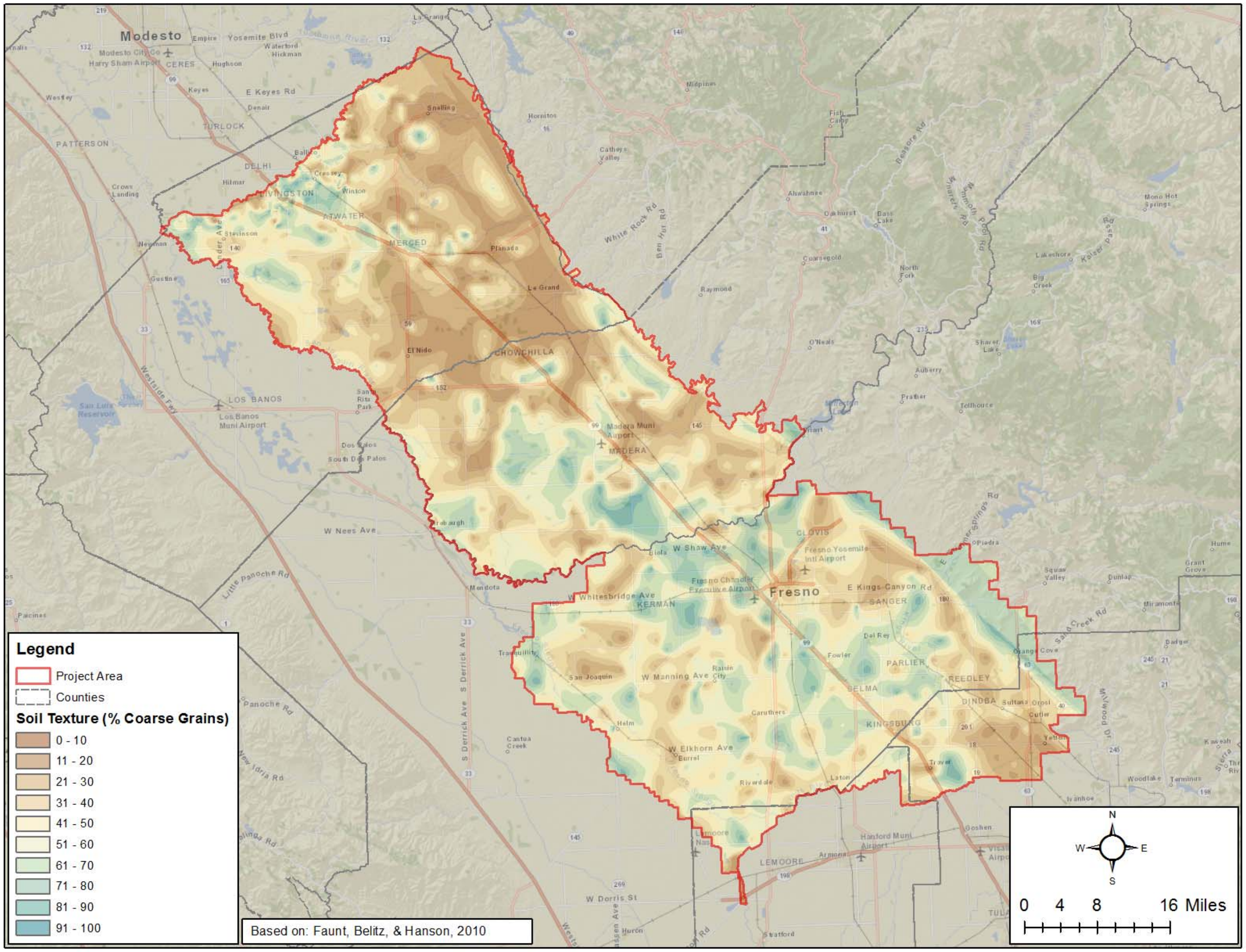
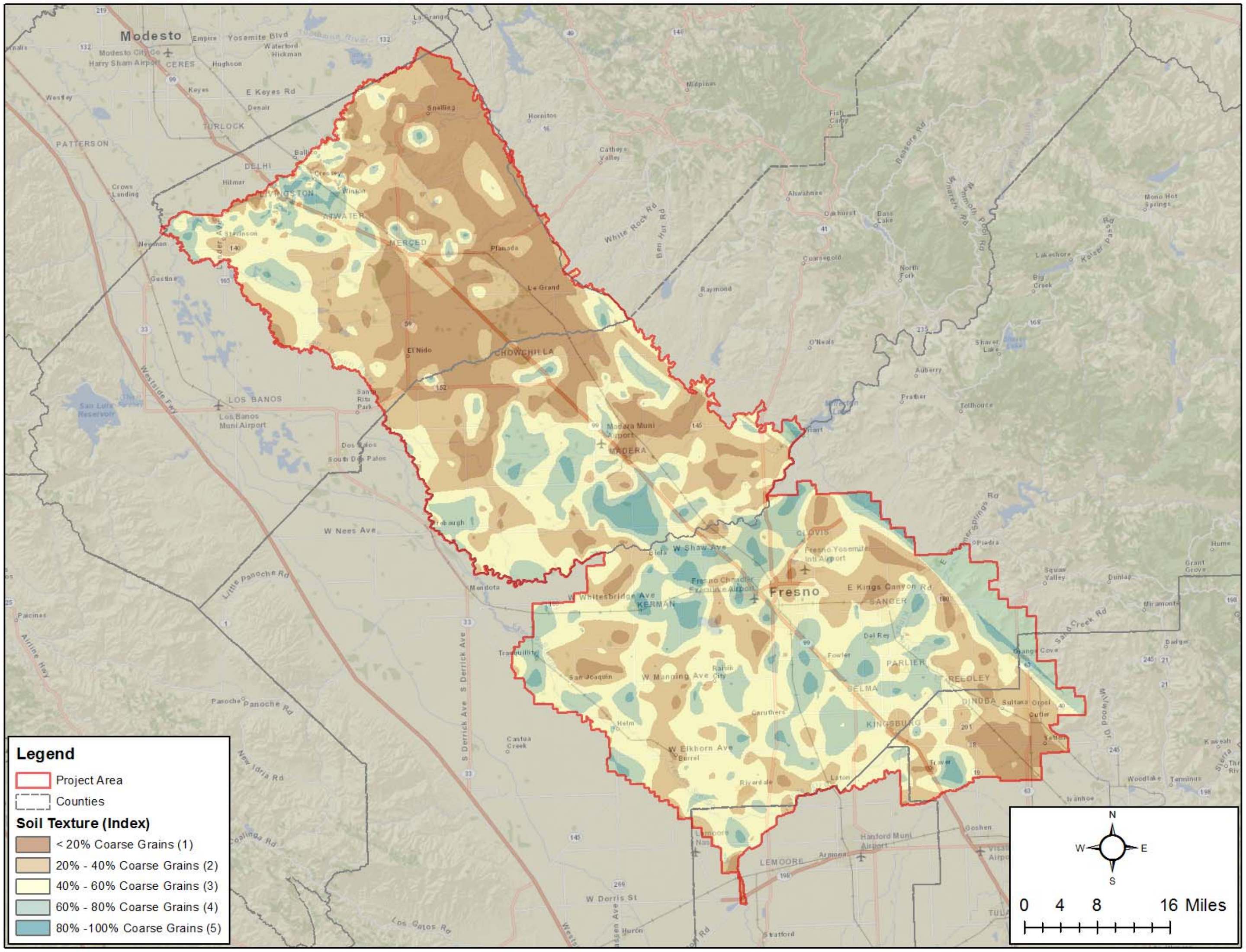


Figure 13: Ranked Texture of Subsurface Materials, 100 – 150 ft below ground surface



Corcoran Clay Thickness

While the average texture of subsurface materials is important to groundwater recharge, more important is how finer-grained materials are distributed in the subsurface. An extensive horizontal layer of fine-grained materials can greatly inhibit the downward flow of water through the subsurface, even within a large deposit of coarse-grained materials. The Corcoran Clay is one such regionally-extensive, fine-grained unit that is typically present along the axis of the San Joaquin Valley. This diatomaceous clay unit underlies approximately 5,000 square miles and ranges in thickness from zero to at least 160 ft. The extensive drilling of wells through the Corcoran Clay is thought to have reduced the confining nature of the unit, as water can pass through the bores in the clay (Bertoldi, Johnston, & Evenston, 1991; Faunt, Hanson, & Belitz, 2009).

The relative impact of a confining layer is related to the degree to which it restricts flow and how that impacts beneficial uses. Within the project area, groundwater production occurs both above and below the Corcoran Clay (Merced Area Groundwater Pool Interests, 2008; Madera County, 2008; Fresno Irrigation District, 2006). Production above the clay could capture recharged water that may pool on top of this feature. While consideration will need to be given to the depth of the unsaturated zone and the ability to store water without harming crops or other uses, the ability to utilize groundwater above the Corcoran Clay limits the clay's negative impact. While outside the scope of this effort, localized studies of the depth of production wells and local groundwater levels can assist in identifying the impact of the Corcoran Clay at individual site locations.

Thicknesses of the Corcoran Clay are shown in Figure 14 (Page & Balding, 1973). The rankings are as follows and are shown in Figure 15:

1: Greater than 60 feet of Corcoran Clay
2: 40 – 60 feet of Corcoran Clay
3: 20 – 40 feet of Corcoran Clay
4: 0 – 20 feet of Corcoran Clay
5: No underlying Corcoran Clay

Figure 14: Thickness of Corcoran Clay

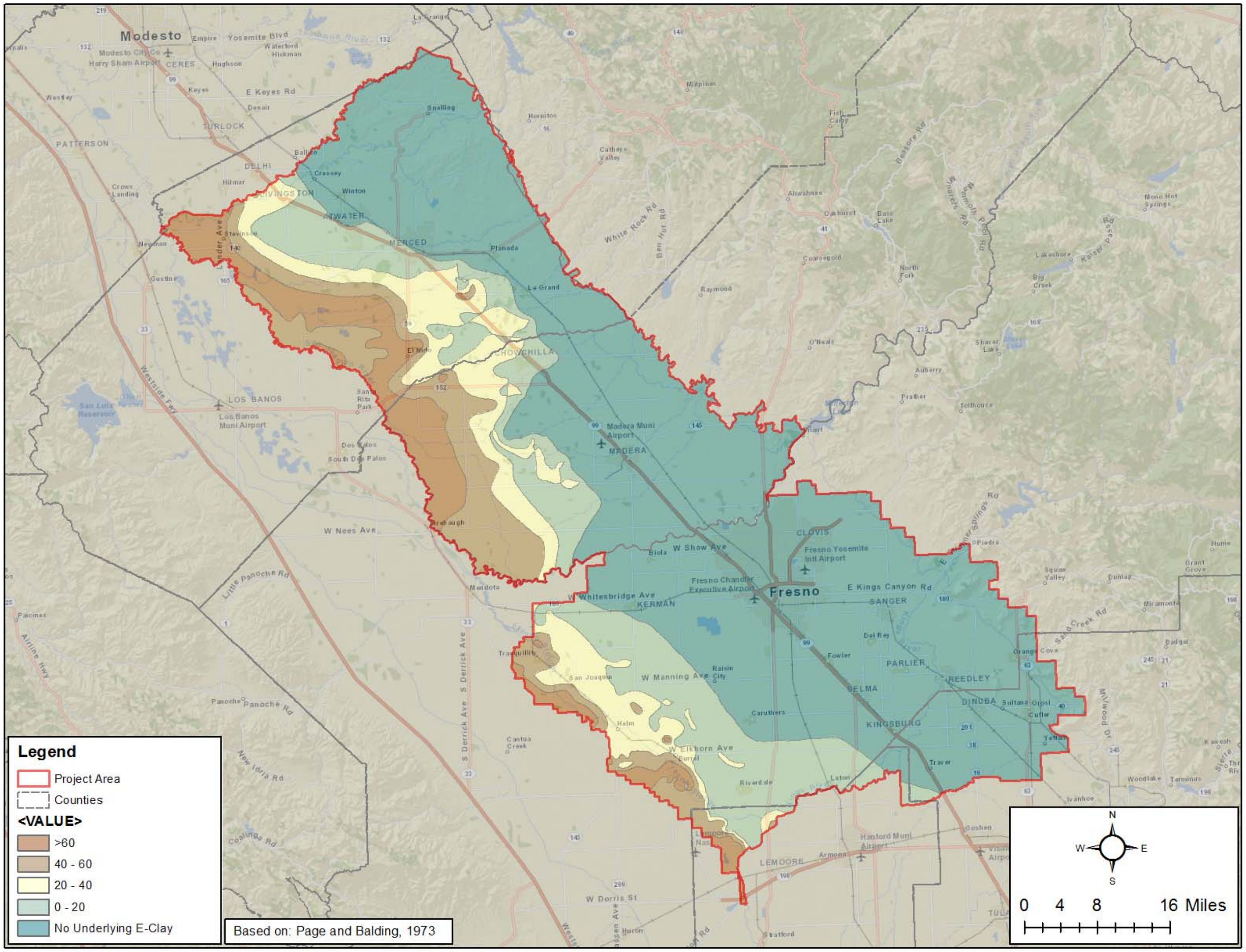
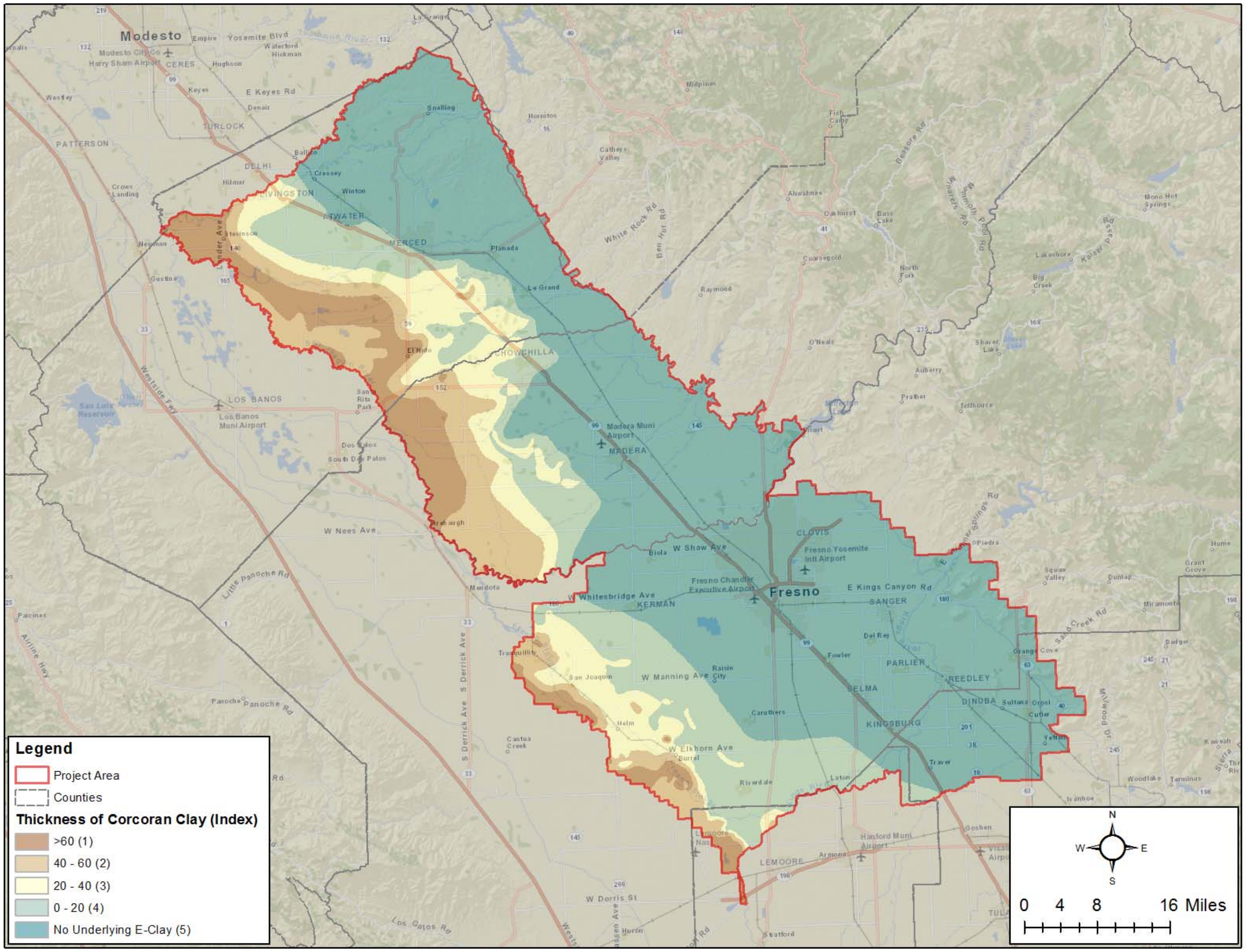


Figure 15: Ranked Thickness of Corcoran Clay



Depth to Groundwater

Depth to groundwater controls part of the basin's ability to physically store water in the subsurface, along with the per-unit-volume ability to store water within the unsaturated zone. If there is insufficient depth to groundwater, additional recharge may raise groundwater levels to an elevation that results in waterlogging of crops or other negative impacts. Such issues may occur in areas where near-surface clay layers inhibit the downward flow of groundwater. Such areas are often correlated with areas indicated as being poorly suited for recharge due to surface soils or subsurface materials in the shallow subsurface. Thus, this issue is covered by three characteristics within the Recharge Suitability Index rankings. Insufficient depth to groundwater is generally more of an issue during wet periods rather than dry periods, which are the periods considered for recharge under this project.

Depth to groundwater data for the project area are available from the California Department of Water Resources (DWR). These data typically represent groundwater levels in the aquifer used for municipal drinking water and agricultural irrigation and thus may not reflect shallow, perched aquifer conditions. However, the deeper groundwater level data are important when considering the ability to store water in the subsurface. Figure 16 shows the depth to groundwater for the most recent available year, 2010 (DWR, 2010). More recent regional depth to groundwater maps or contour data were not available, but are likely to be lower due to the continuing drought (DWR, 2104); however, they not sufficiently lower to substantially change the relative suitability ranking for depth to groundwater or to change the overall conclusions of this study.

The most critical feature for the ranking of depth to groundwater is the lack of a high water table that would impact recharge. Thus, the ranking shown below is focused on differentiating between shallow groundwater and deeper groundwater (see Figure 17):

1: Less than 20 ft to groundwater
2: 20 – 40 ft to groundwater
3: 40 – 60 ft to groundwater
4: 60 – 80 ft to groundwater
5: Greater than 80 ft to groundwater

Data is extrapolated for areas not covered by contour data from DWR (2010), as shown by the hatched areas on Figure 17.

Figure 16: Depth to Groundwater

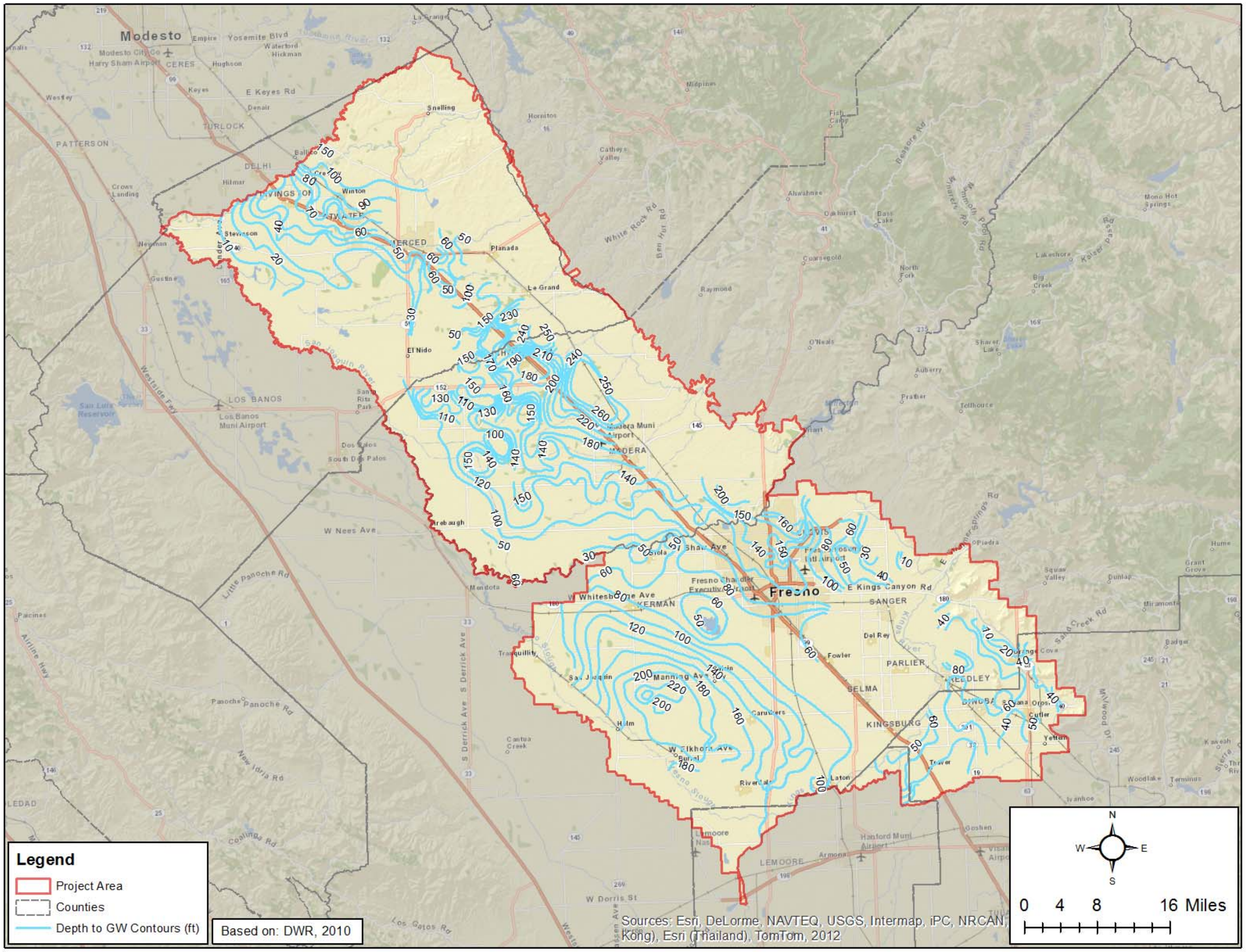
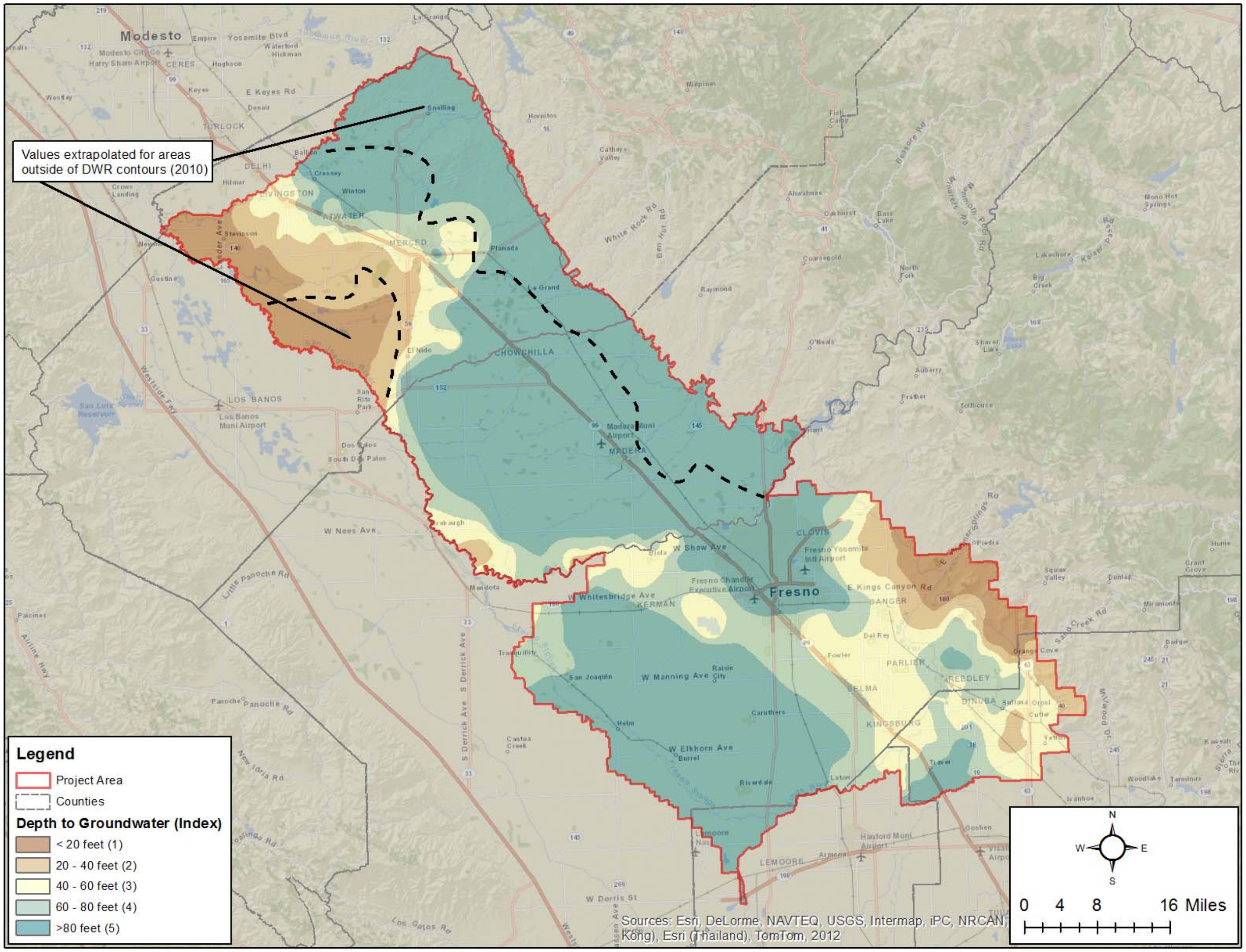


Figure 17: Ranked Depth to Groundwater



Data Set Weighting

The characteristics described above were incorporated into the GIS overlay by 1) applying weights to each data set based on their relative importance to groundwater recharge through winter flooding of agricultural land and 2) spatially adding the weighted values to develop the Recharge Suitability Index. The weight used for each data set is shown in Table 1, along with the rankings described in the preceding sections. The resulting Recharge Suitability Index is provided in Section 4.1.

