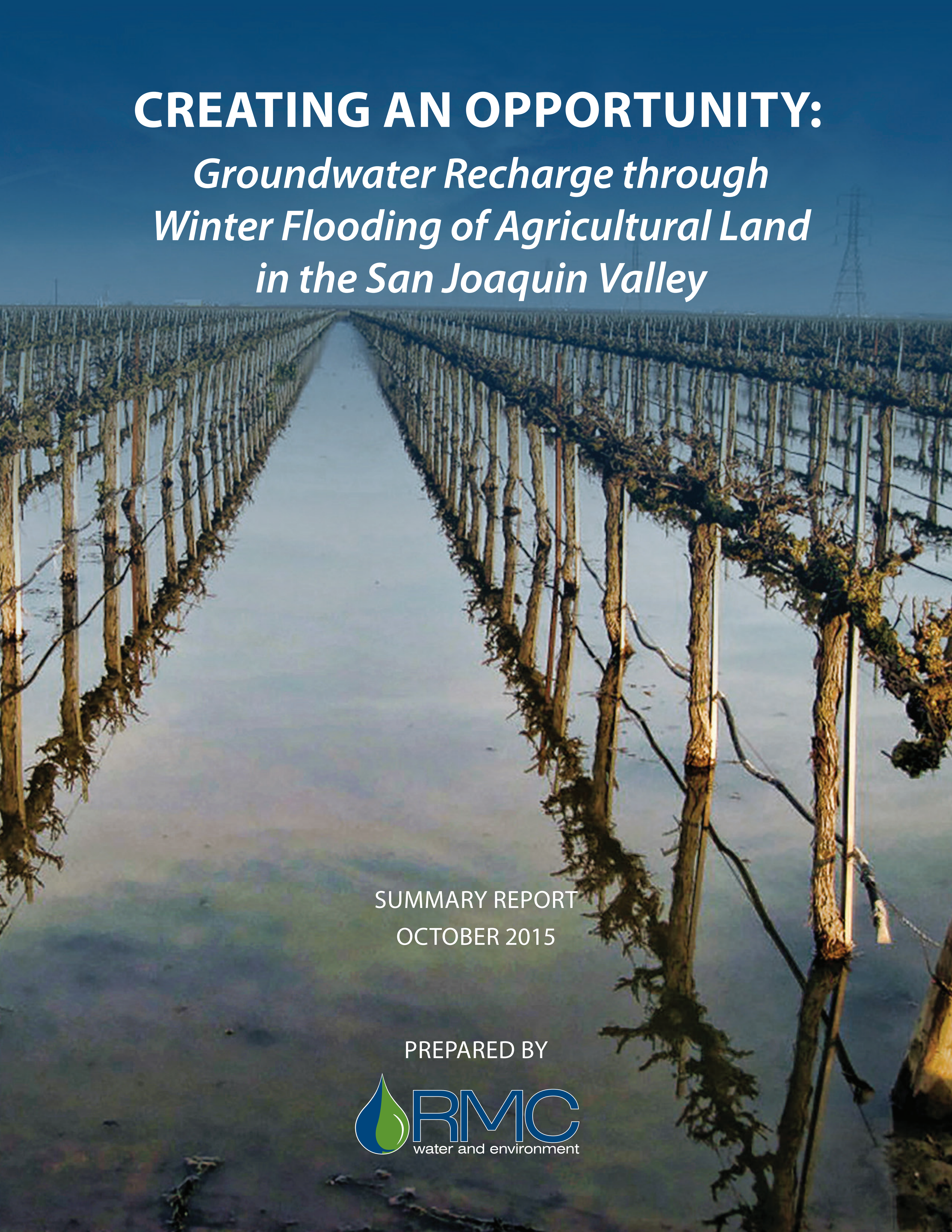

CREATING AN OPPORTUNITY:

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

SUMMARY REPORT
OCTOBER 2015

PREPARED BY

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CALIFORNIA WATER FOUNDATION

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.

Contents

This is the “Summary Report” part of a two-part report. The full report is also available under the same title.

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. However, 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.

As California completes a fourth year of drought, the California Department of Water Resources has reported that groundwater levels have fallen in many basins throughout the state from spring 2013 through fall 2014, and more notably since spring 2010. Basins with notable declines in groundwater levels are in the Sacramento River, San Joaquin River, Tulare Lake, San Francisco Bay, Central Coast, and South Coast hydrologic regions.