Table 1: Ranking Factors and Quantification Methods (1- low and 5- high)

Factor	Quantification Method	Attribute	Weight	Ranking
Surface and Subsurface Conditions	Surface and subsurface conditions are quantified using soils data from USDA-NRCS soil surveys in combination with deep ripping and the thickness of the Corcoran Clay	Hydrologic Soils Group Type A Type B Type C Type D Not Surveyed	5	 5 3.7 2.3 1 3
		Deep ripping Yes No	1	 5 1
		Corcoran Clay Thickness Not present 0-20 ft 20-40 ft 40-60 ft >60 ft	1	 5 4 3 2 1
Available Storage	Available storage is quantified by soil texture and depth to groundwater	Soil texture (0 to 50 ft) (% Coarse-grained Materials) 80–100 60–80 40–60 20–40 0–20	5	 5 4 3 2 1
		Soil texture (50 to 100 ft) (% Coarse-grained Materials) 80–100 60–80 40–60 20–40 0–20	5	 5 4 3 2 1
		Soil texture (100 to 150 ft) (% Coarse-grained Materials) 80–100 60–80 40–60 20–40 0–20	5	 5 4 3 2 1
		Depth to Groundwater (feet) >80 ft 60–80 ft 40–60 ft 20–40 ft 10–20 ft 0–10 ft	5	 5 5 5 5 2.5 1

2.2 Crop Recharge Suitability

The success of on-farm capture of excess winter flows for groundwater recharge requires crops that can tolerate ponded conditions for extended periods of time. Since on-farm capture of excess winter flows is not a common practice, there is little research results or published literature on the subject. The primary source of crop suitability to groundwater recharge through winter flooding of agricultural land is a pilot study in Fresno County titled *Implications of Using On-Farm Flood Flow Capture to Recharge Groundwater and Mitigate Flood Risks Along the Kings River, CA* by Bachand, et al. (2012). The pilot study includes records of the timing and duration of flooding of alfalfa, cotton, onions, pistachios, tomatoes, and wine grapes. This information is supplemented by information from growers and UC Extension agents, and from reports by the University of Florida (1998), Hale as cited in Kasimatis (1967), and others.

General Considerations and Perceptions

Growers typically have concerns about the potential for issues with crop health related to standing water over an extended period of time. The potential impact of standing water was researched through both literature review and through survey results from a survey conducted by Sustainable Conservation (2014). Survey results are used to supplement information from the literature as literature values are focused on areas with fine-grained soils that would be both the most impacted by waterlogging and the least suitable for groundwater recharge through winter flooding of agricultural land. Survey results, along with local studies such as Bachand, et al. (2012), can provide information on how crops grown on coarser grained soils respond to ponded conditions and how to manage ponded conditions to optimize recharge and crop health.

Growers typically become concerned about crop health when standing water persists for more than a few days in orchards, pastures, vineyards, and alfalfa fields. Lack of soil oxygen, increased incidence of disease, and reduced nutrient availability are three important detrimental impacts agronomic researchers have associated with water standing for more than 24 to 36 hours (see Appendix A). The severity of impact varies by crop and within species, depending on growth stage, plant health, and other biological factors. Symptoms often observed include: reduced plant vigor, reduced plant growth and yield, and plant death. These frequently observed symptoms underlie the general literature perspective that water standing for more than a few days on agricultural land is undesirable. An additional concern for orchardists is increased susceptibility to tree blow down when high winds occur during very wet or saturated soil conditions.

This literature information is contrasted by local experience through anecdotal evidence, survey results, and the results published by Bachand, et al. (2012). A grower associated with the work by Bachand, et al. indicated that there was no impact from recharge activities on overall yield, and that any yellowing leaves on grapes associated with ponding could be addressed by drying the field, which would return the plant to green vigor within a few days. The ability to dry a field depended on coarser grained soils and on the ability to drain the field, something likely not present in literature studies focused on fine grained soils and water which is involuntarily placed on the field such as by uncontrolled flood events.

Potential Benefits

There are several potential benefits to participating in recharge activities. Rodent populations may be reduced by winter water applications to agricultural lands. Salts may be leaching from the root zone, improving crop yield. Pumping lifts may be reduced, reducing energy costs. And, by improving the availability of soil moisture in early spring, winter water application may increase yield in some years.

Potential Long-term Impacts

Long-term impacts of both prolonged flooding and intermittent water applications may include reduced soil fertility, degradation of soil structure, and increased disease and pest populations resulting from the cool, moist environment. Plugged soil pores by fine silt carried in flood waters, crusted soils due to the chemical composition of the water applied, and increased soil compaction occur more frequently with additional water applications and degrade the soil structure. Nutrients are leached from the root zone at an increased rate when water remains on the surface for extended periods. Additionally, increased rates of nutrient conversion to forms that are more easily lost from the root zone have been observed under conditions fostered by winter water applications. Water quality impacts are being studied under an ongoing effort by Sustainable Conservation and TetraTech and may provide more information on this potential issue.

Results of the crop suitability analysis are provided in Section 4.2.

2.3 Recharge Water Availability

Wintertime flood flows from the Merced River, Chowchilla River, Fresno River, and Kings River (Figure 18) were considered as potential sources of water for recharge on the agricultural lands. The magnitude and frequency of winter flood flows available for recharge were estimated based on the following for selected major rivers in the study area:

- Historical streamflow
- Minimum flow requirements
- Historical diversions
- Available diversion and conveyance capacity of the existing irrigation infrastructure

The amount of water that could potentially be recharged was estimated starting with the available surface water flood flows, based on historical hydrology. Available surface water flood flows were defined as those flows above minimum flow requirements and within the available distribution capacity. Available distribution capacities were determined by evaluating the differences between conveyance capacities and historical diversions on a daily basis. Diversions and conveyance capacities were estimated where data were not available. The collected data sets, assumptions, and analysis for each river are further described in the following subsections.

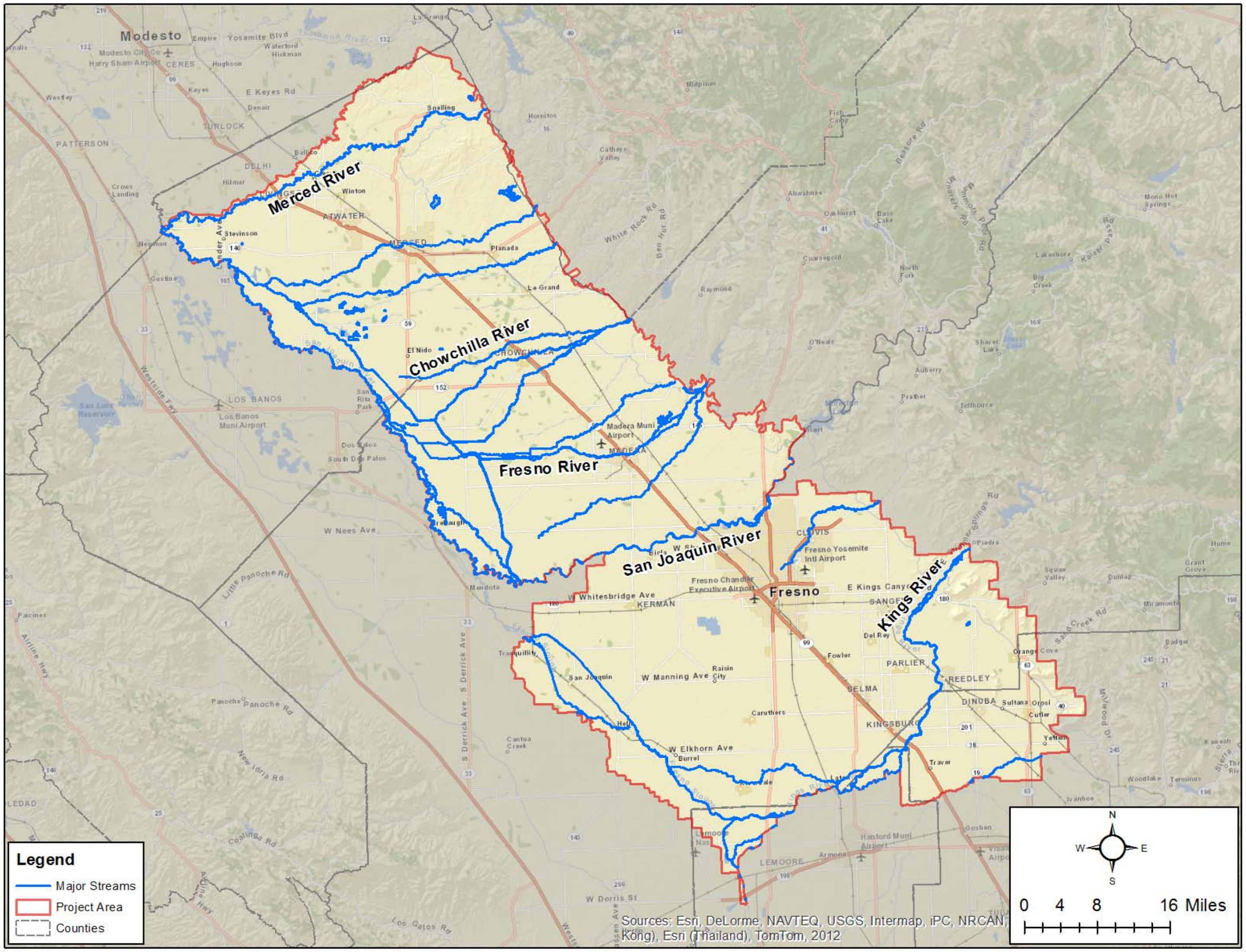
The availability of data or usage of assumptions for the data sets is described in Table 2.

Table 2: Summary of Data and Assumptions for Rivers in the Project Area

River	Historical Hydrology	Minimum Flow Requirements	Available Distribution Capacity[1]
Merced River	Based on flow below Crocker-Huffman Dam	Based on FERC license, Davis-Grunsky contract, and Cowell Agreement	Based on canal capacity and historical diversion data for Merced Irrigation District
Chowchilla River	Based on release data from Buchanan Dam	No minimum flow requirements. 10% of assumed distribution capacity assumed unavailable	Not available. Assumptions made based on summer releases from Buchanan Dam
Fresno River	Based on release data from Hidden Dam	No minimum flow requirements. 10% of assumed distribution capacity assumed unavailable	Not available. Assumptions made based on summer releases from Hidden Dam
Kings River	Based on flows at James Bypass	No minimum flow requirements	Based on canal capacity and historical diversion data for FID, CID, and AID

[1] Dry year as defined by FERC license: Forecasted April through July inflow to Lake McClure is less than 450 TAF, as published in DWR May 1 Bulletin 120.

Figure 18: Major Rivers and Streams in the Project Area



Merced River

The Merced River drains a 1,276-square-mile watershed on the western slope of the Sierra Nevada in the southern portion of California's San Joaquin Valley and joins the San Joaquin River approximately 87 miles south of Sacramento. Flow in the Merced River is regulated by two large dams, New Exchequer Dam and McSwain Dam. In addition, flows released downstream of the dams are diverted at two Merced Irrigation District canals (Main Canal diverted at Crocker-Huffman Dam and Northside Canal diverted at Merced Falls Dam) and at numerous smaller riparian diversions (Stillwater Sciences, 2001). A schematic diagram of the Merced River dams, reservoirs, diversions, and flow gages is shown in Figure 19.

Merced Irrigation District provided stream flow data for the Merced River below Crocker-Huffman Dam from 1966 to present. These data were analyzed to estimate the winter flows that could be used for recharge. Minimum flow requirements in the Merced River are determined by (1) the Federal Energy Commission (FERC) license for the Merced River Development Project, (2) a Davis-Grunsky[1] contract with the State of California, and (3) required releases to provide flows for riparian diversions (Cowell Agreement[2]) (Stillwater Sciences, 2001). To satisfy the flow requirements and the Cowell Agreement, Merced Irrigation District operates at a target flow below Crocker-Huffman Diversion Dam equal to the Cowell Agreement adjudicated entitlement plus the greater of either the FERC or Davis-Grunsky flow requirement (MBK Engineers, 2001). The required minimum flow varies, depending on month and type of water year (e.g., wet or dry). Required minimum flows in the river are summarized in Table 3 and monthly values are shown along with streamflow and diversion values in Figure 20, Figure 21, and Figure 22 for a dry, an average, and a wet year, respectively. Minimum flow requirements were subtracted from the historical Merced River flows below Crocker-Huffman Diversion Dam to estimate the available winter flows that could be used for recharge.

[1] The Davis-Grunsky Act provides financial assistance to public agencies for water development, recreation, and fish and wildlife enhancement.

[2] The Cowell Agreement was established on January 17, 1926 pursuant to a Merced Superior Court Order, and stipulates a scheduled quantity of flow rates, measured at Crocker-Huffman Dam, to be maintained by Merced Irrigation District.

Figure 19: Schematic Diagram of Merced River

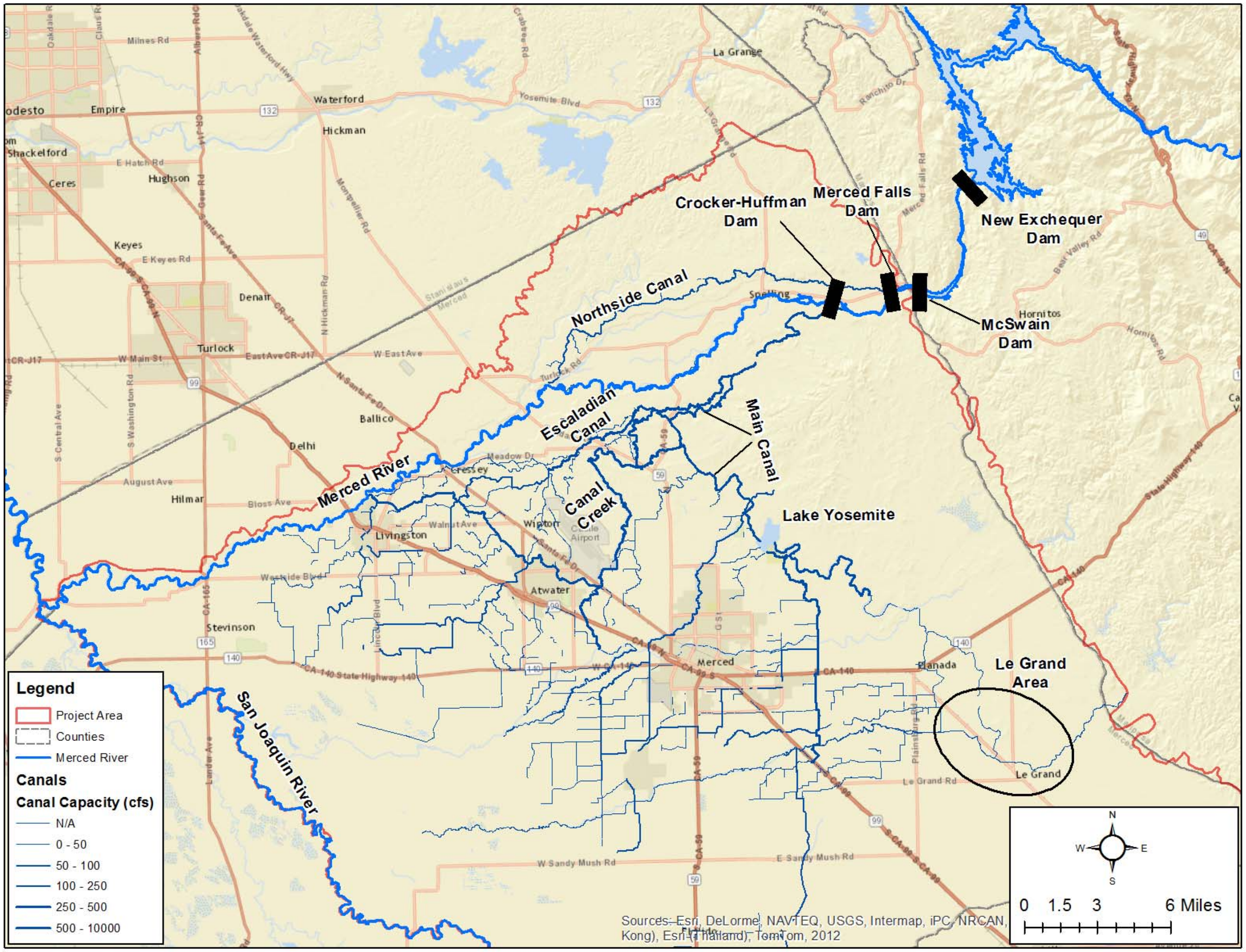


Table 3: Required Monthly Minimum Flows in the Merced River, cubic feet per second (cfs)

Month	Davis-Grunsky	FERC		Cowell Agreement Entitlement
	Crocker-Huffman Dam to Shaffer bridge	At Shaffer Bridge		
		Dry Year[1]	Normal Year[2]	
Oct 1-15	0	25	15	50[3]
Oct 16-31	0	75	60	50[1]
Nov	180-220	100	75	50[1]
Dec	180-220	100	75	50[1]
Jan	180-220	75	60	50[1]
Feb	180-220	75	60	50[1]
Mar	180-220	75	60	100
Apr	0	75	60	175
May	0	75	60	225
Jun	0	25	15	250[1]
Jul	0	25	15	225[2]
Aug	0	25	15	175[2]
Sep	0	25	15	150[2]

Source: MBK, 2001

[1] Normal year as defined by FERC license: Forecasted April through July inflow to Lake McClure is equal to or greater than 450 thousand acre-feet (TAF), as published in DWR May 1 Bulletin 120.

[2] Dry year as defined by FERC license: Forecasted April through July inflow to Lake McClure is less than 450 TAF, as published in DWR May 1 Bulletin 120.

[3] Entitlement is equal to 50 cfs or the natural flow of the Merced River (inflow to Lake McClure), whichever is less.

[4] If the natural flow of the Merced River falls below 1,200 cfs in the month of June, the entitlement flows are reduced accordingly from that day: 225 cfs flow for first 31 days; 175 cfs flow for next 31 days; 150 cfs for next 30 days; 50 cfs for the remainder of September.

Existing canal locations and capacity data were obtained from Merced Irrigation District and are shown in Figure 19 and in Table 4. Merced Irrigation District has two diversion points on the Merced River: Northside Canal and Main Canal (Figure 19). The available capacity of the Northside Canal was not included due to lack of suitable recharge areas in the vicinity of the canal. Only 950 cfs of Main Canal's capacity could be used for this project due to limited suitable recharge areas in the vicinity of lateral canals. Canal Creek and Escaladian Canal are the only two canals connected to Main Canal that can convey water to areas suitable for recharge, with a total capacity of 850 cfs. In addition, 100 cfs of winter flood flows can be conveyed to the La Grand area through Main Canal (Figure 19) and Lake Yosemite for recharge purposes.

Table 4: Total Capacities for Major Canals, Merced Irrigation District

Canal Name	Capacity (cfs)
Northside Canal	90
Main Canal	1900
Canal Creek	500
Escaladian Canal	350

Merced Irrigation District also provided historical records of diversions from the Main Canal. These data were subtracted from the total canal capacity to estimate the remaining distribution capacity during the winter months for delivering excess surface flows for groundwater recharge. Figure 20, Figure 21, and Figure 22 show the monthly Main Canal diversions for a dry, an average, and a wet year, respectively. The Crocker-Huffman Dam impounds water to allow entry into the Main Canal. The required minimum flows are established below the Crocker-Huffman Dam. Thus, these three figures each indicate 1) the amount of water diverted into the Main Canal, 2) the amount of water that is not diverted, but instead continues below Crocker-Huffman Dam, and 3) the minimum flow requirement below the Crocker-Huffman Dam.

Results of the recharge water availability analysis are provided in Section 4.3.

Figure 20: Monthly Merced River Flows below Crocker-Huffman Dam Main Canal Diversions and Minimum Flow Requirements for a Dry Year (Water Year 1992)

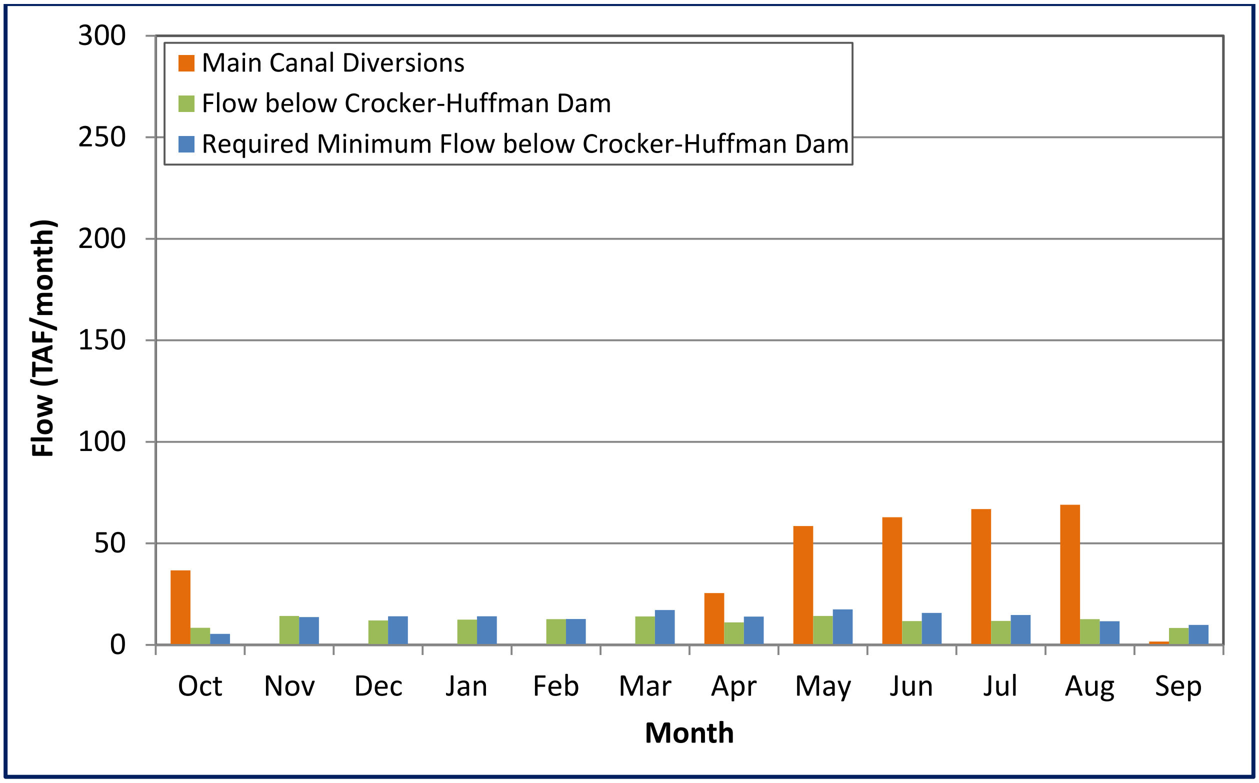


Figure 21: Monthly Merced River Flows below Crocker-Huffman Dam, Main Canal Diversions and Minimum Flow Requirements for an Average Year (Water Year 1979)

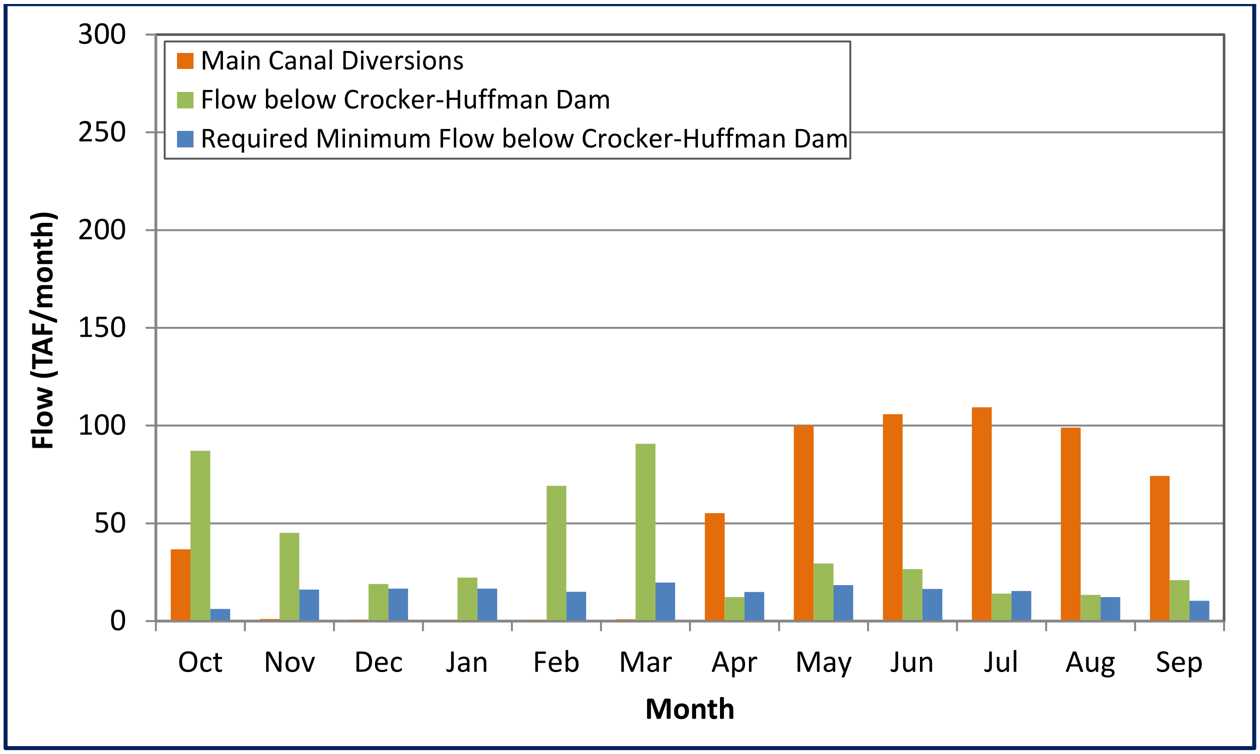
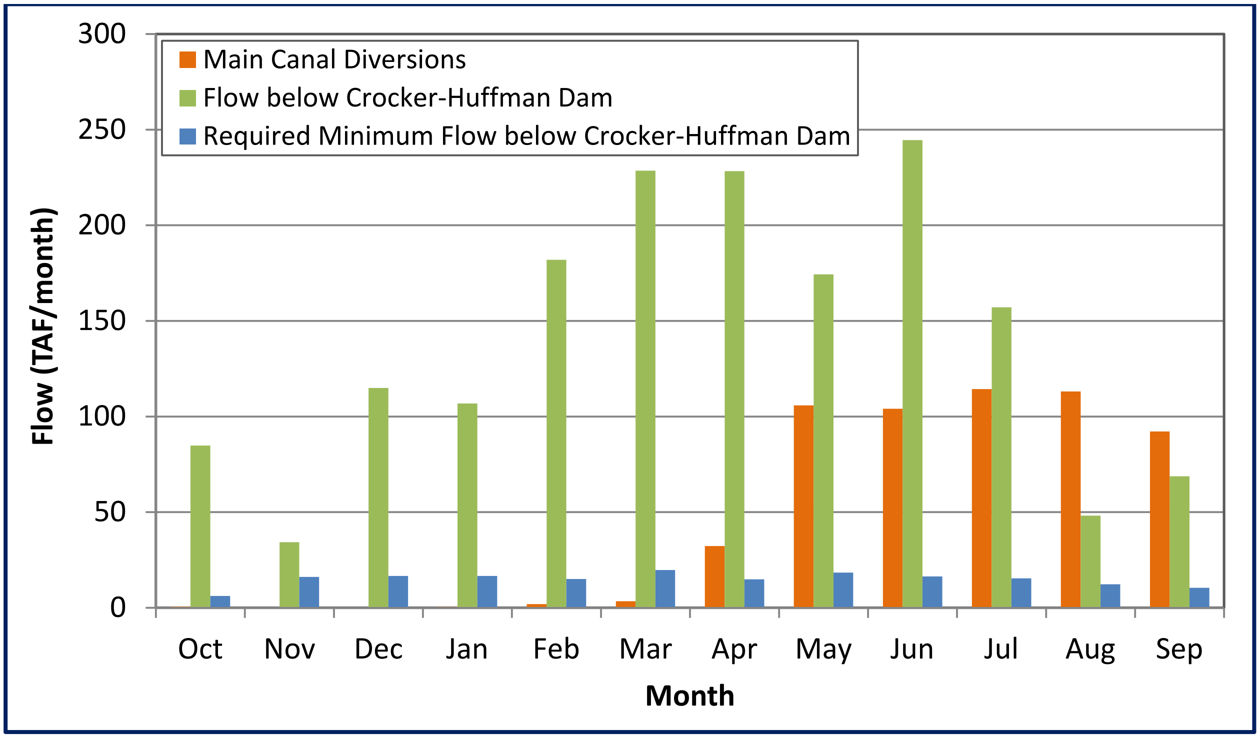


Figure 22: Monthly Merced River Flows below Crocker-Huffman Dam, Main Canal Diversions and Minimum Flow Requirements for a Wet Year (Water Year 1983)



Chowchilla River

The Chowchilla River drains a 254 square-mile watershed on the western slope of the Sierra Nevada in the southern portion of California's San Joaquin Valley. It flows 54 miles from the western side of the Sierra Nevada to the San Joaquin River. Flow in the Chowchilla River is regulated by Buchanan Dam. In addition, some flows downstream of the dam are diverted at Chowchilla Water District canals. A schematic diagram of Chowchilla River is shown in Figure 23.

Buchanan Dam was constructed in 1975 and is operated and maintained by the U.S. Army Corps of Engineers. Average annual natural flows from 1912 to 2008 at Buchanan Dam were approximately 70,000 acre-feet (AF). Chowchilla Water District has been able to take delivery of approximately 43,000 AF annually from the dam. The remaining 27,000 AF have been released as flood flows from the dam (Chowchilla Water District, 2013).

Buchanan Dam monthly historical release data were available from the U.S. Army Corps of Engineers for 1975 to present (J. L. Ballew, personal communication, September 26, 2013). These data were analyzed to estimate the winter flows that could be used for recharge. Figure 24, Figure 25, and Figure 26 show the monthly Buchanan Dam releases for a dry, an average, and a wet year, respectively.

There are no minimum flow requirements for fisheries on the Chowchilla River (State Water Resources Control Board, 2012). Locations of the canals were obtained from the USGS National Hydrography Dataset (U.S. Geological Survey, 2013) and are shown in Figure 23, but deliveries from the Chowchilla River and distribution capacity for Chowchilla Water District's canals were not readily available. As a result, assumptions were made to estimate the available canal capacity. Figure 27 shows the percent exceedance chart of Buchanan Dam release flow during the summer months. The chart shows that the percent exceedance line has a very small slope around 10,000 AF/month. Consequently, it was assumed that operational capacity of Chowchilla Water District's conveyance system is 10,000 AF/month. It was also assumed that 10% of 10,000 AF/month is not available to convey winter flood flows due to capacity used by Chowchilla Water District for other purposes such as deliveries or maintenance, noting that there are no urban users thus winter deliveries are assumed to be minor.

Results of the recharge water availability analysis are provided in Section 4.3.

Figure 23: Schematic Diagram of Chowchilla River

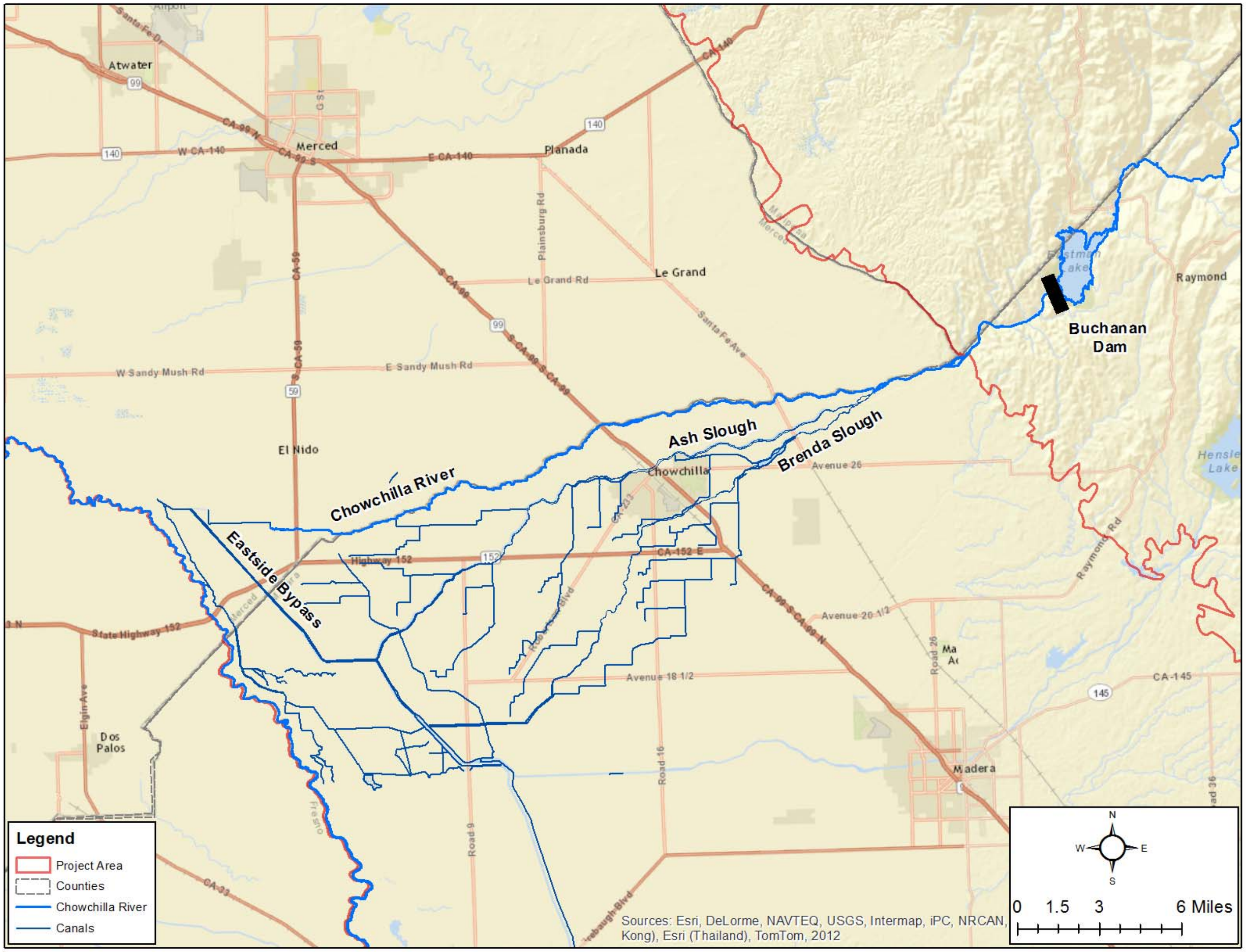


Figure 24: Monthly Releases for Buchanan Dam for a Dry Year (Water Year 1992)

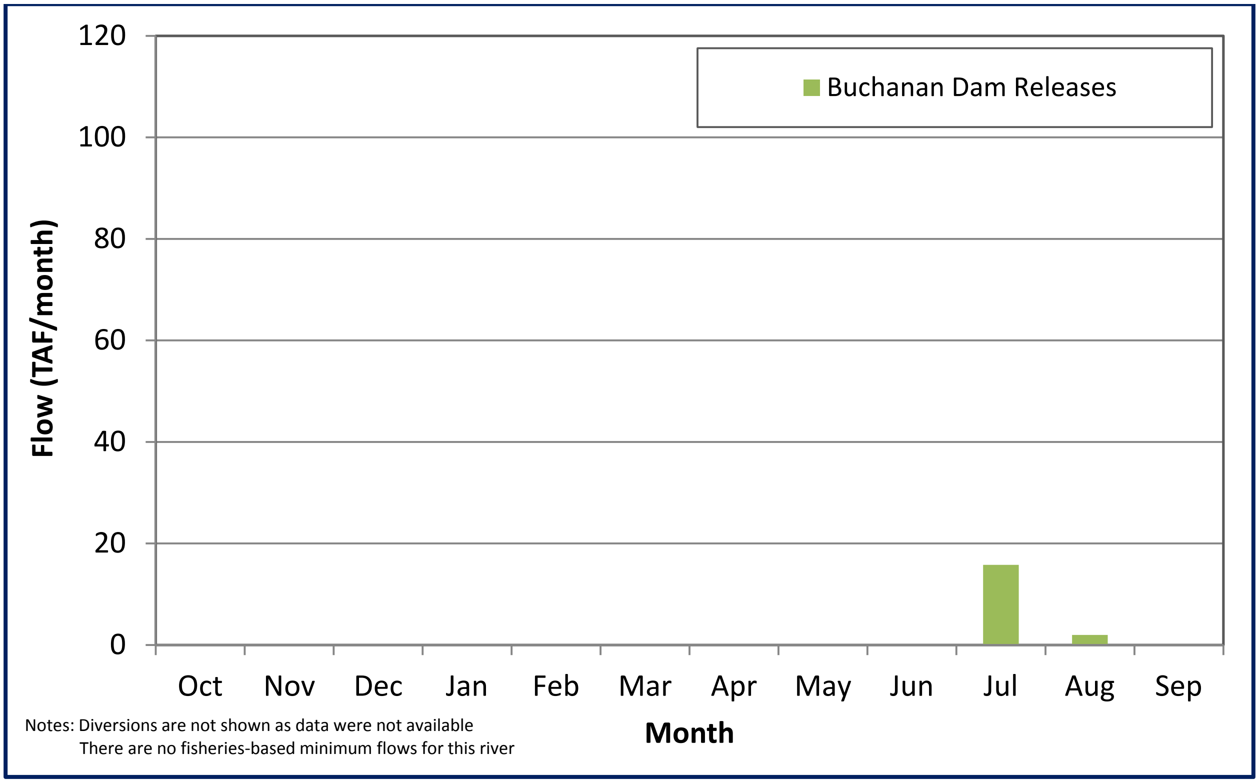


Figure 25: Monthly Releases for Buchanan Dam for an Average Year (Water Year 1979)

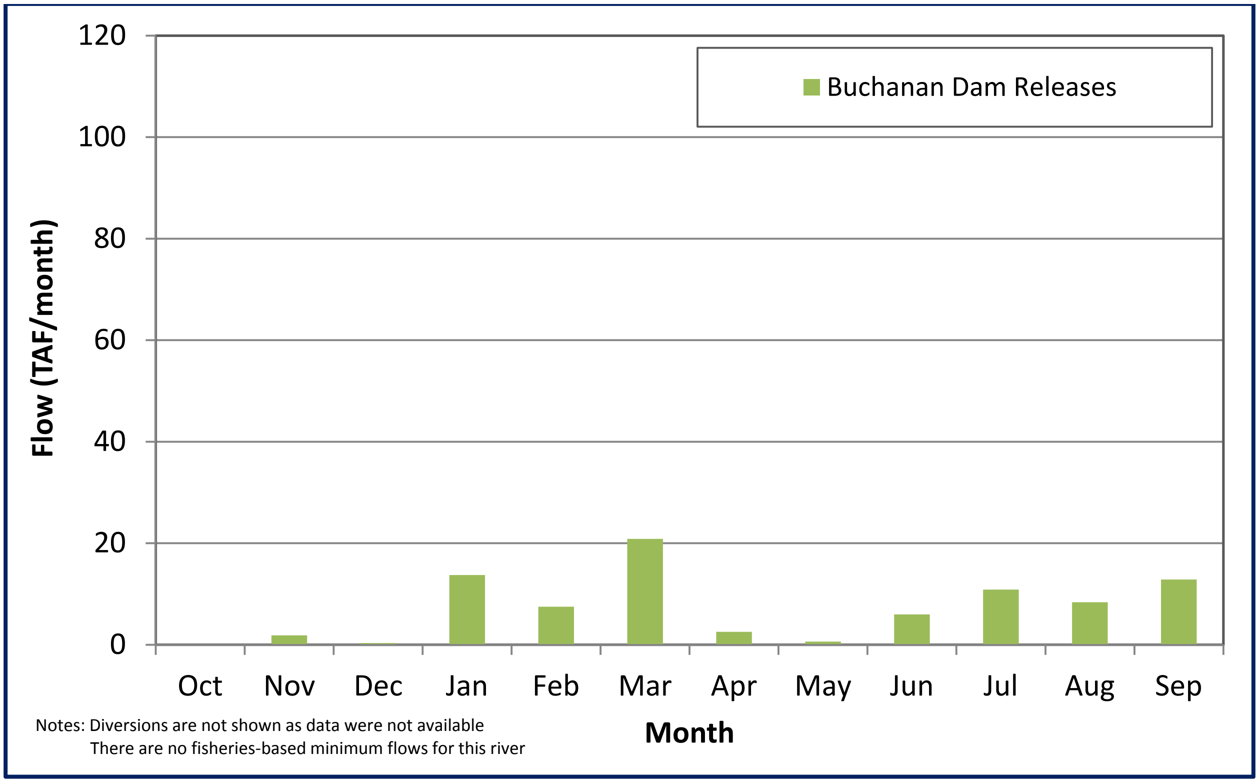


Figure 26: Monthly Releases for Buchanan Dam for a Wet Year (Water Year 1983)

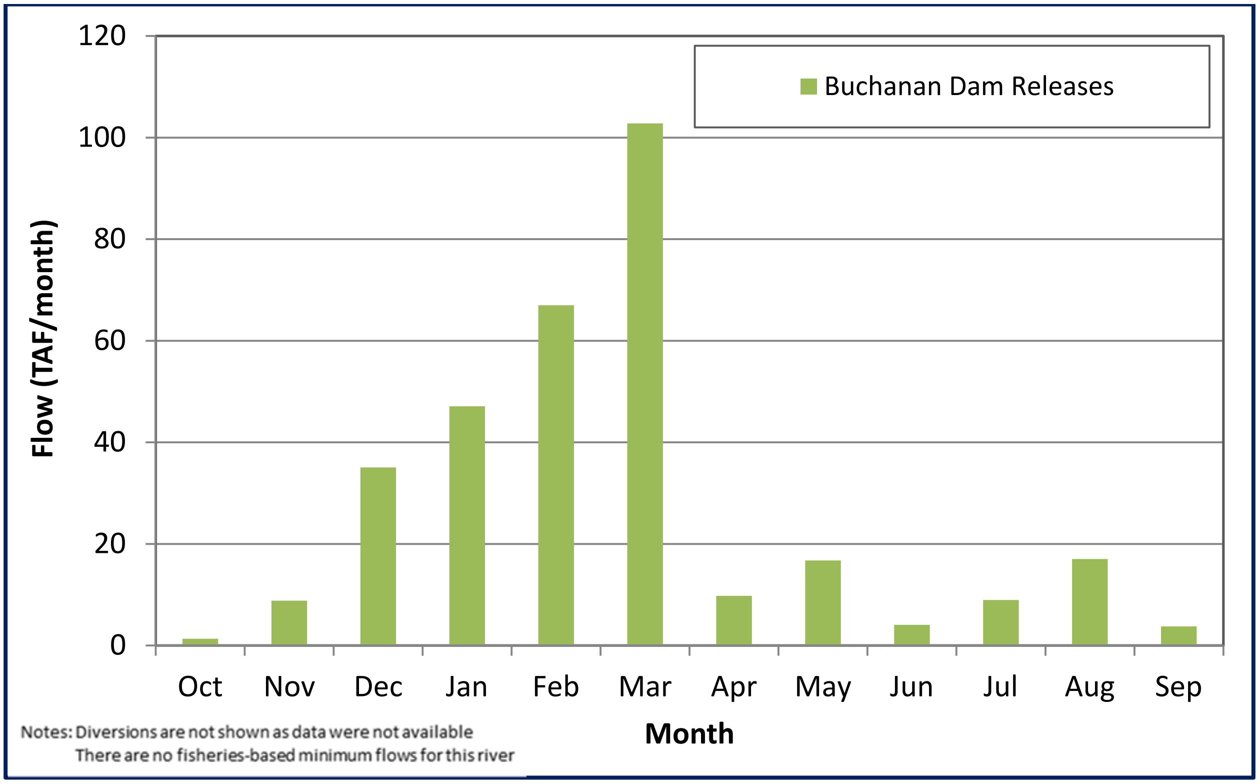
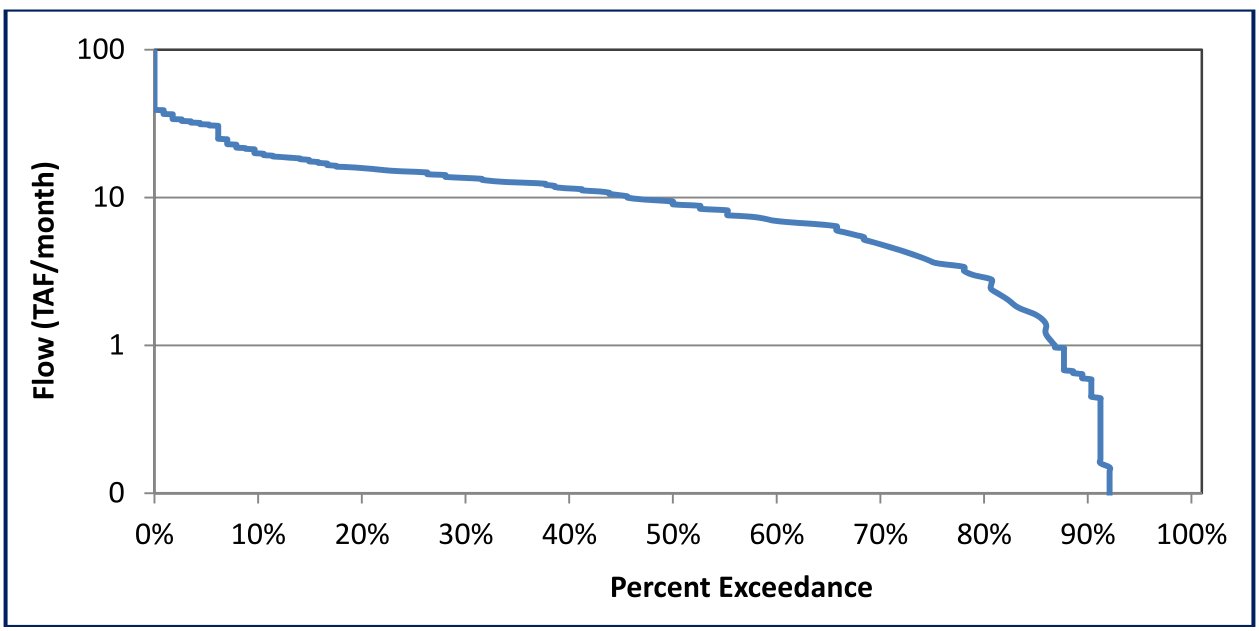


Figure 27: Percent Exceedance of Buchanan Dam Release Flow from June to August



Fresno River

The Fresno River is located in Central California and is the most southerly of the major eastside tributaries of the San Joaquin River. It rises on the western slopes of the Sierra Nevada and flows in a southwesterly direction through the mountains and foothills and across the valley floor (via the Eastside Bypass) to the San Joaquin River. Flow in the Fresno River is regulated by Hidden Dam. The Fresno River drainage area above Hidden Dam consists of 234 square miles of mountainous and foothill terrain (Madera Irrigation District, 2011). There are two additional dams downstream of Hidden Dam to regulate flow and divert water: Madera Lake Reservoir and Franchi Diversion Dam, respectively. In addition, flows released downstream of the dams are diverted at Madera Irrigation District canals and at numerous smaller riparian diversions. A schematic diagram of the Fresno River is shown in Figure 28.

Hidden Dam monthly historical release data are available from the U.S. Army Corps of Engineers for 1975 to present (J. L. Ballew, personal communication, September 26, 2013). These data were analyzed to estimate the winter flows that could be used for recharge. Figure 29, Figure 30, and Figure 31 show the monthly Hidden Dam releases for a dry, an average, and a wet year, respectively.

There are various water rights on the natural flows of the Fresno River. The following are the Fresno River water rights beginning with the highest priority (Madera Irrigation District, 2011):

- Madera Irrigation District's 1916 Judgment decreed right
- Riparian water rights
- Senior appropriative rights who have diversion right licenses issued by the State Water Resources Control Board
- U.S. Bureau of Reclamation Hidden Dam storage water right under License 13836 (Madera Irrigation District Central Valley Project [CVP] Water).

There are numerous riparian water right holders on the Fresno River. Historical riparian diversion data for Fresno River were not readily available.

Locations of the Madera Irrigation District canals are available from Madera Irrigation District’s website (Madera Irrigation District, 2013) and are shown in Figure 28. There are also limited data available for historical deliveries by Madera Irrigation District from Fresno River and delivery capacity of Madera Irrigation District canals. Madera irrigation District can divert up to 10,000 AF/month from Fresno River at headgates, consistent with the streamflow exceedance chart for summer months shown in Figure 32, which shows a lower slope at approximately 10,000 AF/month.

There are no minimum flow requirements for fisheries on the Fresno River (State Water Resources Control Board, 2012). Due to a lack of delivery data, it was assumed that 10% of the Madera Irrigation District’s assumed delivery capacity (10,000 AF/month) is not available to convey winter flood flows. This 10% flow capacity is assumed to be used for riparian water rights and capacity used by Madera Irrigation District for other purposes.

Results of the recharge water availability analysis are provided in Section 4.3.

Figure 28: Schematic Diagram of Fresno River

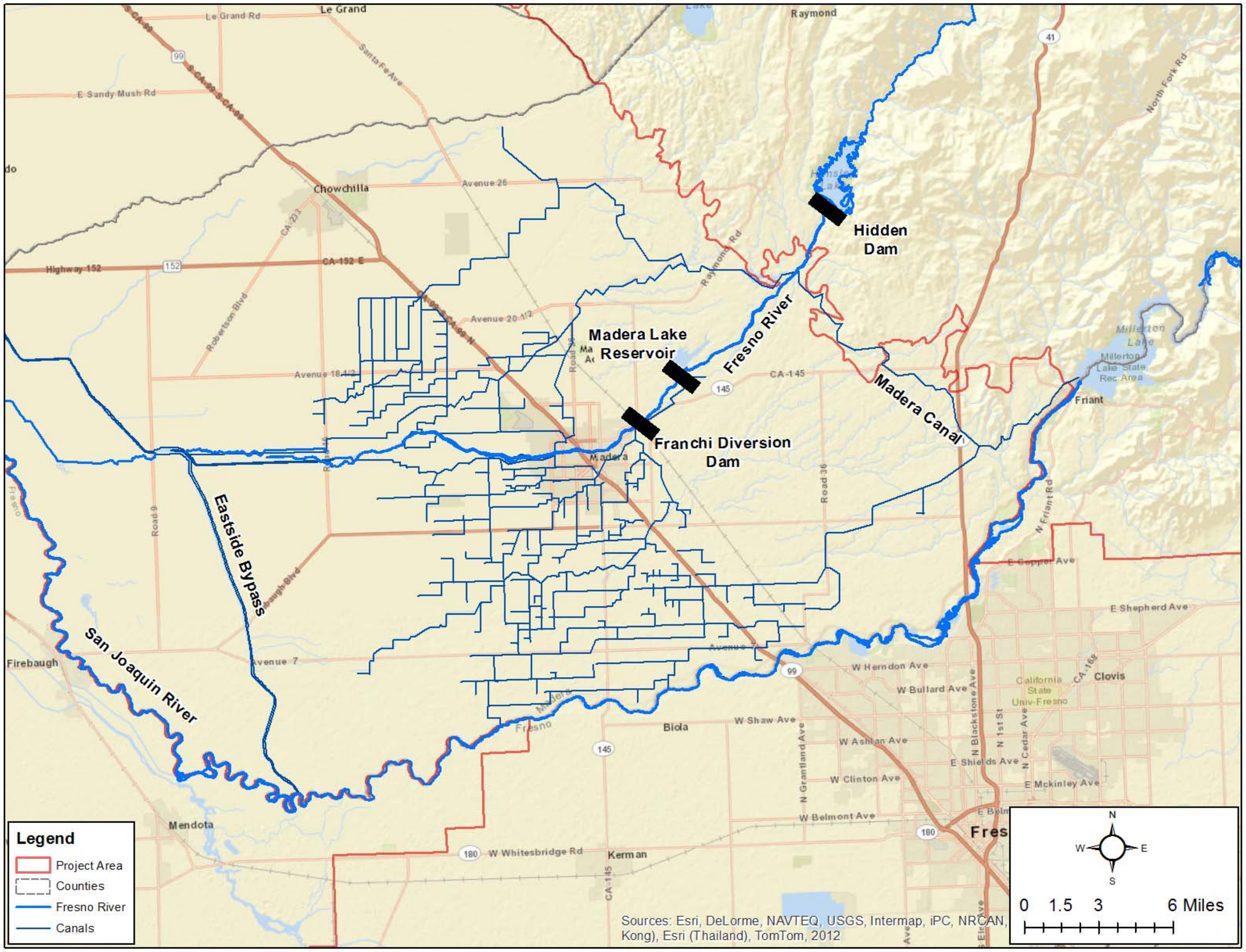


Figure 29: Monthly Releases for Hidden Dam for a Dry Year (Water Year 1992)

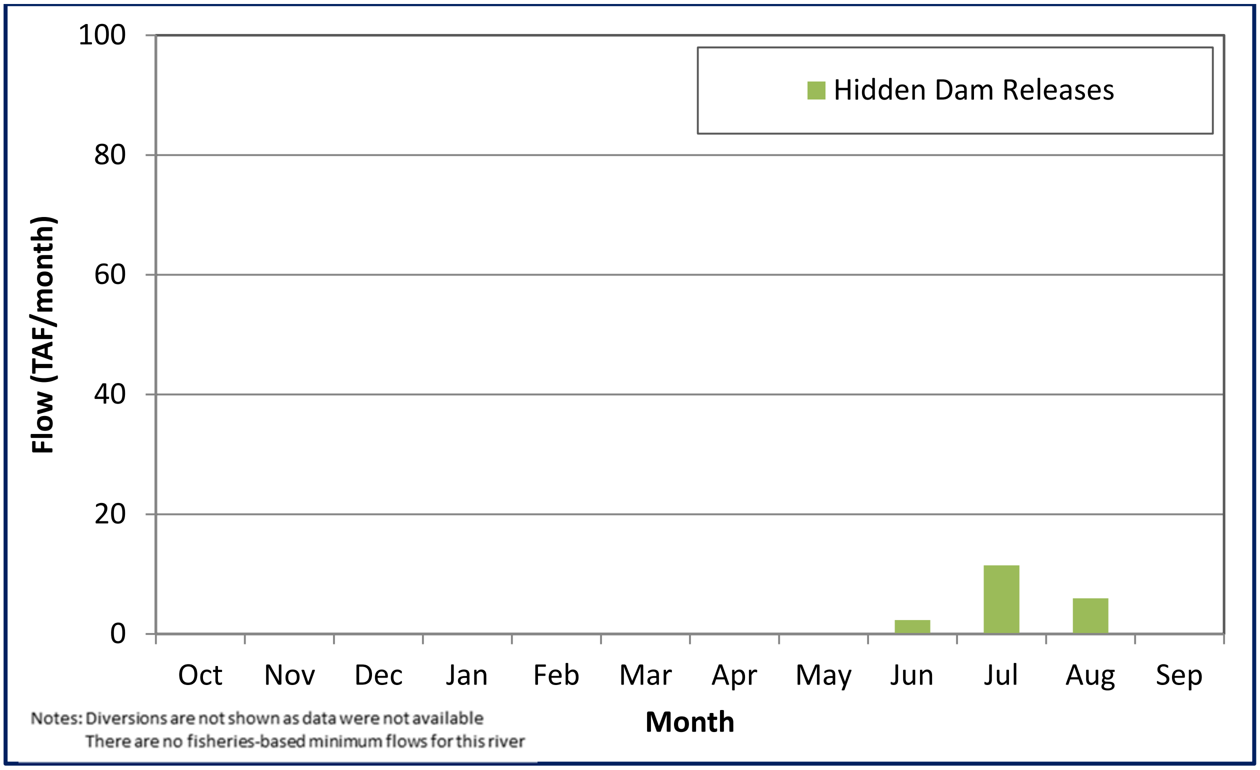


Figure 30: Monthly Releases for Hidden Dam for an Average Year (Water Year 1979)