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. The SGMA requires the formation of locally-controlled Groundwater Sustainability Agencies which must develop Groundwater Sustainability Plans to achieve groundwater sustainability in groundwater basins or subbasins that DWR designates as medium or high priority. SGMA also includes new and expanded responsibilities for DWR, including identifying water available for groundwater replenishment.

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 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 direct 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 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. 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.

This report presents the approach, assumptions, and findings of a study to evaluate the viability and potential benefits of the recharge of winter-time excess river flows through agricultural lands in a portion of the San Joaquin Valley within Merced, Madera, and Fresno counties (Figure 1). 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 using existing canal infrastructure and on-farm spreading, depending on the length of recharge season.

This program can benefit increasing long-term groundwater storage, as well as a long-term increase in surface baseflows by reducing the stream contributions to the groundwater system. Depending on the length of recharge season, the estimated long-term net contribution to increase in groundwater storage is estimated to be between 31,000 and 52,000 AF/year, with approximately 20%-27% of the total project benefits occurring in each of the northern basins, and 48%-70% of the total project benefits occurring 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 basins adjacent to the project area, contributing to the groundwater storage in San Joaquin Valley.

The increases in groundwater in storage can be compared to estimated long-term project area groundwater overdraft of 250,000 AF/year. 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.

The proposed recharge method would reduce overdraft by 12% to 20% in project area.

The analysis consisted of three major factors that affect recharge feasibility:

- **Land recharge suitability** - Identification of areas with subsurface conditions suitable for recharge in the study area;
- **Crop recharge suitability** - Identification of tolerant crop types, period of year for flooding agricultural lands, and duration of ponding;
- **Recharge Water availability** - Estimation of potentially available surface water flows, based on minimum flow requirements, historical streamflows, and historically available conveyance capacity.

The information developed through the land recharge suitability, crop recharge suitability, and water availability analyses was used in the California Central Valley Groundwater-Surface Water Simulation Model (C2VSim) to estimate the potential regional changes in inflows, outflows, and storage for the groundwater system as a result of the proposed recharge.