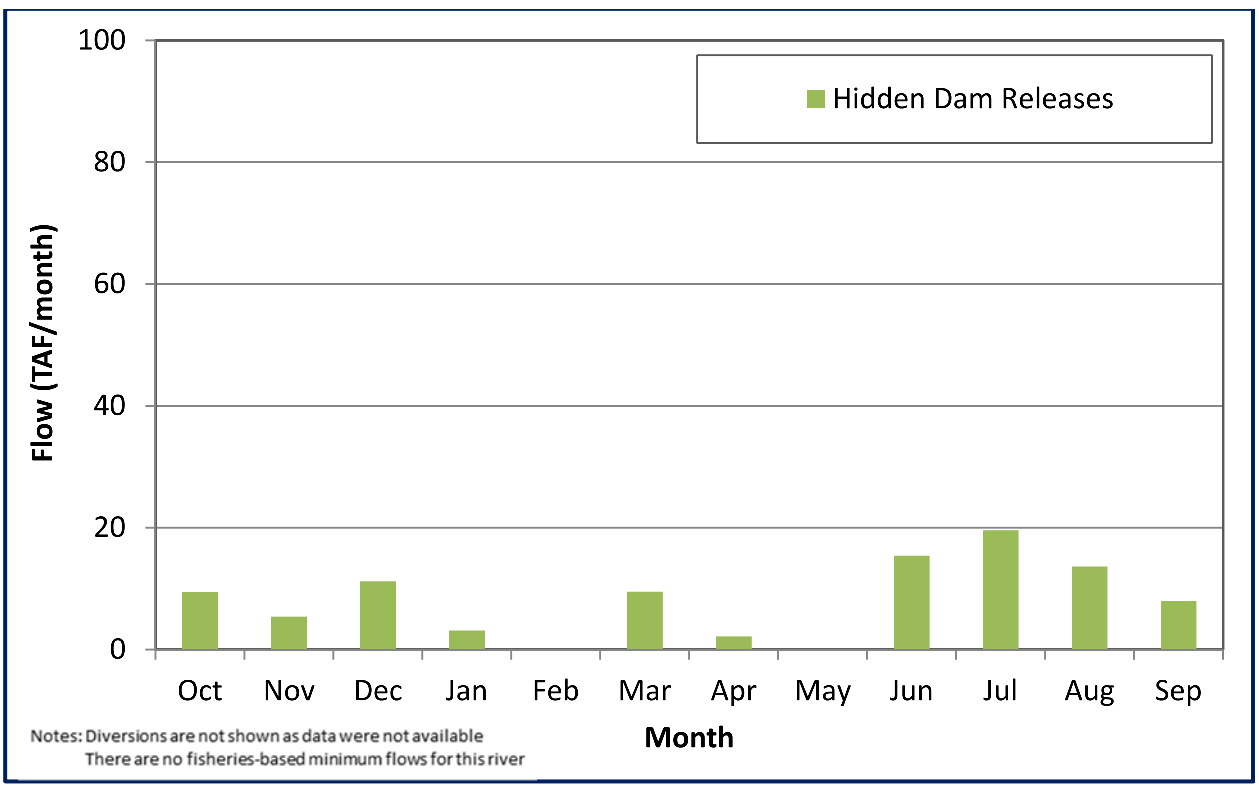


Figure 31: Monthly Releases for Hidden Dam for a Wet Year (Water Year 1983)

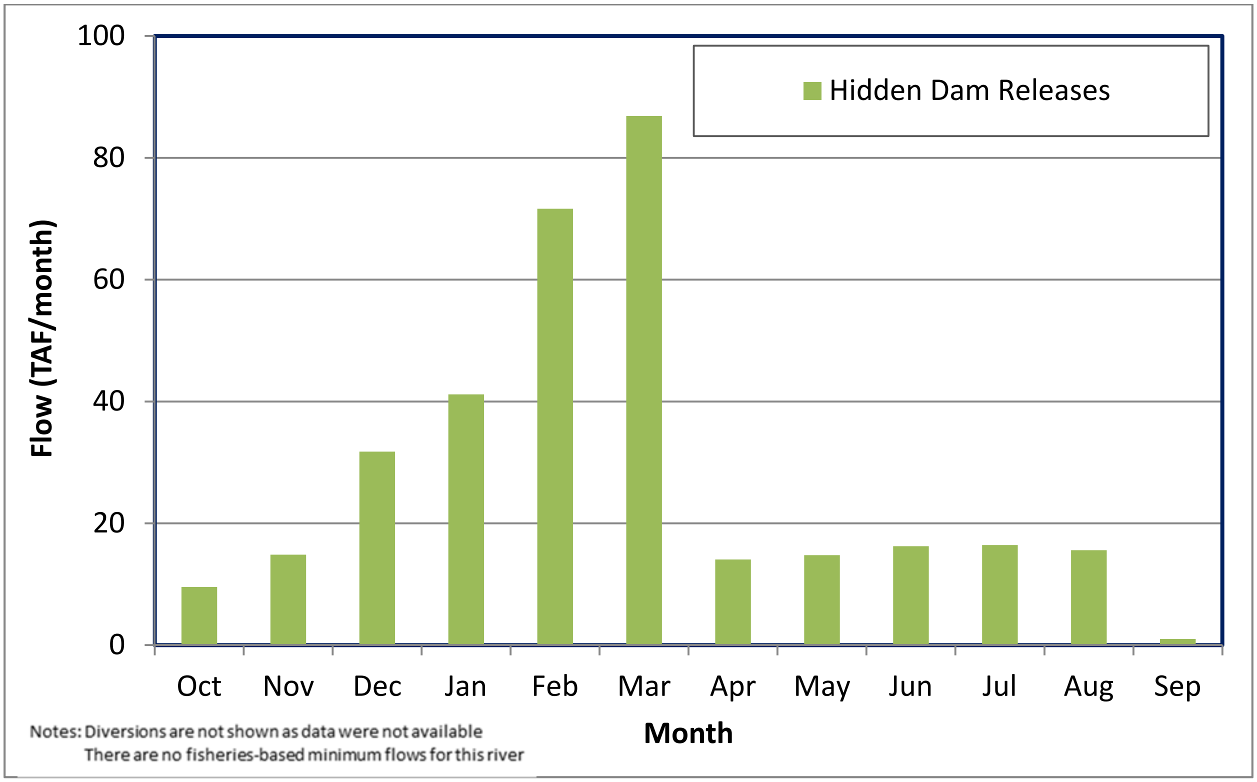
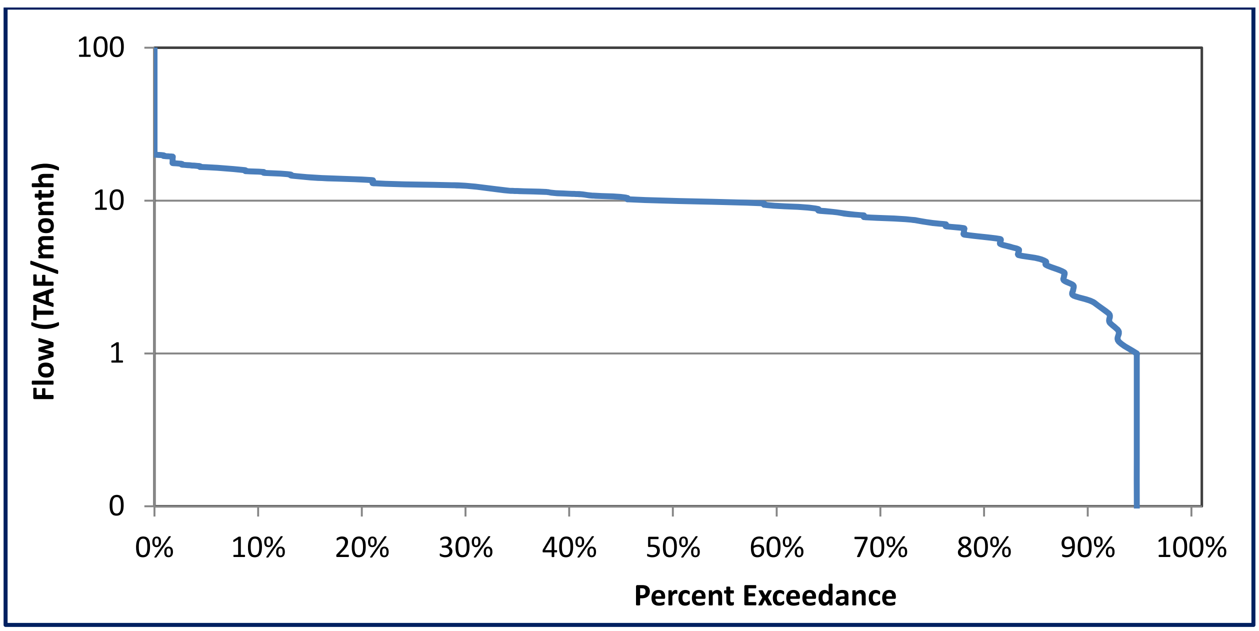


Figure 32: Percent Exceedance of Hidden Dam Release Flow from June to August



Kings River

The Kings River is located in South-Central California. Pine Flat Dam, completed in 1954, separates the upper and lower reaches of the river. The upper reach rises on the western slope of the Sierra Nevada and flows in a southwesterly direction through the mountains to Pine Flat Dam. The drainage area above the dam is 1,545 square miles. The dam is 95 river miles upstream of where the Kings River South Fork joins the Tulare Lakebed, and 113 miles upstream of the North Fork Kings River confluence with the San Joaquin River (Ecorp Consulting, Inc., 2007). In addition to the flow regulation by Pine Flat Dam, numerous weirs downstream of the dam are used to control diversions into the specific canals for Kings River Water Association (KRWA) member water districts or ditch companies. A schematic diagram of Kings River is shown in Figure 33.

Flood flows not stored behind the Pine Flat Dam or diverted into irrigation districts canals run down the Kings River to the Lower Basin. From there, the flood flows may be directed to either the North Fork of the Kings River and the James Bypass flood channel, or to the South Fork of the Kings River and the Tulare Lake Basin. During flood events, river water is available to all of the KRWA member agencies.

Flow in excess of the downstream water supply needs in the Kings River is normally first diverted into the North Fork which flows into Fresno Slough, Fish Slough, and James Bypass; together they constitute the Kings River North channel system (Ecorp Consulting, Inc., 2007). Stream flows at James Bypass gaging station are available from the USGS; this flow represents surface water that has been historically lost from the Kings Basin. These data were used to estimate the winter flows that could be used for recharge in the Kings Basin. Figure 34, Figure 35, and Figure 36 show the monthly Kings River flows at James Bypass for a dry, an average, and a wet year, respectively.

Alta Irrigation District (AID), Consolidated Irrigation District (CID), and Fresno Irrigation District (FID) are members of KWRA and divert water from the Kings River. Existing canal locations and capacity data were obtained from AID, CID, FID, and Kings River Conservation District (KRCD). Canal locations for the major AID, CID, and FID canals are shown in Figure 33. Canal capacity data for the major AID, CID, and FID canals are summarized in Table 5.

Historical headgate diversion data for AID’s Alta Main Channel, CID’s Consolidated Canal, and FID’s Fresno Canal and Gould Canal were obtained from KRWA. These data were subtracted from the headgate capacities in Table 5 to estimate the available distribution capacity during the winter months. Figure 34, Figure 35, and Figure 36 show the monthly diversions from Kings River (total of diversions for AID, CID, and FID) for a dry, an average, and a wet year, respectively.

Results of the recharge water availability analysis are provided in Section 4.3.

Figure 33: Schematic Diagram of Kings River

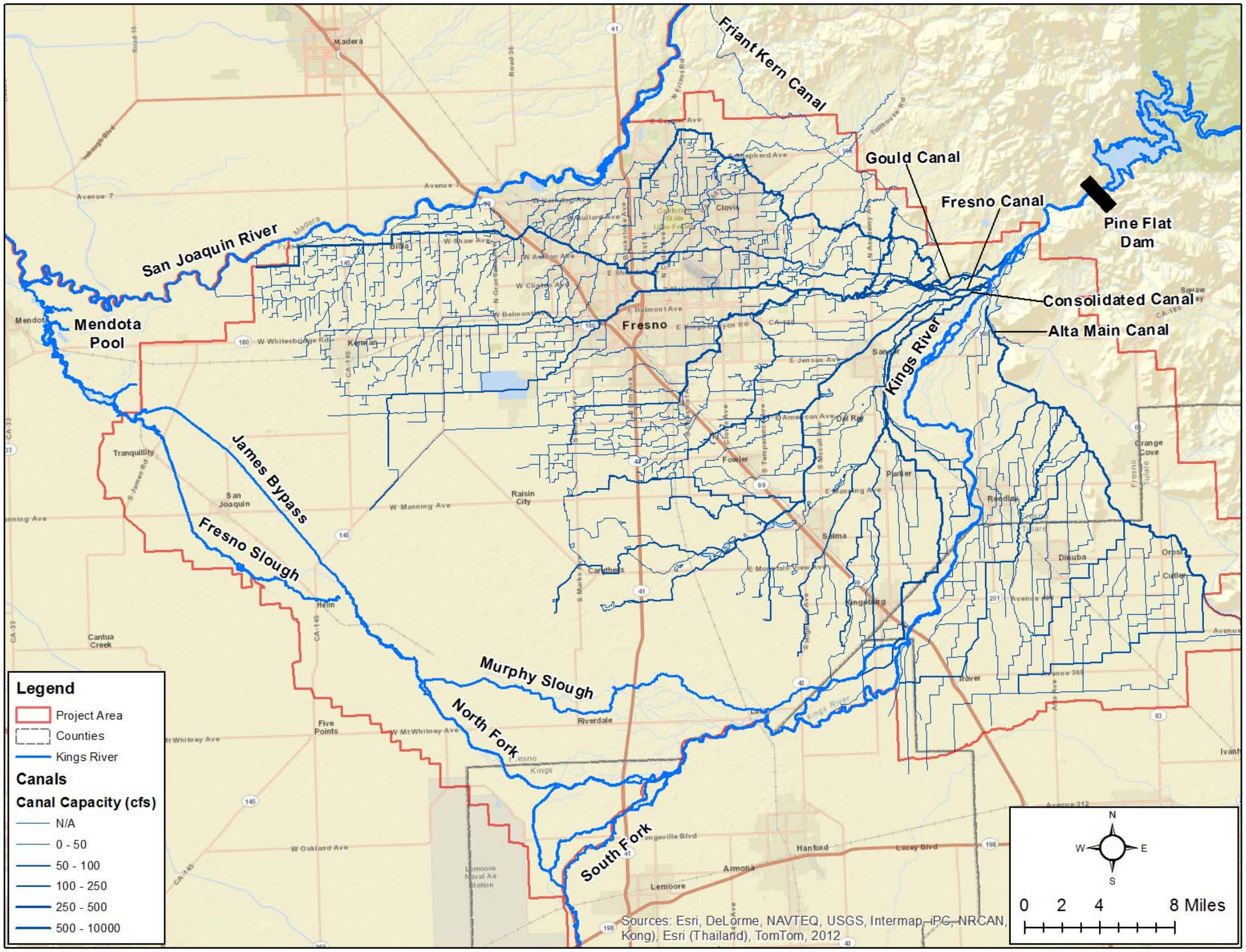


Figure 34: Monthly Kings River Flows at James Bypass and Diversions for a Dry Year (Water Year 1992)

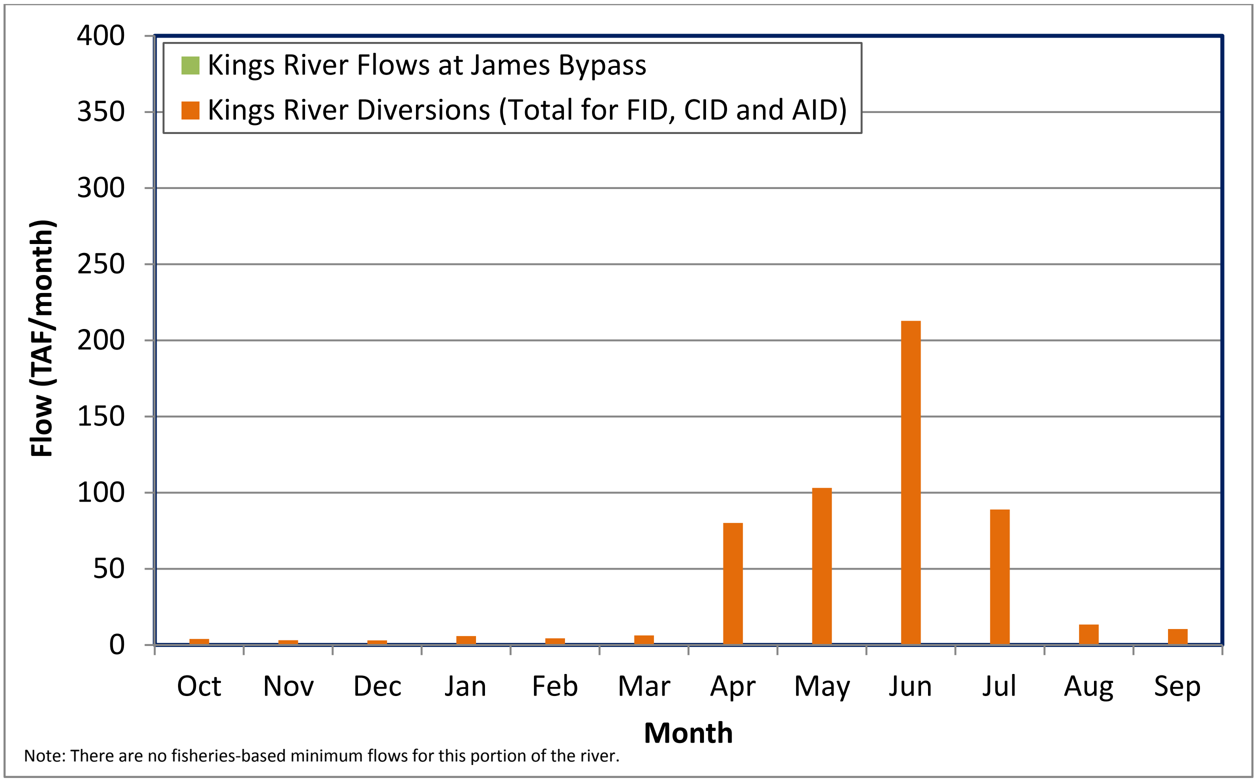


Figure 35: Monthly Kings River Flows at James Bypass and Diversions for an Average Year (Water Year 1979)

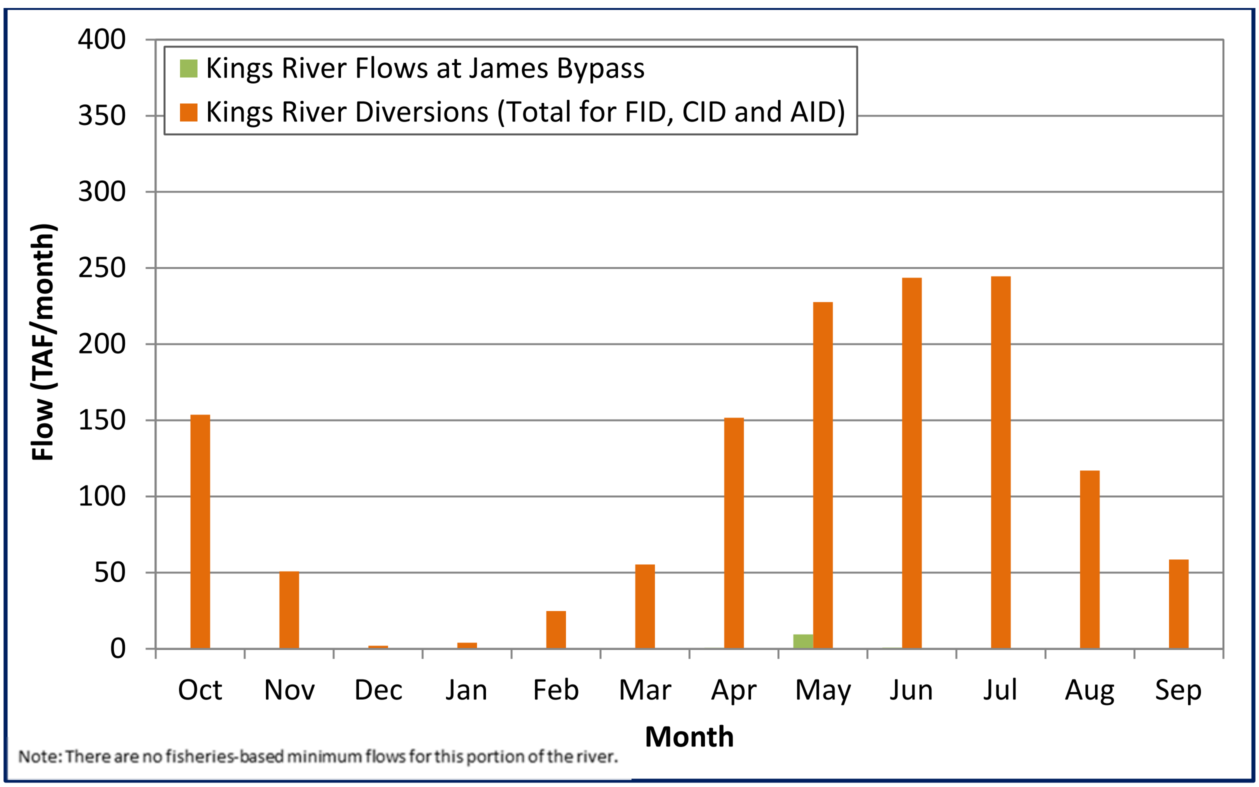
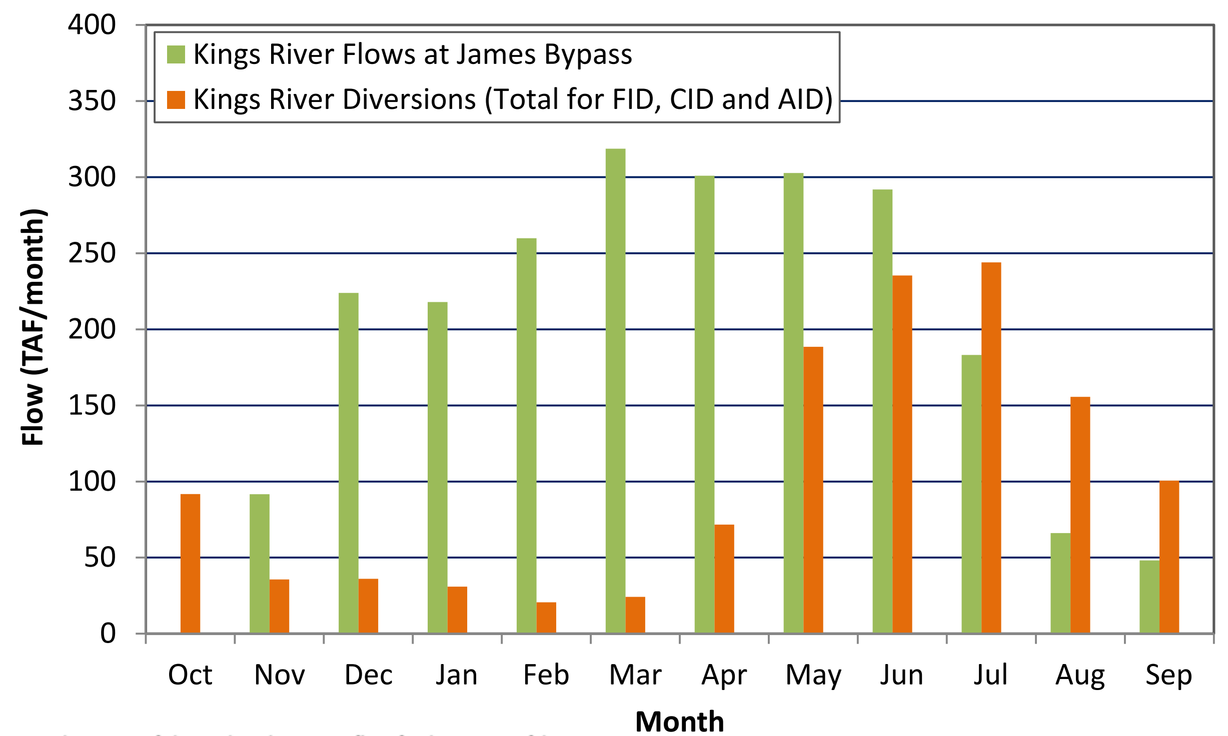


Figure 36: Monthly Kings River Flows at James Bypass and Diversions for a Wet Year (Water Year 1983)



Note: There are no fisheries-based minimum flows for this portion of the river.

Table 5: Headgate Capacities for Major AID, CID and FID Canals

Canal Name	District	Capacity (cfs)
Alta Main Canal	AID	850
Consolidated Canal	CID	2,100
Fresno Canal	FID	1,500
Gould Canal	FID	500

3. Storage and Migration of Recharged Water (Integrated Hydrologic Modeling)

The information developed through the land recharge suitability, crop recharge suitability, and daily recharge water availability analyses was used in the C2VSim model to estimate the recharge potential within the project area as well as the potential changes in inflows, outflows, and storage for the groundwater system at a regional scale.

C2VSIM Integrated Hydrologic Model

Integrated hydrologic modeling to evaluate the effectiveness of recharge through winter flooding was performed using the DWR's C2VSim model, which covers the entire Central Valley (3,300 square miles), including the full project area, as shown Figure 37. The version of model used is the recently developed fine grid one, which has significantly higher spatial resolution, and provides more accurate flow simulation capabilities. C2VSim is based on the Integrated Water Flow Model (IWFM) platform, which is a quasi-three-dimensional model that simulates monthly hydrologic processes in the surface and subsurface environments as one integrated system. The C2VSim model simulates major rivers, including those being analyzed as part of this effort: Merced River, Chowchilla River, Fresno River, and Kings River. The model is calibrated by comparing simulated and recorded groundwater levels and streamflows during the model simulation period of 1922 to 2009. The C2VSim model grid consists of 4,564 nodes and 5,367 elements within the project area. The model grid is refined around the streams with an average 0.5 mile node spacing; the node spacing increases gradually away from the streams to an average of 1.5 miles. The model simulates major rivers, including those being analyzed as part of this effort: Merced River, Chowchilla River, Fresno River, and Kings River. Water and land use management are represented in the C2VSim model by subdividing the model area into 21 subregions (Figure 37). Subregion 13, Subregion 16, Subregion 17, and a portion of Subregion 15 are within the project area. The subregions are used for independent analysis of water budgets and hydrologic conditions for each management area. The model subregions are based on depletion study areas (DSAs), originally created by the DWR Division of Planning for estimating regional water supplies and demands.

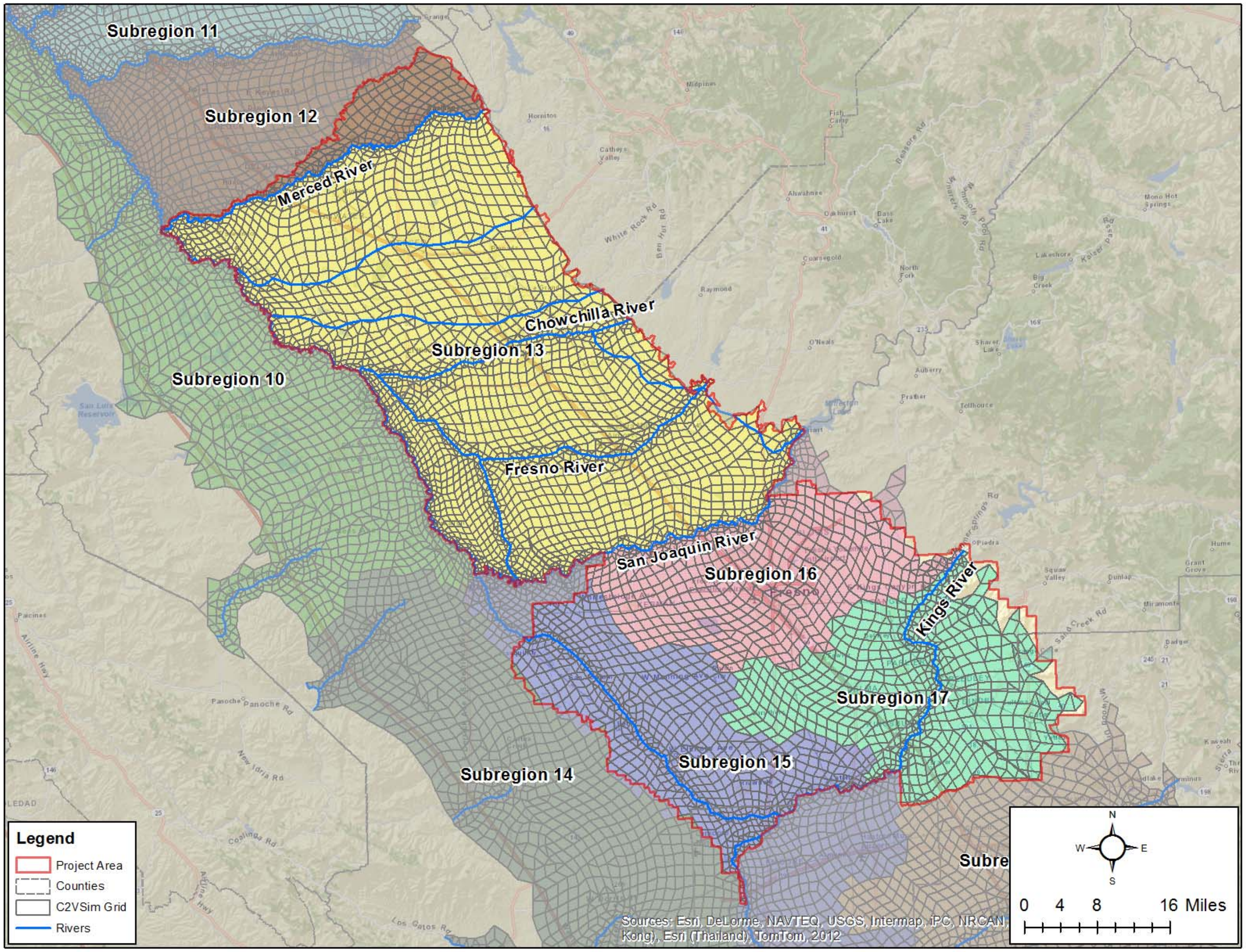
In addition to monthly historical stream inflows, surface water diversions, and precipitation, C2VSim also contains land use and crop acreages from October 1921 through September 2009. C2VSim dynamically calculates crop water demands; allocates contributions from precipitation, soil moisture, and surface water diversions; and calculates the amount of groundwater pumping required to meet the remaining demand. The model simulates the historical response of the Central Valley's groundwater and surface water flow system to historical stresses and can be used to simulate the response to projected future stresses.

Other C2VSim features significant to this study include the following:

- A long hydrologic period, which can incorporate the significant historical hydrological variations (dry, multiple dry, wet, and multiple wet years) in the Central Valley.

- Finer resolution of the C2VSim grid along the major streams, which results in a better simulation of stream-aquifer interaction and more accurate assessment of groundwater recharge impacts on stream flows.
- Detailed water budget information for surface processes including land and water use systems, stream and canal systems, the groundwater system, and the soil system.
- A user-friendly ArcGIS-based graphical user interface (GUI) that is used to perform model scenarios and display and interpret model results.

Figure 37: C2VSim Model Grid and Subregions within the Project Area



Existing Condition Baseline for C2VSim

Using the calibrated C2VSim model, which has a long-term (88 years) hydrologic record from water year 1922 to 2009, an Existing Conditions Baseline (Baseline) was developed to analyze different scenarios. The Baseline applies current levels of land use, water use, and water supplies to the model hydrologic period. The results of the recharge scenarios were compared with the results of the Baseline Scenario to analyze their impacts. The model input files for the Baseline were developed using the following assumptions:

- Land use and crop acreages for the Baseline are based on the latest information in the calibrated C2VSim model.
- Agricultural water demand was estimated based on the Baseline land use and crop acreage.
- Agricultural surface water supply was estimated based on an average water year type.
- Urban water demand estimates are based on the latest information in the calibrated C2VSim model.
- Urban surface water supply was developed from the CalSim-II Draft WSP Delivery Reliability Study.
- Groundwater pumping was calculated internally within the model to meet the remaining demand after the surface water supplies.
- Stream inflows were developed from the latest CalSim-II Draft WSP Delivery Reliability Study.

Recharge Areas

The recharge capacity of the selected recharge areas is dependent on site conditions and significantly influenced by soil conditions, depth to groundwater, and permeability of aquifer material as described in Section 2.1. In addition, maximizing the use of existing infrastructure was considered as a criterion for selecting the recharge areas. The recharge areas were selected using the following steps:

- Historical wintertime flood flows that can be conveyed were examined to determine the maximum volume of water that could be available for recharge during a month (the month with the maximum volume of water for the rivers was December 1982).
- Maximum volume of water that can be recharged was divided by the recharge rate (approximately 9 ft/month[3]) to calculate the maximum area needed for recharge.
- Canals (Figure 19, Figure 23, Figure 28, and Figure 33) and the C2VSim model grid (Figure 37) were overlain on the recharge suitability index map in GIS.
- C2VSIM model elements were selected as recharge areas according to the following criteria:
    - o Adequate delivery capacity from downstream of the canals to the headgates with selection starting from the downstream portion of the canal systems and ending at the headgates.
    - o Connected to a canal to avoid improvements or new facilities.

[3] These recharge rates are relatively conservative given the soil conditions and other information from personal communications with local authorities who have operational experience around the project area. Additionally, these rates are applicable for the maximum volume of water that needs to be recharged during a full month. The recharge rates are considerably lower than these rates for most of the months, which do not have water available for all days.

   - Located away from major rivers to minimize discharge to streams.
   - Located away from areas with shallow groundwater levels to avoid raising the groundwater to a level that waterlogs crops or has other negative impacts.
   - Have a very high or high recharge index. If the maximum area cannot be obtained with very high or high recharge index, then the average recharge index may be considered.
   - The sum of the agricultural areas should be equal to or greater than the maximum area needed for recharge.
- It was assumed that no drying periods are required during the recharge periods, as details on the frequency and duration of drying periods have not been clearly identified. The results of the analysis may remain valid with drying periods, although additional acres of land and/or a longer time period would be required to meet the same volume of recharged water.

Recharge Timing

Flows from the Merced River, Chowchilla River, Fresno River, and Kings River were analyzed for the following time intervals for availability of excess winter flows that can be used for on-farm capture for recharge:

- Winter: Beginning of December to end of February
- Extended Winter: Beginning of November to end of March

These two scenarios were selected to bracket a range of recharge potential from varying flood periods for different crops in the project area. It should be recognized that Bachand, et al. (2012) showed that such on-farm recharge practices can be feasible well into the spring and summer. A longer recharge period can potentially increase the recharge opportunities, pending availability of water, conveyance capacity, and crop suitability.

4. Integrated Hydrologic Modeling Input Data and Results

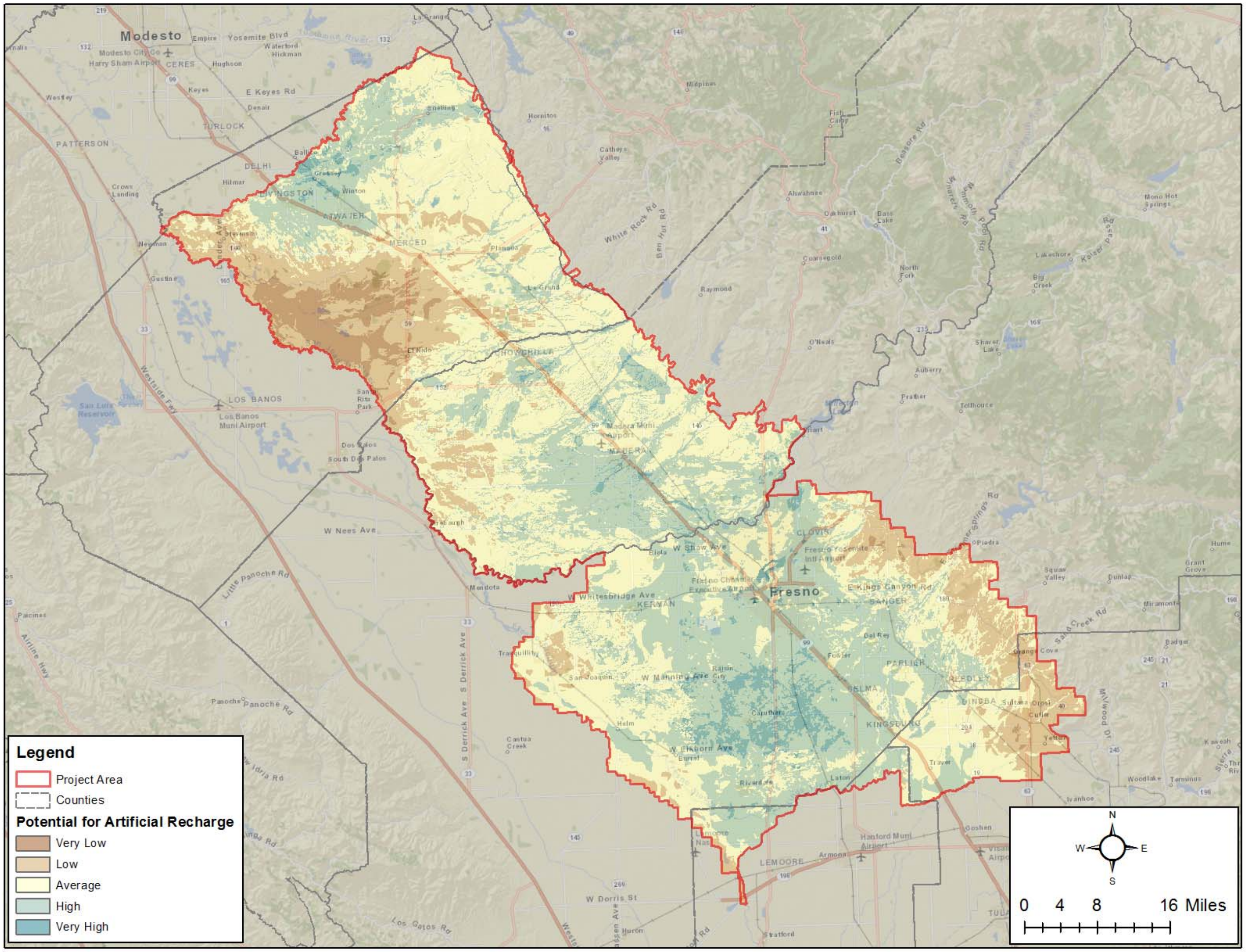
4.1 Land Recharge Suitability

The Recharge Suitability Index was developed through the ranking and weighting procedures discussed in Section 2.1. Figure 38 shows the Recharge Suitability Index, indicating that areas conducive to recharge are generally:

- Along Highway 99 to the northwest of Merced and along the Merced River
- In the middle portions of the Kings River and Fresno River alluvial fans

Areas with lower recharge suitability are primarily in the southern portions of Merced County, western Madera County, and in portions of Fresno County near the foothills.

Figure 38: Recharge Suitability Index



4.2 Crop Recharge Suitability

The suitability of selected crops was evaluated as described in Section 2.2. Results regarding water application timing and duration for different crops are shown below (Table 6).

Water Application Timing

Crop growth cycles and cultural practices were considered to determine the most likely period for winter water application. Local experience (Bachand, et al., 2012) and survey information (Sustainable Conservation, 2014) suggest that ponding on coarser soils is feasible. This local experience highlights the differences between local conditions specific for this effort and most studies of flood impacts on crops, which have generally shown that all crops are likely to suffer ill effects if submerged conditions persist for extended period when the crop is actively growing. Local conditions specific for this effort allow for winter water application due to several factors, including:

- Oxygen deprivation may be less of an issue with cold floodwater which carries more oxygen during the cooler winter months and during snow melt events well into the spring and early summer. Additionally, water application is controlled and thus can be pulsed or otherwise managed to minimize periods of water logging and maximize recharge volumes.
- Literature focuses on heavy soils where flooding and yield declines have been documented, while flood impact studies have rarely been conducted on sandy soils since it is very difficult to achieve standing water without continual input of flood water.
- Most of these crops were historically flood irrigated and can handle short duration flooding well into the growing season. These crops were also historically over-irrigated during the summer months due to inefficiencies of furrow or alley flooding methods. Reproducing or expanding some of these methods when flood water is available can increase recharge while minimizing the flood duration on the crop.
- Damage to soil structure from flooding is usually associated with equipment operation causing compaction of heavier wet soils. Sandy soils drain quickly and are much more difficult to compact. Additionally, water deliveries can be managed to dry soils prior to equipment access.

Local experience is limited with respect to soils, crops, and timing. To reflect the associated uncertainties while additional surveys are performed, potential recharge periods were focused during the winter when crops are not actively growing rather than extending into the growing season where impacts may be more likely.

Table 6 provides potential recharge periods for permanent and semi-permanent crops. Trees and vineyards require careful water management at the period of bud break and through the growing season until harvest. After harvest, leaf fall occurs and the crop enters a dormant period. Water applications at this time must be managed to maintain soil fertility, but to avoid a fall bloom if a period of warm temperatures occurs. Therefore, based on available literature values, potential recharge periods are December through January for almonds and vineyards, and December through February for pistachios, pasture, and alfalfa. Again, local experience (Bachand, et al., 2012) and survey information (Sustainable Conservation, 2014) suggest that these are very conservative recharge periods and that longer periods of recharge are feasible. However, even during the dormant season, literature indicates that water-logged soils may impact long-term plant health, lead to soil structure and fertility problems, and increase the incidence of disease (see Appendix A). For alfalfa and pasture, water-logged soils would impact harvesting operations, leading to undesirable compaction and potentially preventing access during harvest. Additional work may be required to reconcile the differences in crop tolerances seen in the Bachand, et al. (2012) study and the general body of literature.

Table 6: Potential Recharge Periods for Perennial Crops based on Cultural Practices and Growth Periods

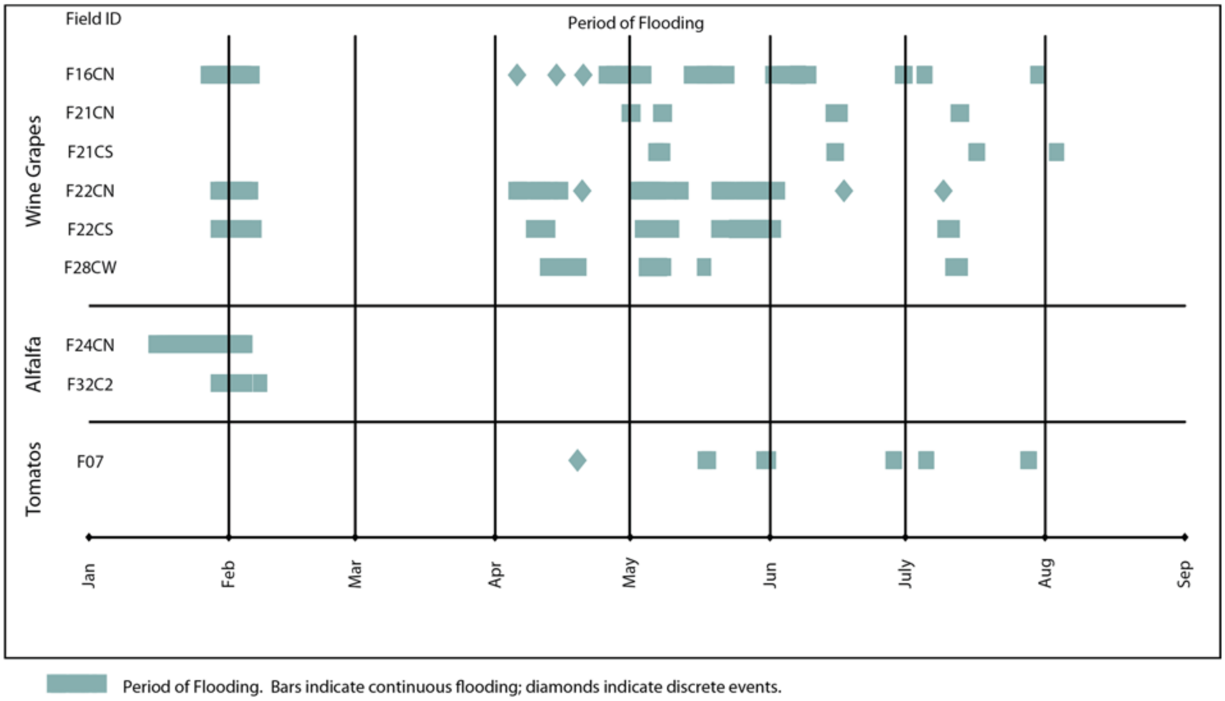
Crop	Bud Break	Typical Harvest Date[1]	Leaf Fall	Potential Recharge Period[2]	Source
Almonds	Late February	August - October	November	December - January	Blue Diamond
Vineyards	Mid February	Late August - Early October	Early November	December - January	Geisel, Farnham, & Vossen, 2002
Pistachios	Late March	September	Late November	December - February	UC Davis, 2005
Pasture		November - December		December - February	
Alfalfa		November - December		December - February	Orloff & Putnam, 2007

[1] For alfalfa and pasture, harvest dates apply to the last cutting of the calendar year.

[2] Potential recharge periods are based solely on the timing of critical cultural practices and crop growth periods. Other factors may further impact potential recharge period. Local experience (Bachand, et al., 2012) suggests recharge periods may be longer for local conditions considered as part of this project.

These literature-based periods of recharge are more limited than the periods implemented as part of the Terranova Ranch pilot project (Bachand, et al., 2012), located 25 miles southwest of Fresno. At Terranova, a pilot project was performed to study the potential impacts and benefits of groundwater recharge through winter flooding of agricultural land, as well as flooding during the growing season. The period flooded for different fields at Terranova is shown in Figure 39. Little to no impacts were noted on plants or yield. Additional field studies are planned to help confirm and expand these results.

Figure 39: Period of Flooding, Terranova Pilot Project 2011



For annual crops, Table 7 provides potential recharge periods. In California, most grains are planted in late fall and harvested in spring. This practice utilizes winter rains to supply crop water needs or to augment irrigation supplies. The winter growth period is also the most likely time that excess winter water would be available for additional applications for recharge. Corn, cotton, and tomatoes are typically planted in early to late spring and harvested in late summer to early fall. This leaves the winter months available for potential recharge periods, although impacts to soil structure and fertility must be considered. In addition, preparation of the land for planting and cultivation after harvest require soil that is sufficiently dry to permit equipment travel with minimal compaction. This may further shorten the potential recharge period.

Table 7: Potential Recharge Periods for Annual Crops Based on Cultural Practices and Growth Periods

Crop	Typical Plant Date[1]	Typical Harvest Date[1]	Potential Recharge Period[2]	Source
Grain/Hay				
Oats	October - January	May - June	June - September	UC Division of Agriculture and Natural Resources, 2006
Wheat	Mid November - January	May - June	June - October	
Barley	Mid November - February	May - June	June - October	
Corn				
Silage	Late May	September	October - April	Frate, Marsh, Klonsky, & De Moura, 2012
Sweet	February - July	June - October	July - January	Smith, Aguiar, & Caprile, 1997
Cotton	April - May	October - November	November - March	Hutmacher, et al., 2012
Tomatoes				
Fresh Market	March - July	June - October	July - February	Strange, Schrader, & Hartz, 2000
Processing	Late January - Early June	June - October	July - December	Hartz, et al., 2008

[1] Plant and harvest dates were reported for the region of interest, where provided by the listed source.
[2] Potential recharge periods are based solely on the timing of critical cultural practices and crop growth periods. Other factors may further impact potential recharge period. Presence of double cropping would further reduce the potential recharge period for the indicated crop. Local experience (Bachand, et al., 2012) suggests recharge periods may be longer for local conditions considered as part of this project.

Water Application Duration

While crops are actively growing, one to two days is generally considered by the literature to be the maximum duration that water can stand on a field without impacting crop growth and period yields. However, opportunities exist to hold water on the field for longer durations during the dormant period (Table 6). Hale (1959), as reported by Kasimatis (1967), showed that an 8-week flooding period on dormant grapevines did not affect bud break nor the subsequent growth of roots or shoots. The University of Florida (1998) reported that water can be held on dormant alfalfa for 7 to 10 days without impacting future yields.

During the growing season, water application depths could be increased slightly and intervals between irrigation could be reduced for most crops. This must be done with care so that the soil does not remain saturated for extended periods of time. Recommendations will have to be tailored to each crop's agronomic needs and cultural practices. For example, a number of alfalfa diseases and pests have had intensified impacts under conditions of frequent irrigation and high water tables. Additionally, the frequent cutting cycles must be considered when planning to apply floodwaters to alfalfa fields. Soil fertility management also needs to be considered with flooding fields for recharge to prevent nutrient loss.

Table 8: Maximum Periods for Standing Water

Crop	Maximum Period for Standing Water Without Crop Damage	
	Growing Season	Dormant Period
Almonds	Information Not Found in Literature	Information Not Found in Literature
Vineyards (Established)	1 day, "Managing" (State of Victoria, 2011) 1-2 weeks (Terranova pilot study)	Eight weeks (Hale, 1959 as cited in Kasimatis, 1967)
Pasture	Withstand several days (~3 days) of flooding without injury (University of Florida, 1998)	Information Not Found in Literature
Alfalfa	Less than 3 to 4 days (University of Florida, 1998)	7 - 10 days (University of Florida, 1998) 1-2 weeks (Terranova pilot study)
Pistachios	Information Not Found in Literature	Information Not Found in Literature
Oats	Greater ability to recover from waterlogging compared to wheat and barley (Setter & Waters, 2003)	
Wheat	6 days immediately after germination reduces populations to 12 - 38% of non-waterlogged plants (Setter & Waters, 2003)	
Barley	10 - 15 days reduces yield by 1% to over 40% damage depending on variety (Setter & Waters, 2003)	
Corn	For young corn: 4 days (with temperature less than 65 deg. F) or fewer days for warmer temperature (Nielsen, 2014)	
Cotton	2 days (Thongbai, Milroy, Bange, Rapp, & Smith, 2001)	
Tomatoes	2 days (University of Delaware, Cooperative Extension, 2013) One day (Terranova pilot study)	

Overall Compatibility

Established vineyards and alfalfa appear to be suitable for winter water application and further investigation is warranted. Local research at Terranova (Bachand, et al., 2012) and survey information (Sustainable Conservation, 2014) suggest that recharge may occur in the winter for these crops as well as in the growing season for vineyards. Bachand et al. (2012) also indicated opportunities for recharge on tomatoes during the growing season. The local research is utilized along with information from the literature, which is only partially applicable as literature information tends to focus on fine-grained soils with uncontrolled flooding. Literature research indicates that vineyards and alfalfa are tolerant of standing water during the dormant period from December through January for established vineyards and into February for alfalfa. For established vineyards, literature indicates that water should be released from the field prior to bud break, typically in February, although field studies at Terranova suggested there are opportunities for recharge later in the year. Additional caution and monitoring is needed for flooding after bud break. Alfalfa fields should be drained prior to the start of the active growing season (typically early March) when respiration and transpiration increase dramatically. Additionally, alfalfa fields should be sufficiently dry prior to the first cutting, usually in early April. A recommended drying interval following application of winter water to alfalfa fields was not found in the literature.

During the active growing season, Bachand et al. (2012) showed successful recharge at vineyards and tomato fields. This success is tempered with literature, which indicates that, when a crop is actively growing, it is not advisable to keep the field inundated for more than 24 hours because research indicates that, with few exceptions, crop growth and yield is impacted if the soil remains saturated longer than 24 hours. The local difference is the coarse, sandy soils targeted for research and the ability to control water application to avoid waterlogging. For some crops, application depths can be increased or water can be applied more frequently than normal during the growing season to increase recharge. Given the local success at the pilot level to recharge on different crops at different stages of growth, additional research is needed to evaluate and verify the ability to recharge over a wider variety of crops and time periods than indicated by the existing literature. Such research will increase the confidence of potential grower participants in the program. An additional option is water application for recharge to cropped land that is idle or to land areas maintained in native vegetation, which may both present fewer constraints.

4.3 Recharge Water Availability

The approach for the assessment of wintertime stream flows, minimum flow requirements, and total distribution capacity for the Merced River, Chowchilla River, Fresno River, and Kings River was developed in Section 2.3. Available surface water flows were defined as those flows above minimum flow requirements and within the available distribution capacity. Available distribution capacities were determined by evaluating the differences between capacities and historical diversions. Table 9 summarizes, from 1973 to 2009, the flow analysis for both scenarios, including the flood flows that can be conveyed with existing capacity and the remaining flows that are above the remaining capacity of existing infrastructure and thus are not available without expansion of conveyance and distribution systems. This period was selected due to availability of Pine Flat operations and release data.

Annual averages are presented here and elsewhere in the report to allow the volumes to be compared to estimates of recharge needs to address potential sustainability issues or other recharge needs. Given the wide variability in flow volumes, efforts should not be made to, for instance, build infrastructure to capture average flows without consideration of that variability.