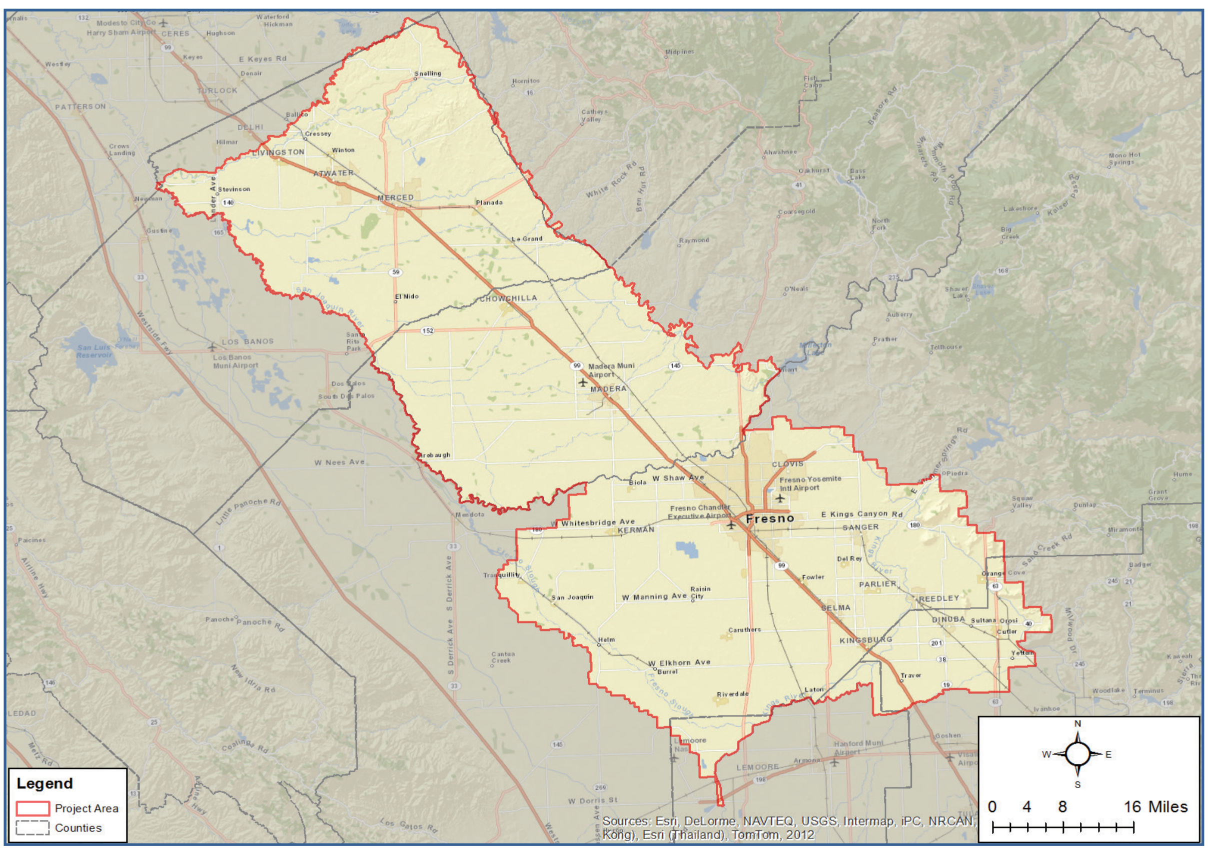


Figure 1: Project Area

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 general areas identified in this study for groundwater recharge through winter flooding of agricultural land are conceptual, areas suitable for winter flooding, and are not intended to identify specific land parcels.

Water Rights – A water rights analysis of available recharge water was beyond the scope of this study. An assumption was made that excess flows are available for diversion and use by the water purveyors.

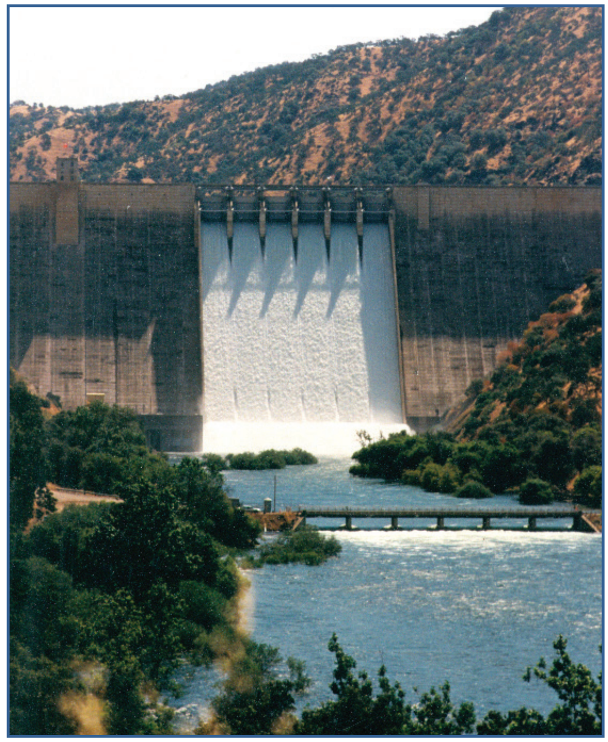
Infrastructure – A general evaluation of existing conveyance and distribution facilities was made for this study to identify the capacity to convey the recharge water. It was assumed that no new conveyance and/or distribution facilities (beyond field-level work necessary to pond and infiltrate water) would be needed.

Use of Recharged Water – The analysis did not include the recovery and use of the recharged water.

Land Recharge Suitability

The land recharge suitability analysis was performed using a 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 results of the analysis indicate that there is significant agricultural acreage in the project area that is suitable for recharge.



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

1. Soil type
2. Deep ripping of soils
3. Subsurface materials
4. Corcoran Clay thickness
5. Depth to groundwater

Figure 2 displays the resulting Recharge Suitability Index. The results of the analysis indicate that there is significant agricultural acreage in the project area that is suitable for recharge. The majority of lands found suitable for recharge through winter flooding are along Highway 99 to the northwest of Merced and along the Merced River, and 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.