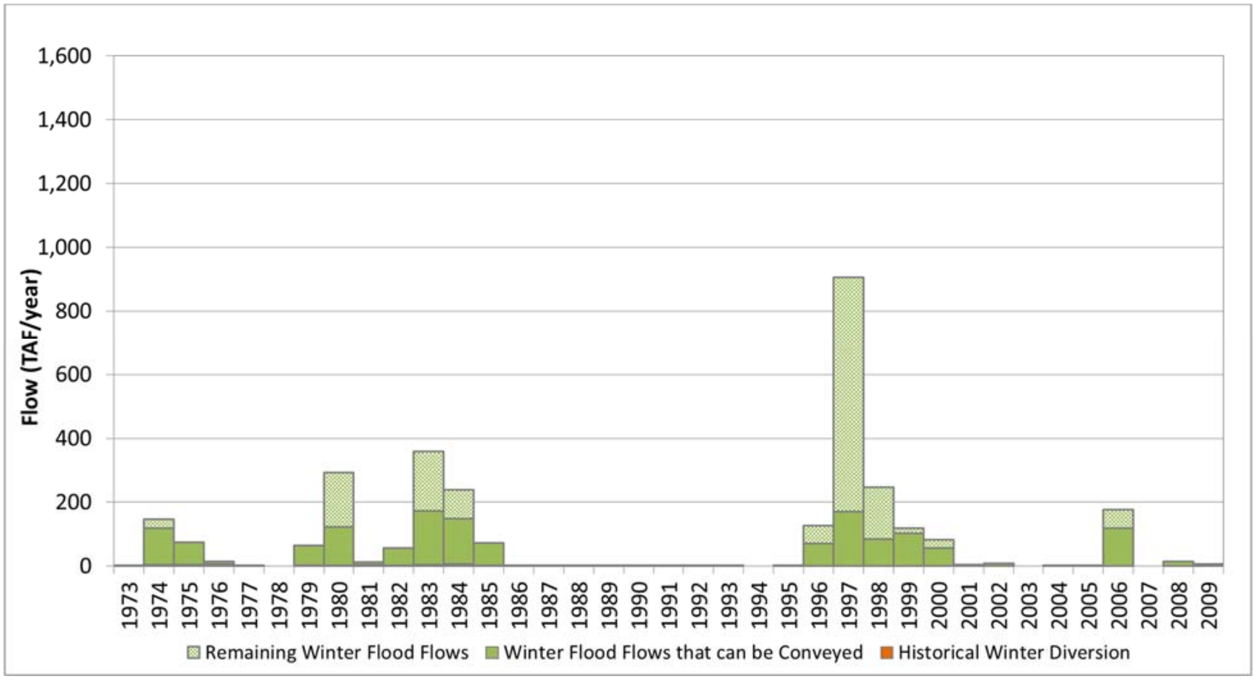
Table 9: Annual Average Flows for Winter and Extended Winter Recharge Periods (AF/year)[1]

Water Source	Recharge Period	Total Flood Flows	Diversions	Flood Flows that can be Conveyed	Remaining Flood Flows beyond Conveyance Capacity
Merced River	Winter	81,650	1,250	39,200	41,200
	Extended Winter	143,300	16,000	65,000	62,300
Chowchilla River	Winter	13,800	N/A[2]	3,600	10,200
	Extended Winter	20,700	N/A	6,700	14,000
Fresno River	Winter	17,800	N/A	6,200	11,600
	Extended Winter	28,100	N/A	10,700	17,400
Kings River	Winter	67,300	24,100	30,200	13,000
	Extended Winter	154,100	76,800	47,600	29,700
Total	Winter	168,130	23,350	79,200	76,000
	Extended Winter	346,200	92,800	130,000	123,400

[1] The hydrologic record used for this analysis is water years 1973 to 2009.
[2] N/A: Not available, assumed to be zero for this study.

The winter diversions, flood flows that can be conveyed as recharge water, and remaining flood flows that cannot be utilized due to distribution capacity limitations for the Merced River are shown in Figure 40 and Figure 41 for the Winter and Extended Winter recharge periods, respectively. The Merced River flood flows are highly variable from year to year. The year 1983 had the most available recharge water (170,000 AF for the Winter recharge period and 245,000 AF for the Extended Winter recharge period). Average available water for recharge from 1973 to 2009 for the Merced River is 39,200 AF for the Winter recharge period and 65,000 AF for the Extended Winter recharge period, as shown in Table 9. Table 9 also shows the amounts of additional flood water that could be recharged if there were sufficient distribution capacity.

Figure 40: Merced River Flows (Winter Recharge Period)



Note: Historical Winter Diversions occur in most years, but at volumes not visible at the chart scale, typically less than 5 TAFY.

Figure 41: Merced River Flows (Extended Winter Recharge Period)

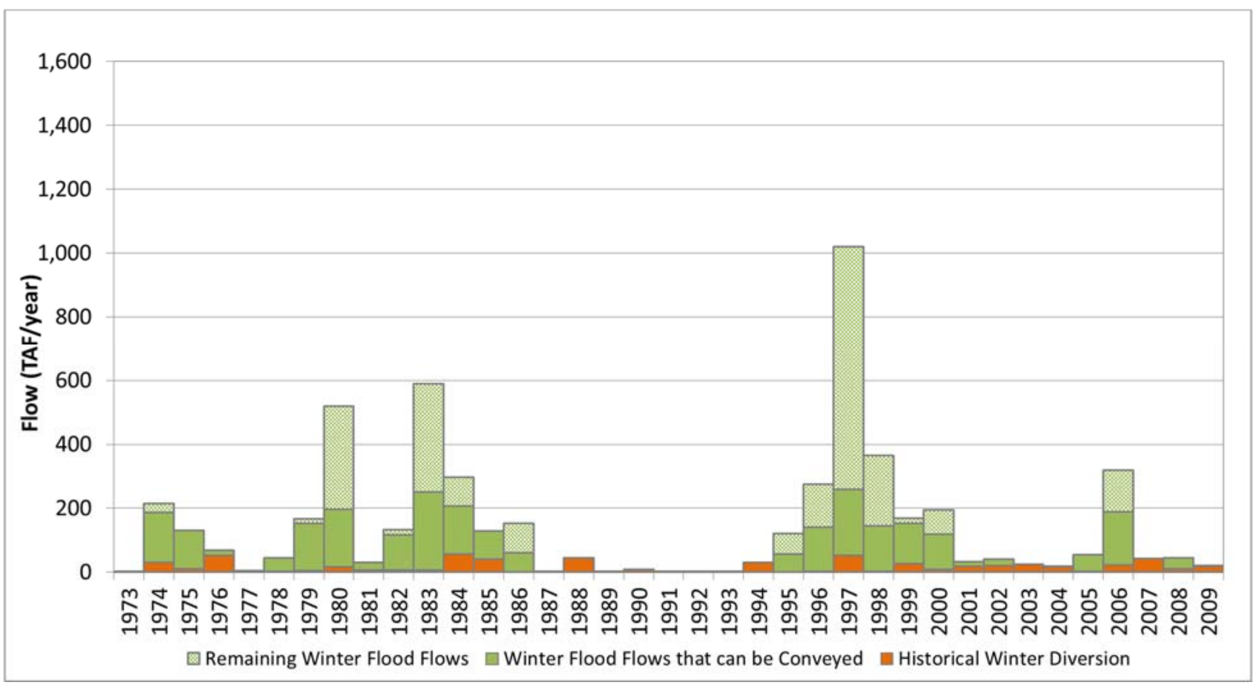
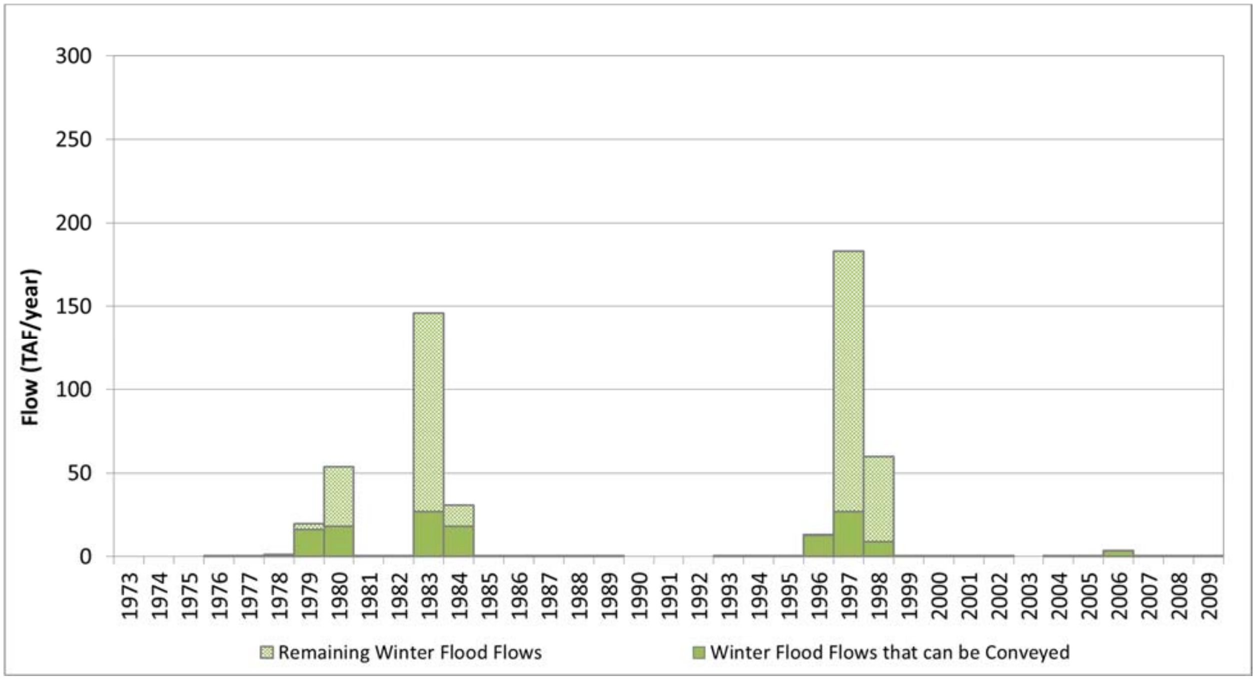


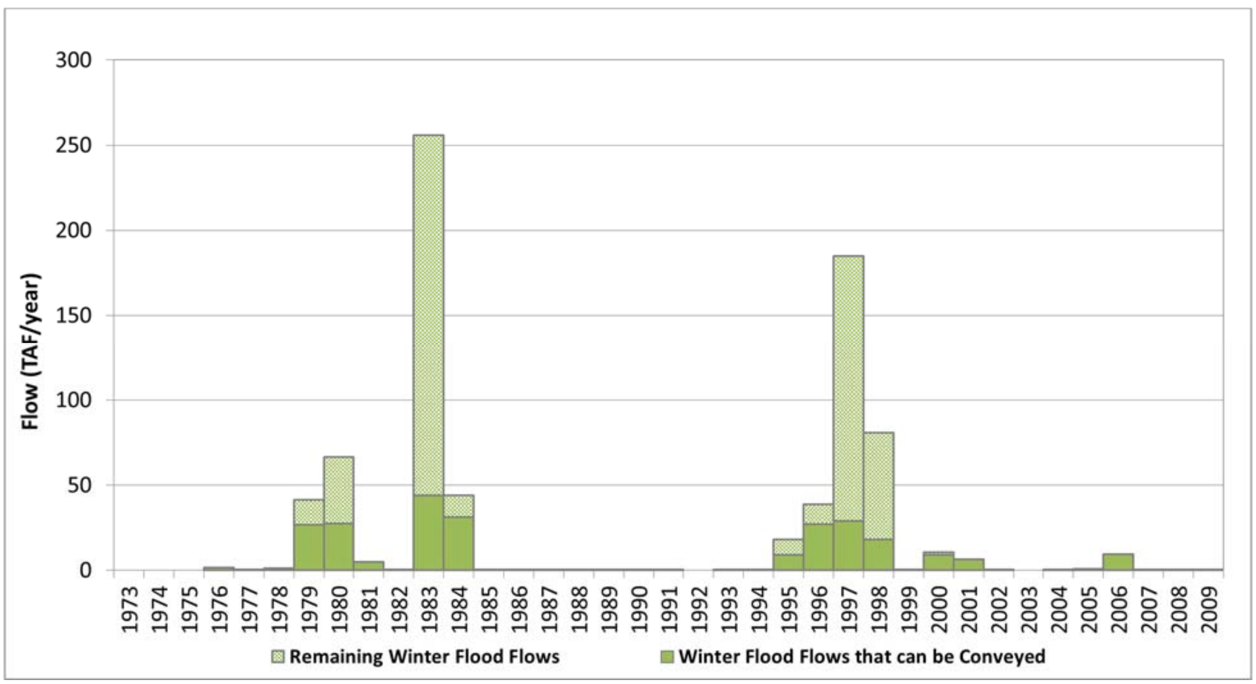
Figure 42 and Figure 43 show the winter diversions, flood flows that can be conveyed as recharge water, and remaining flood flows that cannot be utilized due to distribution capacity limitations for the Chowchilla River for the Winter and Extended Winter recharge periods, respectively. The Chowchilla River flood flows are neither as frequent nor as large as the Merced River flood flows. The year 1983 had the most available recharge water (27,000 AF for the Winter recharge period and 45,000 AF for the Extended Winter recharge period). Average available water for recharge from 1973 to 2009 for the Chowchilla River is 3,600 AF/year for the Winter recharge period and 6,700 AF/year for the Extended Winter recharge period, as shown in Table 9. Table 9 also shows the amount of additional flood water that could be recharged if there were sufficient distribution capacity.

Figure 42: Chowchilla River Flows (Winter Recharge Period)



Note: Historical diversion data were unavailable. See text for additional assumptions.

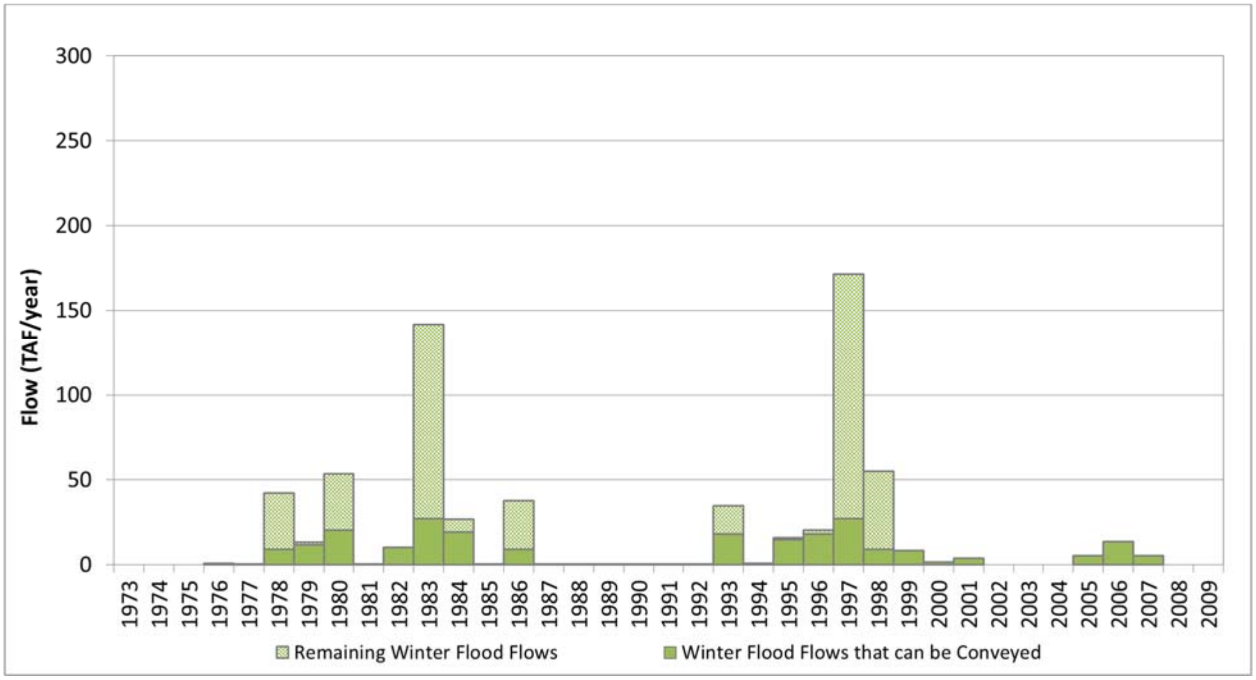
Figure 43: Chowchilla River Flows (Extended Winter Recharge Period)



Note: Historical diversion data were unavailable. See text for additional assumptions.

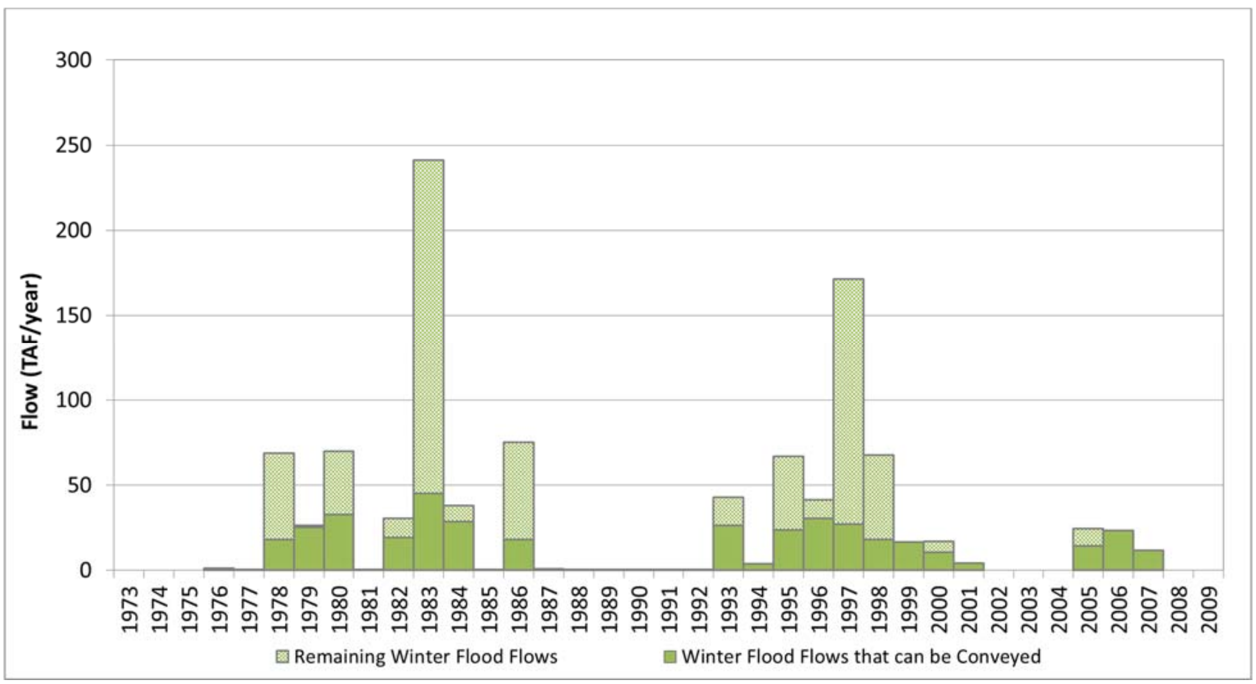
Figure 44 and Figure 45 show the winter diversions, flood flows that can be conveyed as recharge water, and remaining flood flows that cannot be utilized due to distribution capacity limitations for the Fresno River for the Winter and Extended Winter recharge periods, respectively. The Fresno River flood flows are more frequent than the Chowchilla River flood flows but are not as frequent as those on the Merced River. The year 1983 had the most available recharge water (27,000 AF for the Winter recharge period and 45,000 AF for the Extended Winter recharge period). Average available water for recharge from 1973 to 2009 for Fresno River is 6,200 AF/year for the Winter recharge period and 10,700 AF/year for the Extended Winter recharge period, as shown in Table 9. Table 9 also shows additional flood water available that could be recharged if there were sufficient distribution capacity.

Figure 44: Fresno River Flows (Winter Recharge Period)



Note: Historical diversion data were unavailable. See text for additional assumptions.

Figure 45: Fresno River Flows (Extended Winter Recharge Period)



Note: Historical diversion data were unavailable. See text for additional assumptions.

Figure 46 and Figure 47 show the winter diversions, flood flows that can be conveyed as recharge water, and remaining flood flows that cannot be utilized due to distribution capacity limitations for the Kings River for the Winter and Extended Winter recharge periods, respectively. The magnitude of the Kings River flood flows is comparable to the Merced River but they are not as frequent as the Merced River flood flows. The distribution capacity for Kings River is higher than all of the other rivers. As a result, most of the Kings River flood flows can be utilized. The year 1983 had the most available recharge water (500,000 AF for the Winter recharge period and 632,000 AF for the Extended Winter recharge period). Average available water for recharge from 1973 to 2009 for Kings River is 30,200 AF/year for the Winter recharge period and 47,600 AF/year for the Extended Winter recharge period, as shown in Table 9. Table 9 also shows that distribution capacity of Kings River is capable of capturing most of the flood water. Only an additional 13,000 AF/year and 29,700 AF/year of flood water could be recharged if there were sufficient distribution capacity for the Winter and Extended Winter recharge periods, respectively.

The annual available recharge water volumes and schedules shown in Figure 40 to Figure 47 were used to develop the recharge scenarios described in the next section.

Figure 46: Kings River Flows (Winter Recharge Period)

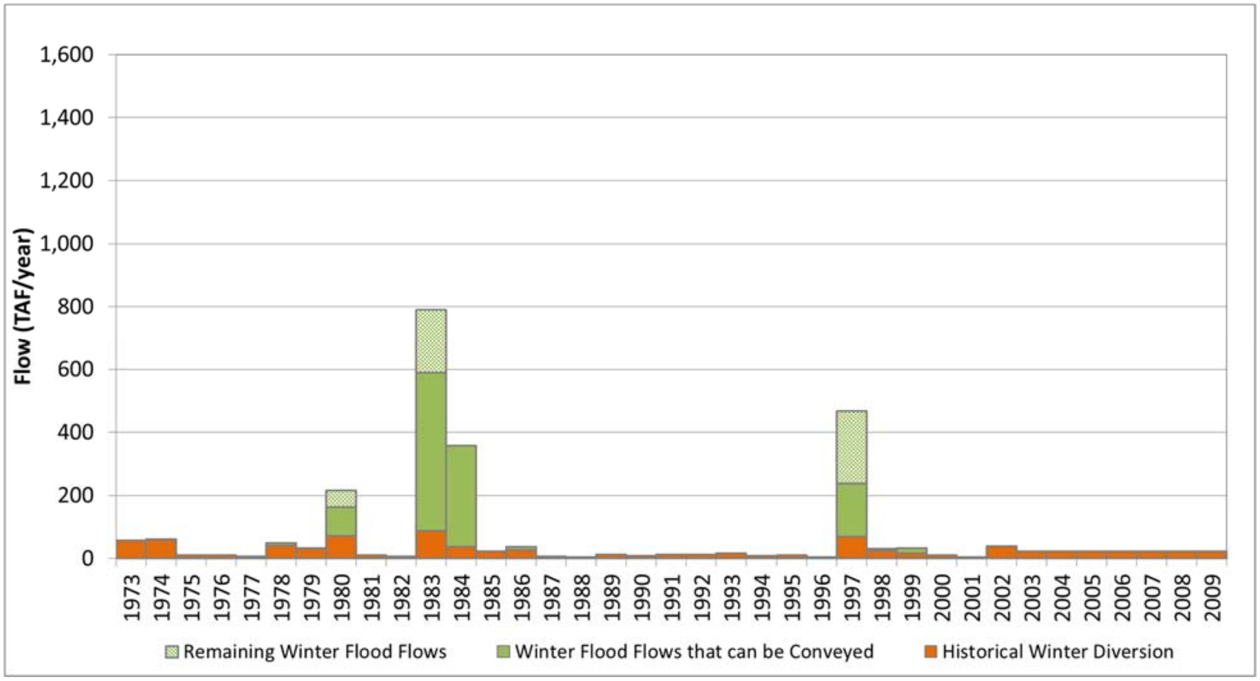


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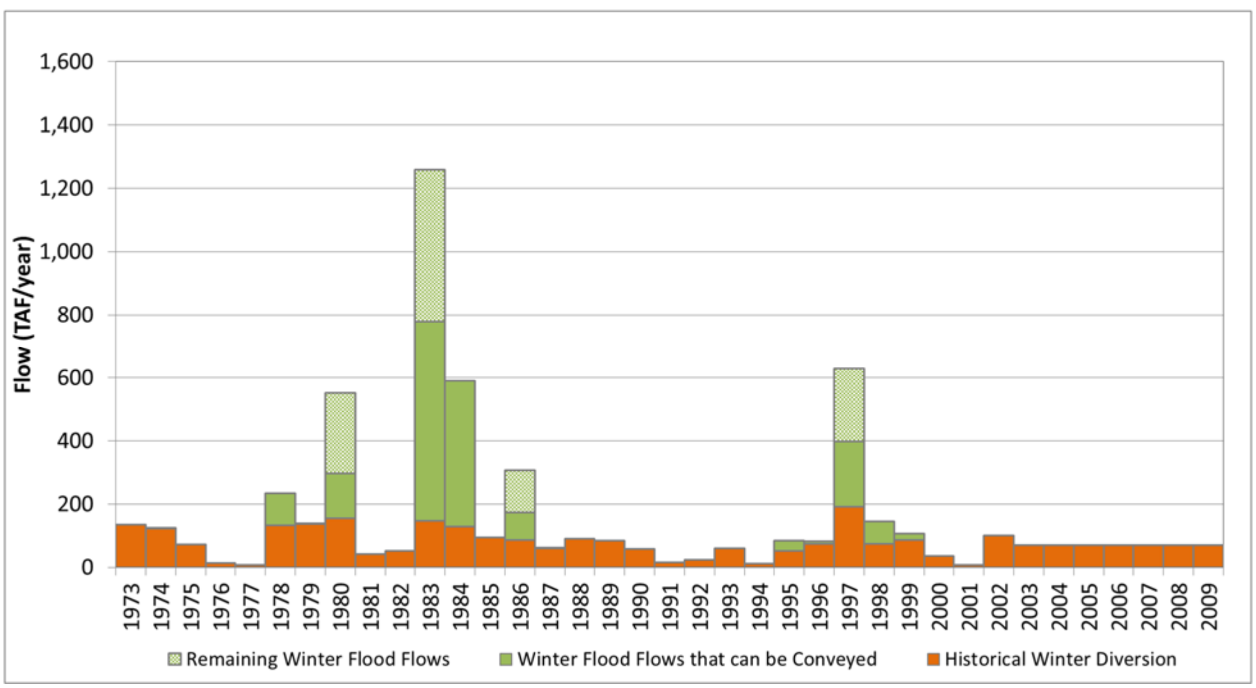
Figure 47: Kings River Flows (Extended Winter Recharge Period)



4.4 Recharge Areas

The land area needed for recharge was estimated by identifying the individual month with the maximum available monthly recharge from the Merced, Chowchilla, Fresno, and Kings rivers based on streamflow, minimum flow requirements, and available headgate and canal capacity. Maximum potential recharge volumes occur in a hydrologic period similar to December 1983 for each river, with a total volume of approximately 299,000 AF within that month. The bulk of this volume, 224,000 AF, was on the Kings River, with 57,000 AF on the Merced River and 9,000 AF on both the Chowchilla and Fresno Rivers. Based on the hydrologic soil conditions, a recharge rate of 9 feet per month is reasonable for the suitable lands in the pilot project area. Assuming a 9 feet per month recharge rate, a total of approximately 33,400 acres of land are needed to recharge the monthly maximum volume (Table 10).

Table 10: Estimated Recharge Volumes and Recharge Area Needed

Water Source	Max Monthly Recharge Volume[1] (AF/month)	Recharge Rate (Feet/month)	Max Area Needed (Acres)
Merced River	57,200	9	6,350
Chowchilla River	9,000	9	1,000
Fresno River	9,000	9	1,000
Kings River	224,000	9	25,000
Total	299,200	9	33,350

[1] Based on flows above minimum flow requirements and within the available distribution capacity. Available distribution capacities were determined by evaluating the differences between capacities and historical diversions.

The required acreage of recharge areas, location along conveyance facilities, distance from surface water courses, and Recharge Suitability Index values were used to identify hypothetical areas for use in the C2VSim model for analysis of recharge scenarios. Major surface water conveyance systems in the project area are shown in Figure 48. The Crop Recharge Suitability Index for areas within 0.5 miles of these major water conveyance systems is shown in Figure 49. Model elements were selected (Figure 50) based on the available capacity of the conveyance system (where known), a high score on the Crop Recharge Suitability Index, a relatively even spatial distribution, and relatively distant from major surface water features to maximize groundwater storage benefits.

Figure 48: Major Surface Water Conveyance Systems

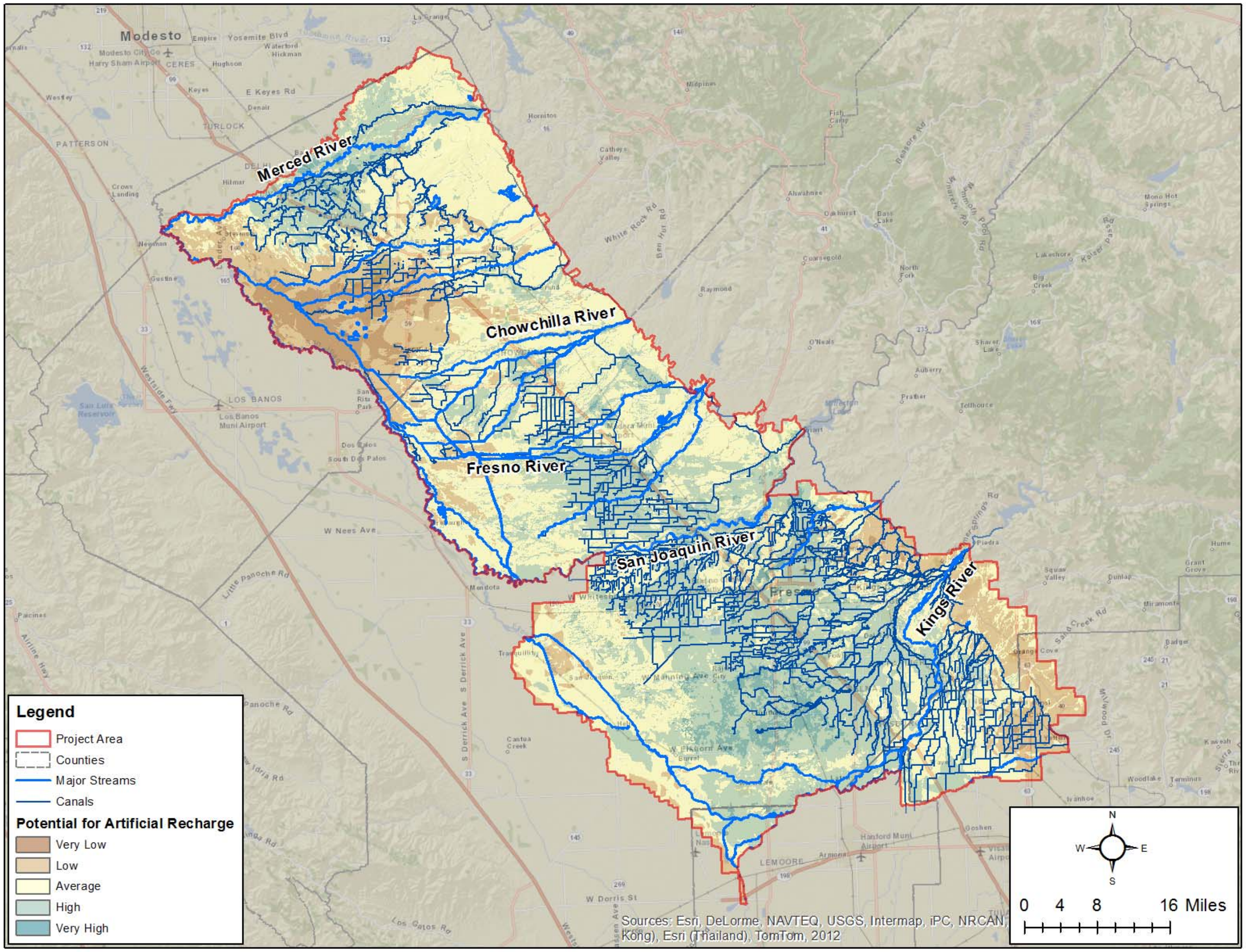


Figure 49: Recharge Suitability Index for Areas within a Half Mile of Major Surface Water Conveyance Systems

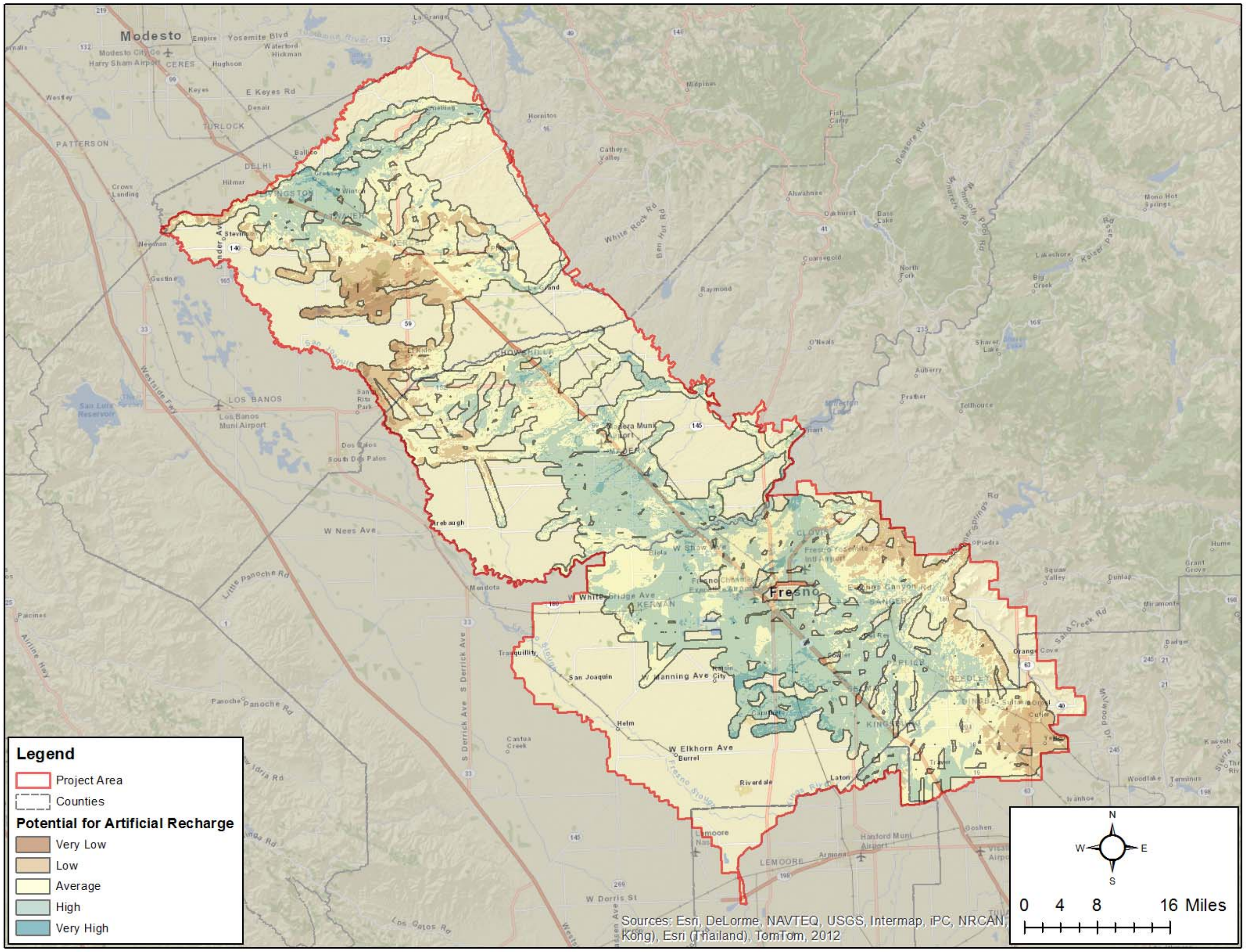
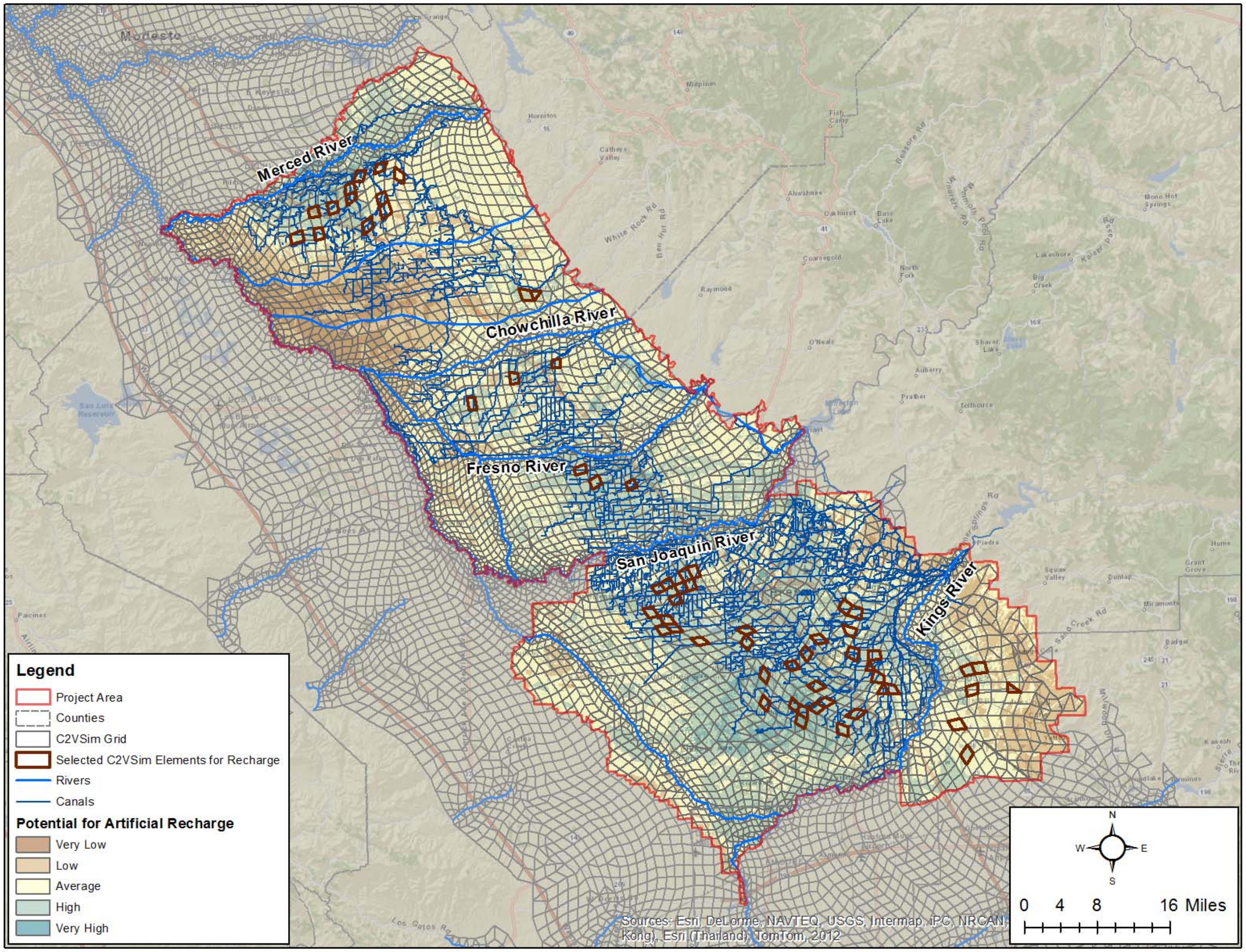


Figure 50: C2VSim Grid Elements Selected for Recharge Scenarios



4.5 Storage and Migration of Recharged Water (Integrated Hydrologic Modeling)

Recharge Scenarios

As discussed in Section 3, C2VSim was used to estimate the potential regional changes in inflows, outflows, and storage for the groundwater system, as a result of project-related recharge.

To address the uncertainty in the preferred timing and duration of on-farm capture of excess winter flows, two scenarios were developed as follows:

- Winter: Recharge from December to February
- Extended Winter: Recharge from November to March

The volume and timing of the available water for recharge and recharge areas are presented in Section 4.3.

The impacts of the two recharge scenarios were evaluated using the C2VSim model and compared to the results of the Baseline scenario using the following criteria:

- Groundwater level difference (Scenario minus Baseline) contour maps to quantify changes in groundwater levels.
- Groundwater budget difference (Scenario minus Baseline) tables to quantify changes in groundwater storage and stream capture.

The results are presented in the following sections.

Changes in Groundwater System

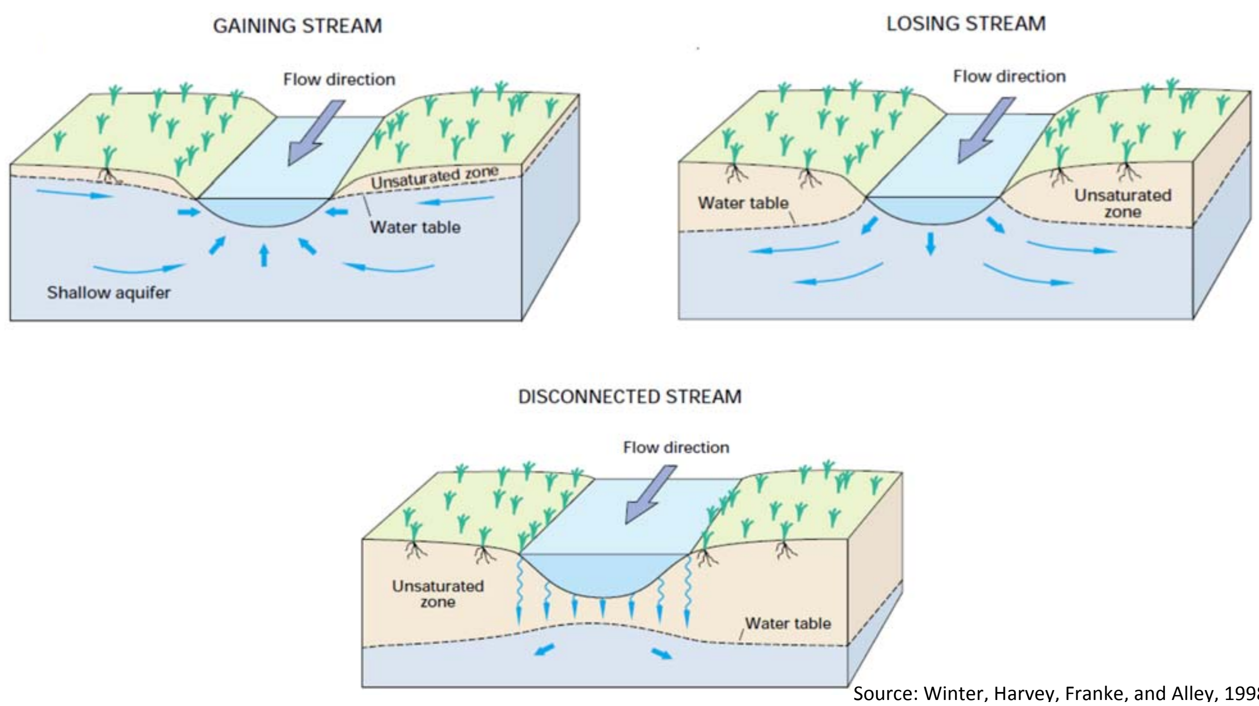
The recharge results in three major changes in the groundwater system:

- **Higher groundwater levels.** As additional water is recharged to groundwater, groundwater elevations rise and the volume of groundwater increases in storage. This change is initially seen near the areas of recharge, but over time these changes expand outward from the recharge areas to cover a larger area. The changes in groundwater elevation results in changes in stream capture and subsurface flows, as discussed below.
- **Reduced stream capture.** Stream capture is a combination of increased recharge of groundwater from a stream and decreased discharge from groundwater to a stream. Stream capture generally occurs as groundwater is extracted, resulting in lowered groundwater elevations and a change in the gradient between the groundwater elevation and surface water elevation. Groundwater elevations and capture change to find a new equilibrium. The project-related recharge of groundwater and resulting higher groundwater elevations will reduce stream capture. These changes may be due to increased discharge of groundwater to surface water (gaining stream) and/or reduced recharge from surface water to groundwater (losing streams). If the surface water body is fully disconnected from the groundwater system, then

there will be no impact of the change in groundwater elevations. These conditions are shown graphically in Figure 51.

- **Changes in subsurface flows.** The project area is bordered to the north, south, and west by other groundwater subbasins, with groundwater moving freely between these subbasins. Increases in groundwater elevation within the project area will either increase subsurface flows out of the project area or decrease subsurface flows into the project area. Ultimately, it is intended that winter flooding of agricultural lands would be implemented regionally across the San Joaquin Valley for regional benefits, such changes in subsurface flows would be minimized in the future due to regional implementation of the effort and more uniform regional increases in groundwater elevations. Additionally, increases in groundwater volume in neighboring subbasins would be recognized as a regional benefit. Therefore, changes in subsurface flows are not incorporated into project accounting, but are instead captured as overall increases in groundwater in storage.

Figure 51: Major Types of Stream-Aquifer Interaction



Source: Winter, Harvey, Franke, and Alley, 1998

Changes in Groundwater Levels

The long-term effects of on-farm capture of excess winter flows on groundwater levels for both the Winter and Extended Winter recharge periods were simulated using the C2VSim and illustrated by developing contour maps of groundwater level differences (compared to Baseline) for wet and dry hydrology, as well as for the end of the model simulation (see Table 11).

Table 11: Changes in Groundwater Elevation for Winter and Extended Winter Recharge Periods for Selected Years and Locations

Hydrology	Change in Groundwater Elevation Figure		Maximum Increase in Groundwater Elevation (ft)					
			South of Merced River		South of Chowchilla River		Between San Joaquin and Kings Rivers	
	Winter	Extended Winter	Winter	Extended Winter	Winter	Extended Winter	Winter	Extended Winter
Wet Year	Figure 52	Figure 53	50-75	>75	5-15	15-25	50-75	50-75
Dry Year	Figure 54	Figure 55	25-35	35-50	5-15	5-15	15-25	25-35
End of Simulation	Figure 56	Figure 57	25-35	35-50	5-15	5-15	5-15	15-25

The figures and groundwater elevation listed in Table 11 show the higher groundwater levels around the recharge areas under both scenarios after a wet year (Figure 52 and Figure 53). Increases in groundwater elevations are reduced moving away from the recharge areas and approach zero around the streams due to decreased stream capture, a result of groundwater elevations attempting to increase near those streams but being damped by resulting changes in stream-aquifer interactions.

Moving into dry conditions, with no recharge occurring, Figure 54 and Figure 55 show how the recharged water disperses away from the recharge areas. The groundwater level differences around the recharge areas are significantly smaller compared to the wet year conditions. However, the spatial extent of the areas with groundwater level differences higher than 5 feet are wider compared to the wet year conditions.

The end of simulation results represent normal hydrologic conditions after several cycles of wet and dry periods. Figure 56 and Figure 57 show groundwater elevations at the end of simulation, which more closely resemble the elevations for the dry conditions as there has been no recharge in 12 years at that point. The end of simulation is also useful to show how the benefits of increased groundwater elevations expand over time, resulting in a larger footprint of benefits as mounded groundwater spreads horizontally over time.

For all conditions, the groundwater level differences for Extended Winter are higher than Winter groundwater level differences and the spatial extent of Extended Winter is wider than that of Winter. Additionally, the groundwater level differences are the highest in the Merced Groundwater Basin, specifically south of the Merced River around Highway 99, and the Kings Groundwater Basin, specifically southwest of Highway 99.

Benefits to Groundwater Storage and Stream Capture

The benefits of capturing excess winter flows for recharge on groundwater storage and stream capture were quantified by developing average annual summary of the key components that affect groundwater budget (Table 12).

As is typical in efforts that increase recharge or discharge from the groundwater system (Konikow & Leake, 2014), early changes are largely to groundwater storage and long-term changes are largely to stream capture, due to the connectivity between groundwater and surface water and due to the time scales required for groundwater systems to establish new equilibria with surface water systems.

As both groundwater and surface water systems are stressed in the San Joaquin Valley, it is important to note that, in the long-term, the project would both increase groundwater in storage and decrease stream capture, with resulting higher groundwater elevations and increased streamflow. Such improvements in water resources conditions could benefit a range of beneficial uses.
The study findings indicate that, in the long-term, there can be approximately 80,000 to 130,000 AF/year of excess winter time water available for recharge through on-farm spreading, depending on the length of recharge season.

(i) Increase in groundwater storage in the immediate vicinity of the project area ranging from 21% to 79%, depending on the location;
(ii) Increase in surface water baseflow conditions in the form of stream capture ranging from 28% to 70%, depending on the location; and
(iii) Contribution to increased groundwater storage outside of the immediate project area, but in the San Joaquin Valley ranging from 9% to 23%, depending on the location.

This program can benefit increased long-term groundwater storage, as well as a long-term increase in surface flows by reducing the stream contributions to the groundwater system. Depending on the length of recharge season, the estimated long-term net contribution to increased in groundwater storage underlying the project area is estimated to be between 31,000 and 52,000 AF/year, with approximately 20%-25% of the recharge benefits occurring in the north and 50%-70% of the benefits in the southern parts of the project area. The estimated long-term increase in streamflows can be between 34,000 and 56,000 AF/year, ranging from approximately 55%-60% in the north to approximately 15%-25% to the south. Remaining recharged water would flow to groundwater adjacent to the project area, contributing to the groundwater storage in adjacent areas. When compared to the approximate estimated annual overdraft of 250,000 AF/year in the same area, the proposed recharge method would reduce overdraft by 12% to 20% of the overdraft conditions.

The study results also indicate that the proposed recharge method in the study area can significantly reduce the estimated average annual overdraft of 1,200,000 AF/year in San Joaquin Valley. Additionally, expansion of the proposed methodology to other watersheds in the San Joaquin Valley, including the San Joaquin, Tuolumne and Stanislaus rivers, would provide significant contribution towards addressing overdraft in the San Joaquin Valley.

Table 12: Average Annual Groundwater Budget (Scenario – Baseline)

Item	Winter		Extended Winter	
	(AF/year)	% of Recharge	(AF/year)	% of Recharge
Recharge	79,200	N/A	130,000	N/A
Stream Capture	-34,200	43%	-55,500	43%
Subsurface Flow to Adjacent Areas	-14,000	18%	-22,700	17%
Change in GW Storage	31,000	39%	51,800	39%

Figure 52: Simulated Groundwater Level Differences (Scenario – Baseline) for a Wet Year, Winter Recharge Scenario

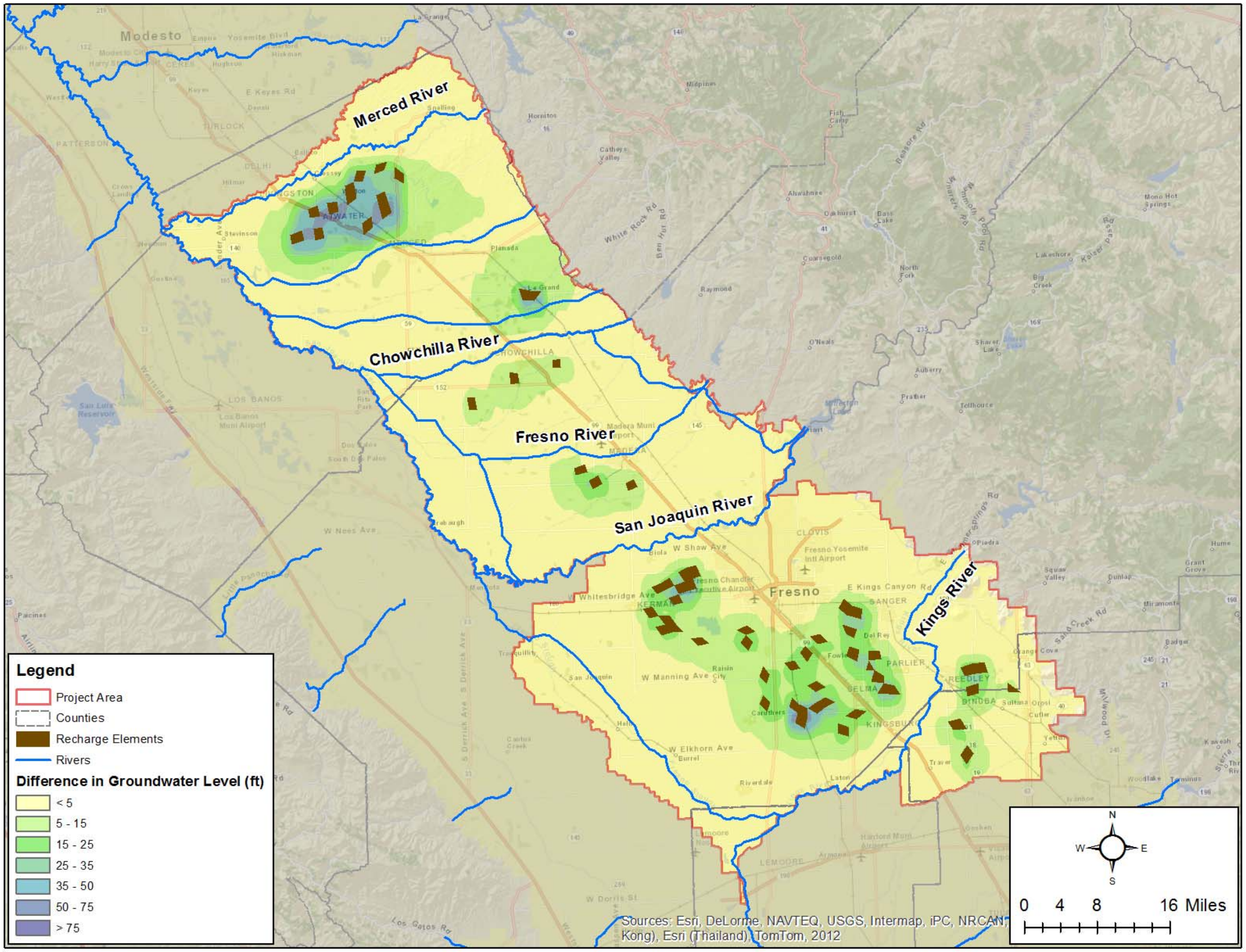


Figure 53: Simulated Groundwater Level Differences (Scenario – Baseline) for a Wet Year, Extended Winter Recharge Scenario

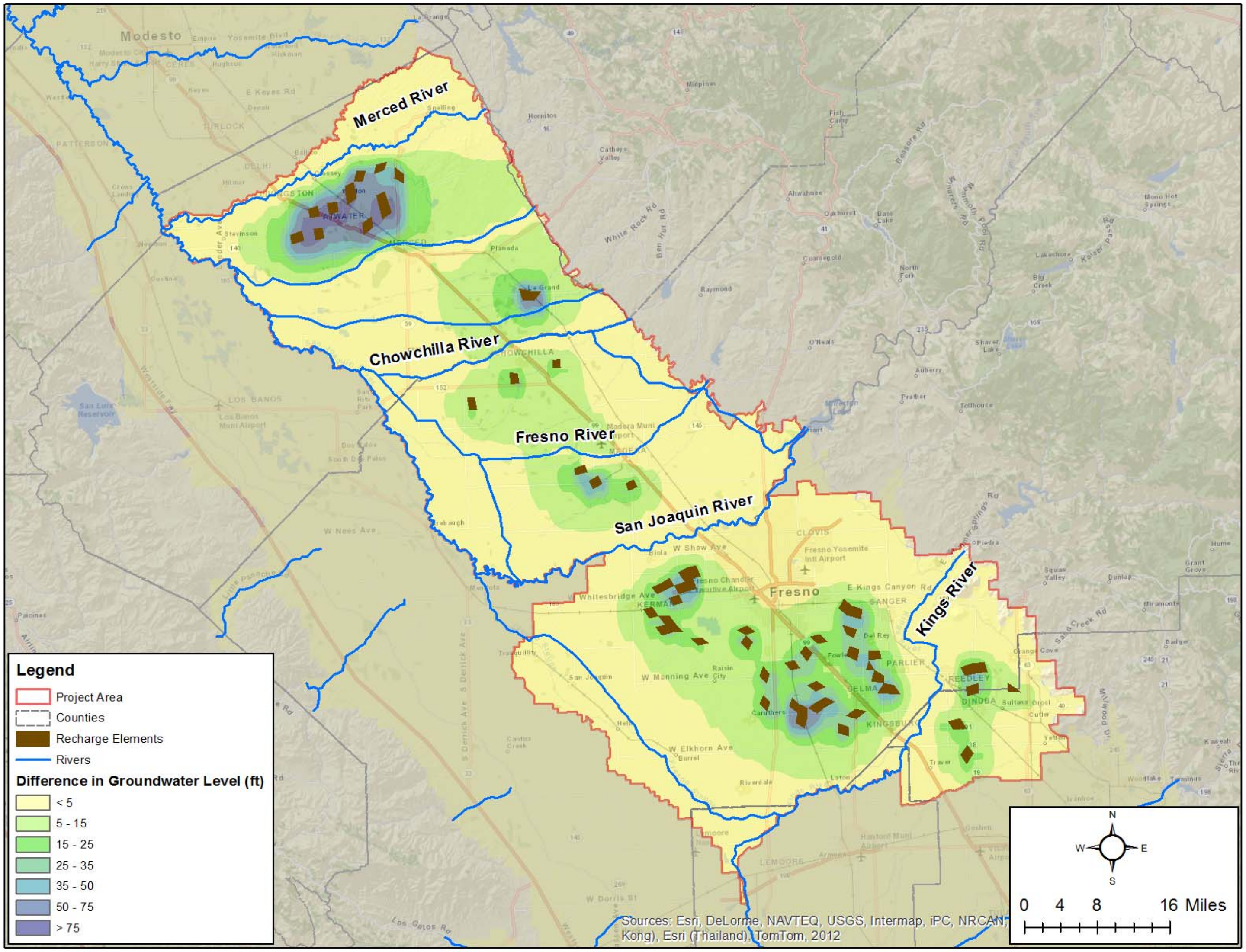


Figure 54: Simulated Groundwater Level Differences (Scenario – Baseline) for a Dry Year, Winter Recharge Scenario

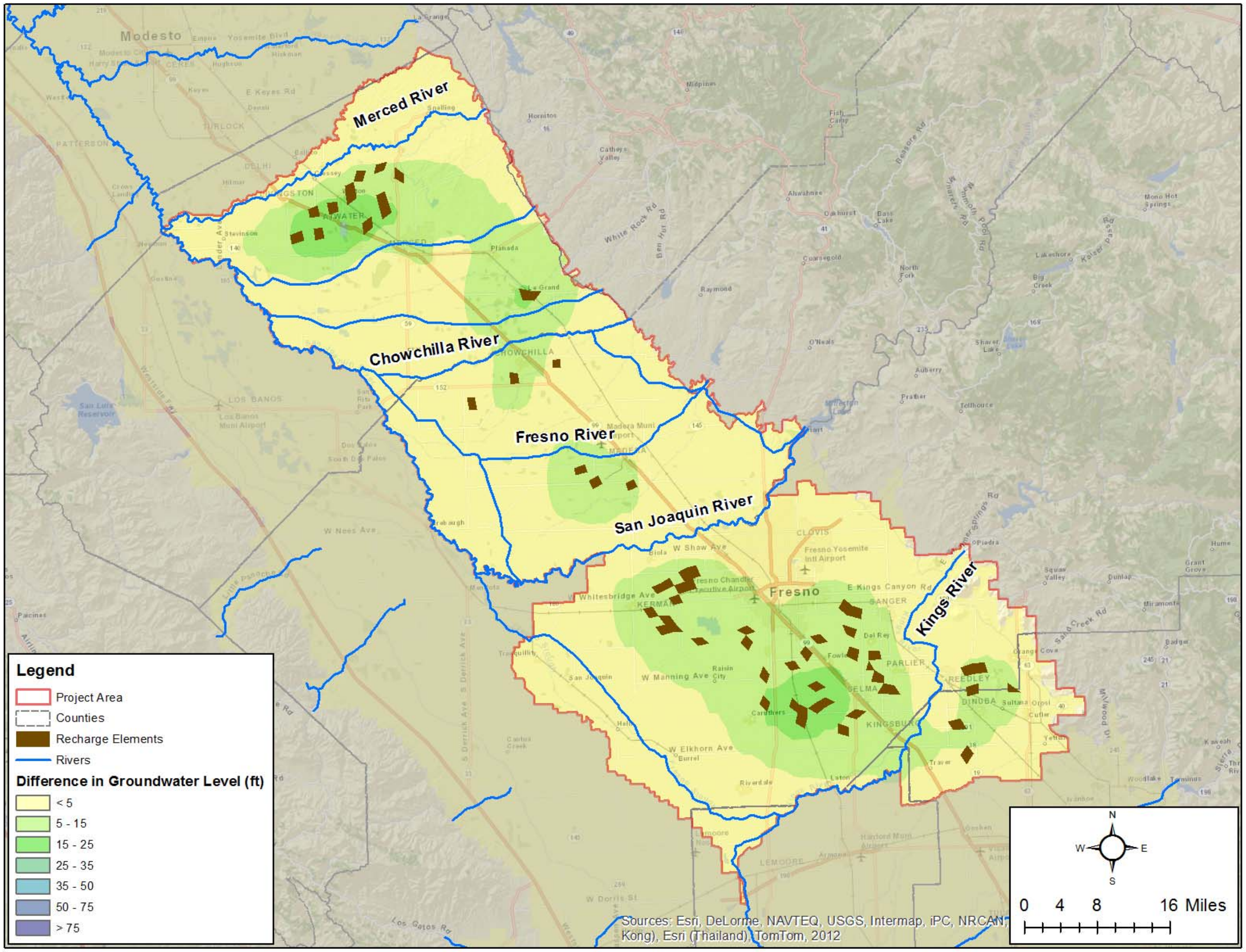


Figure 55: Simulated Groundwater Level Differences (Scenario – Baseline) for a Dry Year, Extended Winter Recharge Scenario

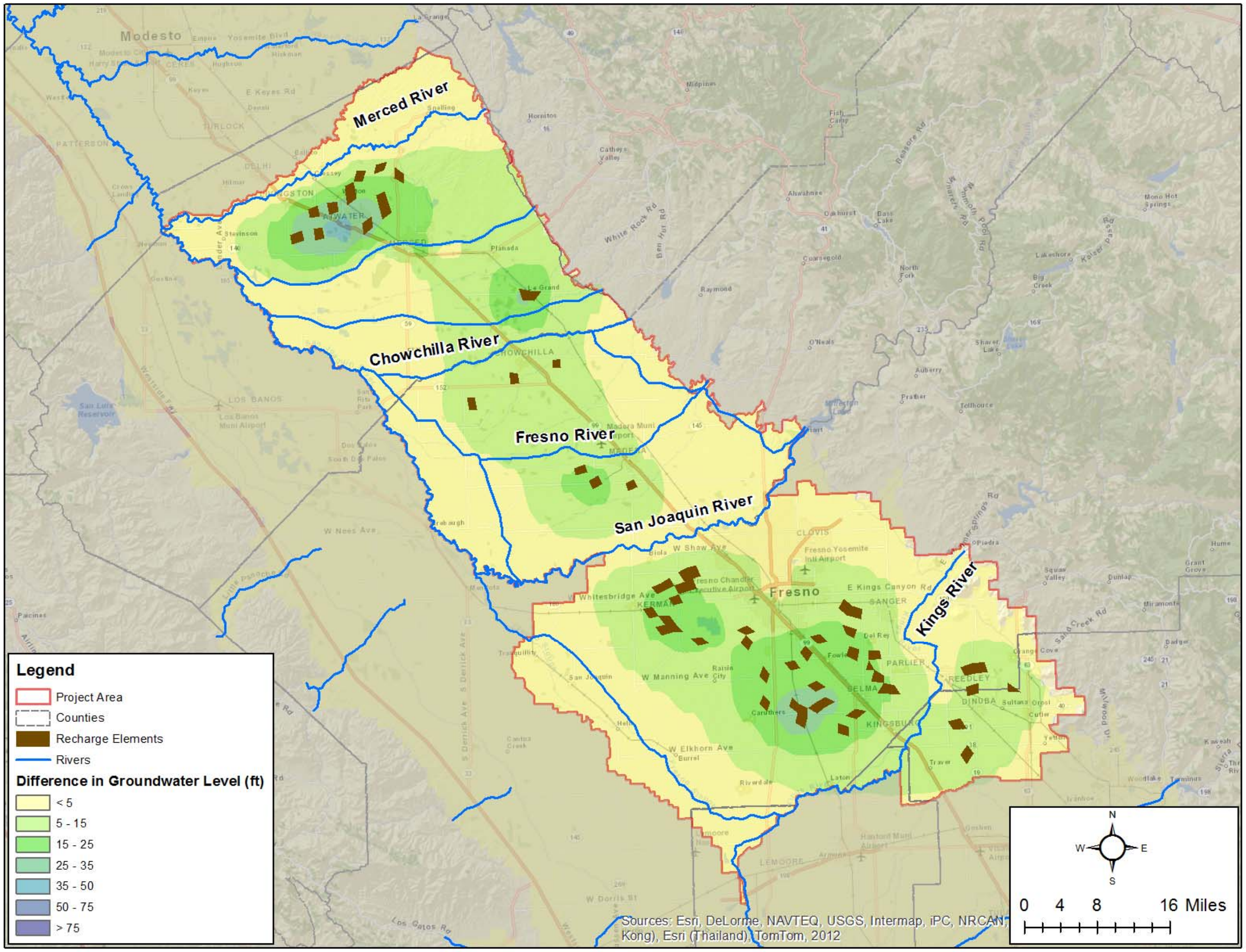


Figure 56: Simulated Groundwater Level Differences (Scenario – Baseline) for the End of the Simulation for Winter Recharge Scenario

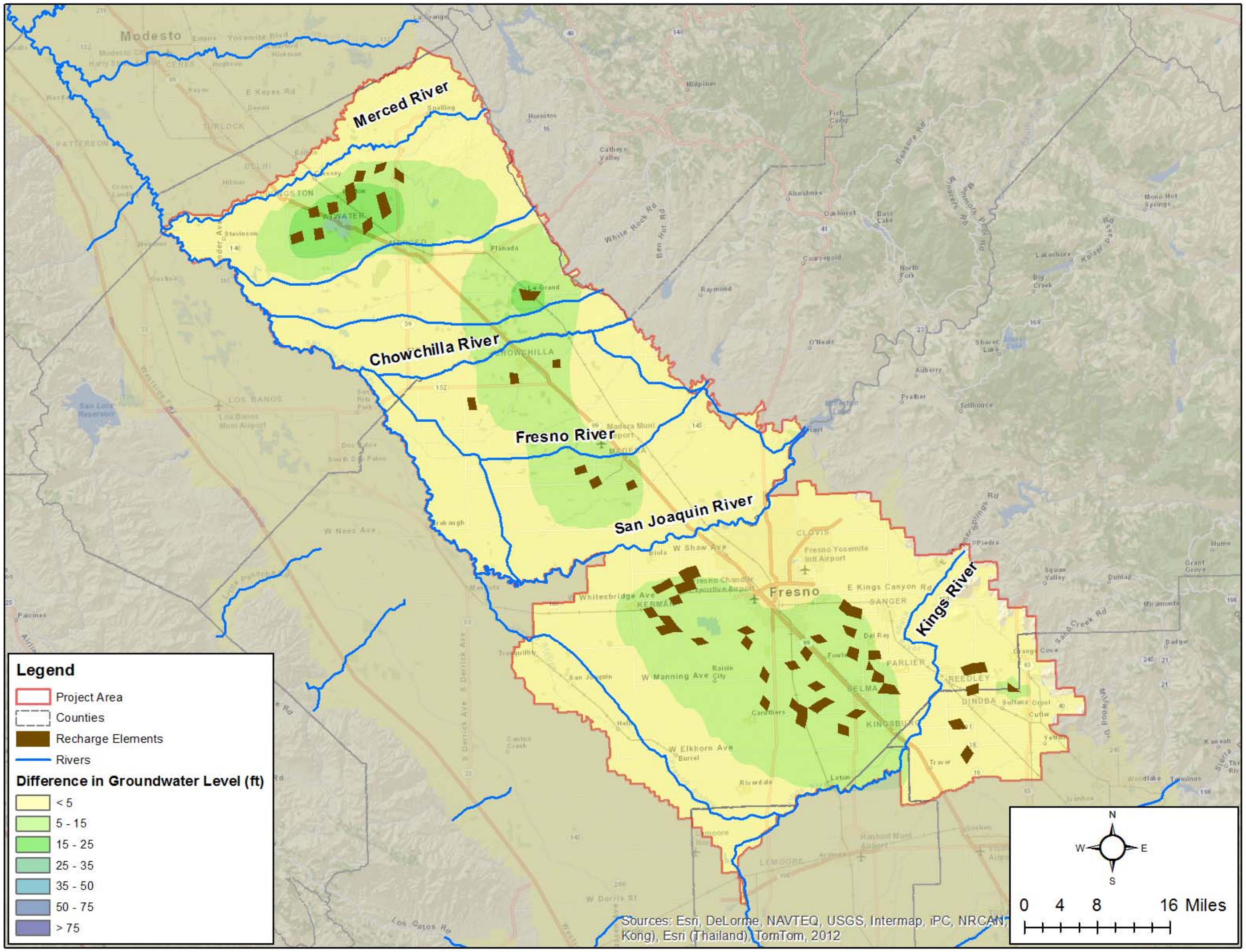
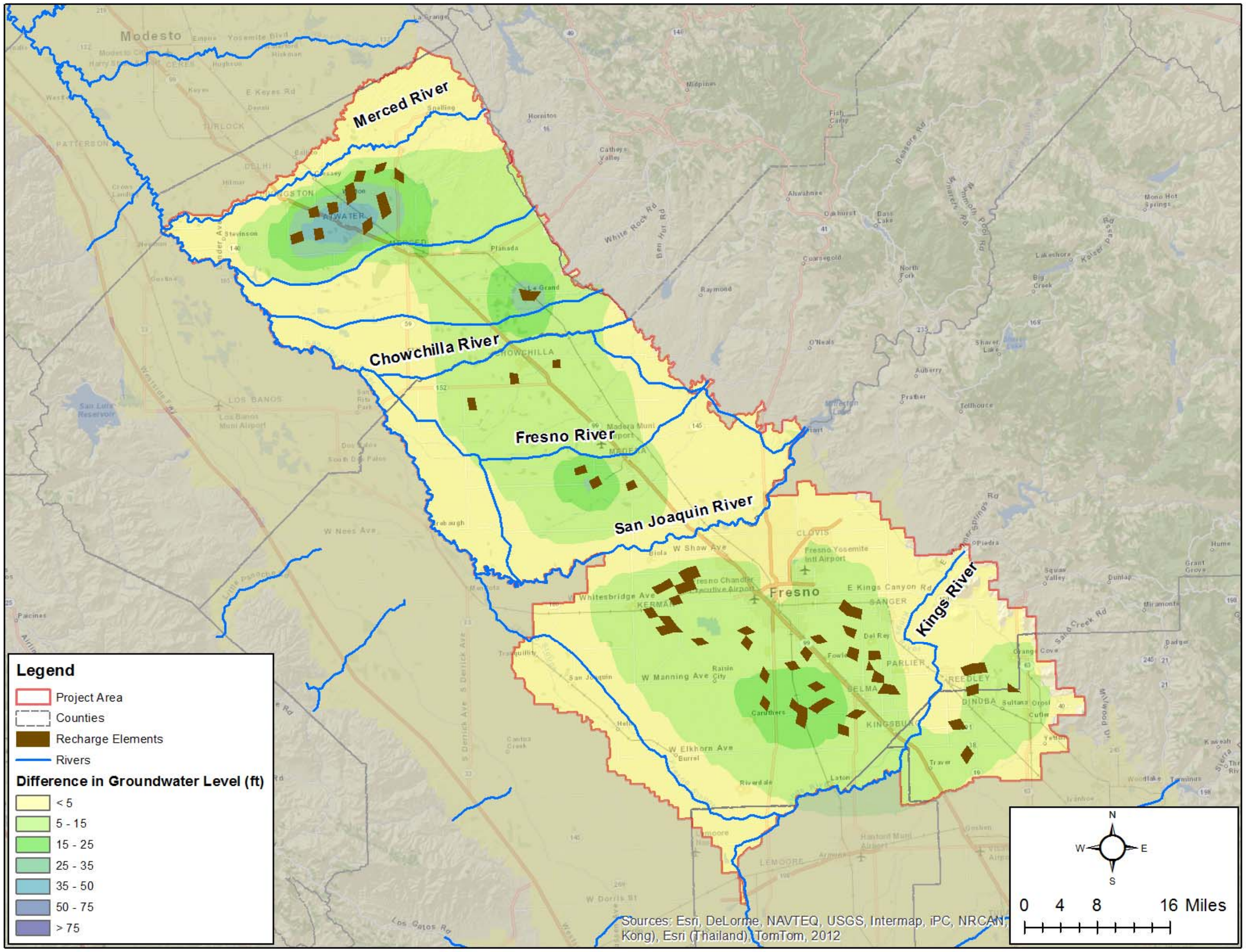


Figure 57: Simulated Groundwater Level Differences (Scenario – Baseline) for the End of the Simulation for Extended Winter Recharge Scenario



Annual

5. Groundwater Quality Implications

One potential risk of a program to promote on-farm capture of excess winter flows is negative impacts to groundwater quality. Such impacts could occur as wintertime recharge flushes salts, nutrients, and other agrochemicals through the root zone and unsaturated zone into the aquifer system. As wintertime irrigation for recharge is not a common practice, there is little literature on the subject of impacts to groundwater quality. The primary source of information for this topic is a pilot study in Fresno County titled *Implications of Using On-Farm Flood Flow Capture to Recharge Groundwater and Mitigate Flood Risks along the Kings River, CA* by Bachand, et al. (2012). This report focuses on nitrogen and salt impacts, as data on pesticides, herbicides, and other agrochemicals are not available. The analysis of salts differs from that of nitrogen because nitrogen can be removed from the system through plant uptake and denitrification, while salts are generally conservative, with nearly all of the salt mass eventually reaching the aquifer system.

6. Summary of Findings

This report presents an analysis of the potential benefits of groundwater recharge through on-farm capture of excess winter flows on existing agricultural lands in Merced, Madera, and Fresno Counties on the east side of the San Joaquin Valley. The effort included estimation of land suitability for recharge to the aquifer system, crop compatibility for groundwater recharge through winter flooding of agricultural land, and availability of wintertime surface water supplies to provide the information needed to estimate, through the use of an integrated hydrologic model, the volume of water that could be recharged and the fate of that water in the subsurface.

A Recharge Suitability Index was developed using spatial characteristics of subsurface properties to identify areas best suited for recharge. The index indicates that areas conducive to recharge are, generally:

- Centered along Highway 99 to the northwest of Merced and along the Merced River
- In the upper and middle portions of the Kings River alluvial fan

Areas with lower recharge suitability are primarily in the southeastern portions of Merced County, throughout most of Madera County, and in portions of Fresno County near the foothills.

Field testing at Terranova Farms located 25 miles southwest of Fresno demonstrated the ability to flood alfalfa, orchards, row crops and vineyards significantly later in the year than what was reported in the literature. Additional field studies can assist in developing a local body of knowledge that is necessary for project success. Available reports indicated that established vineyards and alfalfa appear to be suitable for winter recharge although further investigation is warranted. Research indicates that these established vineyards are tolerant of standing water during the dormant period from December through January and alfalfa from December into February. For established vineyards, research showed that water should be released from the field prior to bud break, typically in February. Although it should be noted that field studies at Terranova Farms showed that significant recharge could be achieved later in the year.

The analysis of recharge water availability looked at two different time periods: Winter (December to February) and Extended Winter (November to March). The analysis was developed using available surface water flows, based on historical hydrology, above minimum flow requirements and within the existing distribution capacity. On an average annual basis, significant volumes of water were found to be available for conveyance with existing facilities: approximately 79,200 AF/year for the Winter period and 130,000 AF/year for the Extended Winter period. However, these annual averages are based on a highly variable hydrology that includes many years with no available water and a smaller number of years with large volumes of water.

Incorporating the information developed through the land recharge suitability, crop recharge suitability, and recharge water availability analyses, the DWR's fine grid version of C2VSim model was used to estimate the potential regional changes in inflows, outflows, and storage for the groundwater system, as a result of project-related recharge. *The recharge program benefits three major components of the hydrologic system in San Joaquin Valley: (i) Approximately 40% of recharge water would directly increase regional groundwater storage in the project area, (ii) approximately 43% of recharge water benefits streamflows by increasing the baseflows, and (iii) approximately 17% of recharge water benefits groundwater storage in areas outside the project area, but in the San Joaquin Valley.*

Both the Winter and the Extended Winter scenarios showed benefits to groundwater storage and streamflow. Average annual water available for recharge for Winter period Scenario is approximately 79,200 AF/year, of which approximately 34,200 AF/year (43%) is captured by the streams. The stream capture conditions vary geographically from north to south. In the Merced region, there are more opportunities of interaction between the surface water and groundwater systems. This condition is somewhat more limited in the south along the Kings River. Therefore, stream capture ranges from 48% of recharge water in the north to 28% of recharge water in the southern part of the project area. Additionally, approximately 14,000 AF/year (18%) of the water available for recharge migrates to groundwater basins adjacent to the project area, contributing to the groundwater storage in these areas. Therefore, net increase in groundwater storage in the project area ends up to be approximately 31,000 AF/year or 39% of all recharge water. This net benefit to groundwater storage varies geographically with approximately 26% of the total project area benefit occurring in each of the northern and central basins and 48% of the total project benefit occurring in the southern portions of the project area.

Average annual water available for recharge for Extended Winter period Scenario is approximately 130,000 AF/year, of which approximately 55,500 AF/year (43%) is captured by the streams. Similar to the Winter recharge Scenario discussed above, the stream capture conditions vary geographically from north to south, with more opportunities of interaction between the surface water and groundwater systems in the Merced area, compared to more limited opportunities in the south along the Kings River. Therefore, stream capture ranges from 51% of recharge water in the north to 24% of recharge water in the southern part of the project area. Additionally, approximately 22,700 AF/year (17%) of the water available for recharge migrates to groundwater basins adjacent to the project area, contributing to the groundwater storage in these areas. Therefore, net increase in groundwater storage in the project area ends up to be approximately 51,800 AF/year or 40% of all recharge water. This net benefit to groundwater storage varies geographically with approximately 15% of the total project area benefit occurring in each of the northern and central basins and 70% of the total project benefit occurring in the southern portions of the project area.

The proposed water available for recharge is based on the existing available diversion and conveyance capacities. Table 9 shows that there is additional water, to the tune of approximately 76,000 AF/year for Winter and 123,000 AF/year for Extended Winter scenario, that can potentially be available for recharge, if the infrastructure capacity is expanded and upgraded. Additional more detail engineering and economic analysis are needed to assess the feasibility and viability of such infrastructure expansion.

Water quality may be impacted as a result of flushing of nitrate, salts, and other constituents from the unsaturated zone. These are already present in the subsurface and are migrating towards the aquifer system, but the increase in recharged water would accelerate this migration and could result in increased application of fertilizer. Additional study is warranted to identify potential water quality impacts.

7. Conclusions and Recommendations

This study evaluated the feasibility of using excess winter streamflows to recharge groundwater basins through flooding of agricultural fields in the study area on a portion of the east side of the San Joaquin Valley. The following conclusions can be made:

1. While excess winter flows are not available every year, an average of 80,000 to 130,000 AF/year can be diverted through the existing available capacities in the diversion turn-outs, conveyance, and distribution canals for delivery to farms.
2. The proposed on-farm recharge effort can yield approximately 31,000 to 52,000 AF per year of increased groundwater storage. When compared to estimated overdraft in the project area of 250,000 AF per year, this recharge method would reduce overdraft in the area by 12% to 20%.
3. Given the low cost of implementation of on-farm recharge, this is a very cost-effective manner of improved groundwater sustainability for the project area.
4. The recharge benefits vary significantly in the project area. The southern region near Fresno County has a greater potential for groundwater recharge and improved storage than the two counties in the northern project areas (Madera and Merced).
5. Expansion of such an approach across a broader geographic area, including excess winter flows from other major watersheds in the valley, such as the San Joaquin, Tuolumne and Stanislaus rivers, would provide significant contribution towards addressing the estimated annual overdraft of 1,200,000 AF/year in the San Joaquin Valley and achieving sustainable groundwater management.
6. Additional investments in building more diversion turn-out, conveyance, and distribution capacity will likely increase the benefits of the project. More detail feasibility studies, including engineering economic analysis is needed to further define the benefits.

The following additional work is recommended:

Crop Suitability Pilot Studies

Additional pilot studies, building on existing local field studies, are needed to estimate the potential impacts to crops, as grower acceptance will depend on a well-understood assessment of risk. This is particularly true for permanent crops, which have a high value beyond the current year crop. By performing additional pilot studies in the San Joaquin Valley, real-world data can be collected and analyzed to identify the preferred period for recharge and the required recovery periods for crop health.

Water Quality Pilot Studies

Pilot studies are also needed to investigate water quality impacts. Such impacts could occur as wintertime recharge flushes salts, nutrients, or other agrochemicals through the root zone and unsaturated zone into the aquifer system. Pilot studies could assist in quantification of these effects.

Comprehensive Understanding of Water Rights

This report assumed that existing water rights documentation would be sufficient for delivery of water to the existing surface water holders. However, additional research is needed to evaluate water rights implications.

Improved Understanding of Grower Needs and Incentives

Ultimate project success will require the voluntary participation of growers. The pilot studies and analysis will need to address technical questions in a manner that resolves outstanding issues for the growers. Additionally, proper economic incentives will need to be developed to encourage participation, recognizing risk and on-farm management costs, as well as potential quantifiable benefits such as salt leaching from the root zone and reduced pumping lift. Grower outreach through surveys or interviews can assist in identifying the primary concerns and needs of the growers to tailor the technical and institutional development of the project.

Enhancements in simulation capabilities of C2VSim

Additional enhancements to the C2VSim crop acreage, crop evapotranspirative capabilities, and demand estimates during winter can help provide more accurate estimates of winter recharge.

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