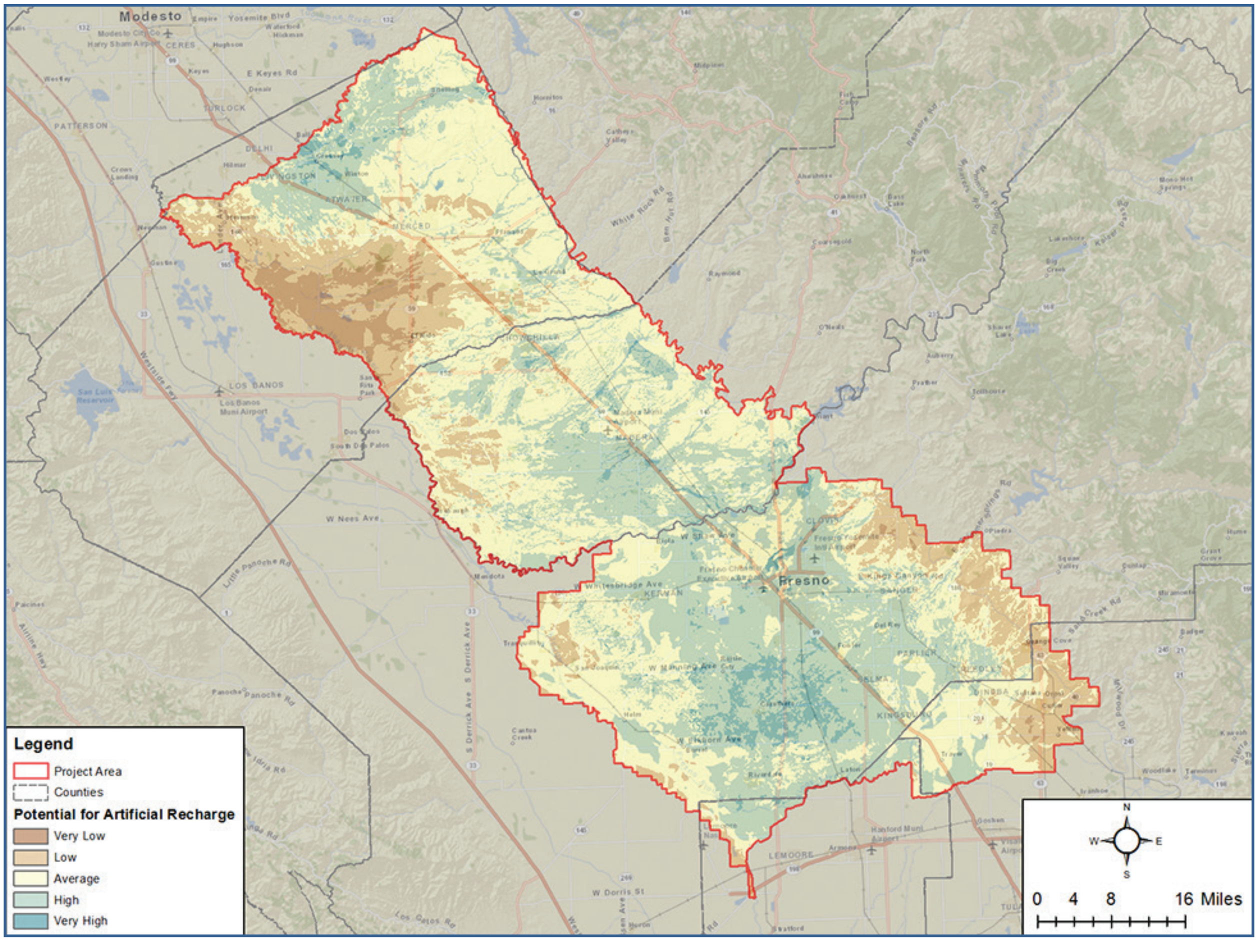


Figure 2: Lands Suitable for Recharge – Recharge Suitability Index

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, UC Extension agents, and available literature. The study by Bachand, et al. (2012) included flooding periods well into the summer, and the grower, who participated in the research, indicated no impact on overall yield. Most existing literature on agricultural impacts of flooding, however, suggests much shorter flooding periods; much of the areas studied by the literature are in areas that have more fine grained soils and were subject to uncontrolled flood waters. 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.

Given the uncertainties in crop recharge suitability, this study did not limit identification of suitable lands or farm plots to any certain particular type, but the time intervals for flooding were limited to the winter dorment-period, as discussed in the following section in more detail.

Recharge Water Availability

Wintertime flood flows from the Merced River, Chowchilla River, Fresno River, and Kings River (Figure 3) were considered as potential sources of water for recharge on the agricultural lands.

The following scenarios were analyzed 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.

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

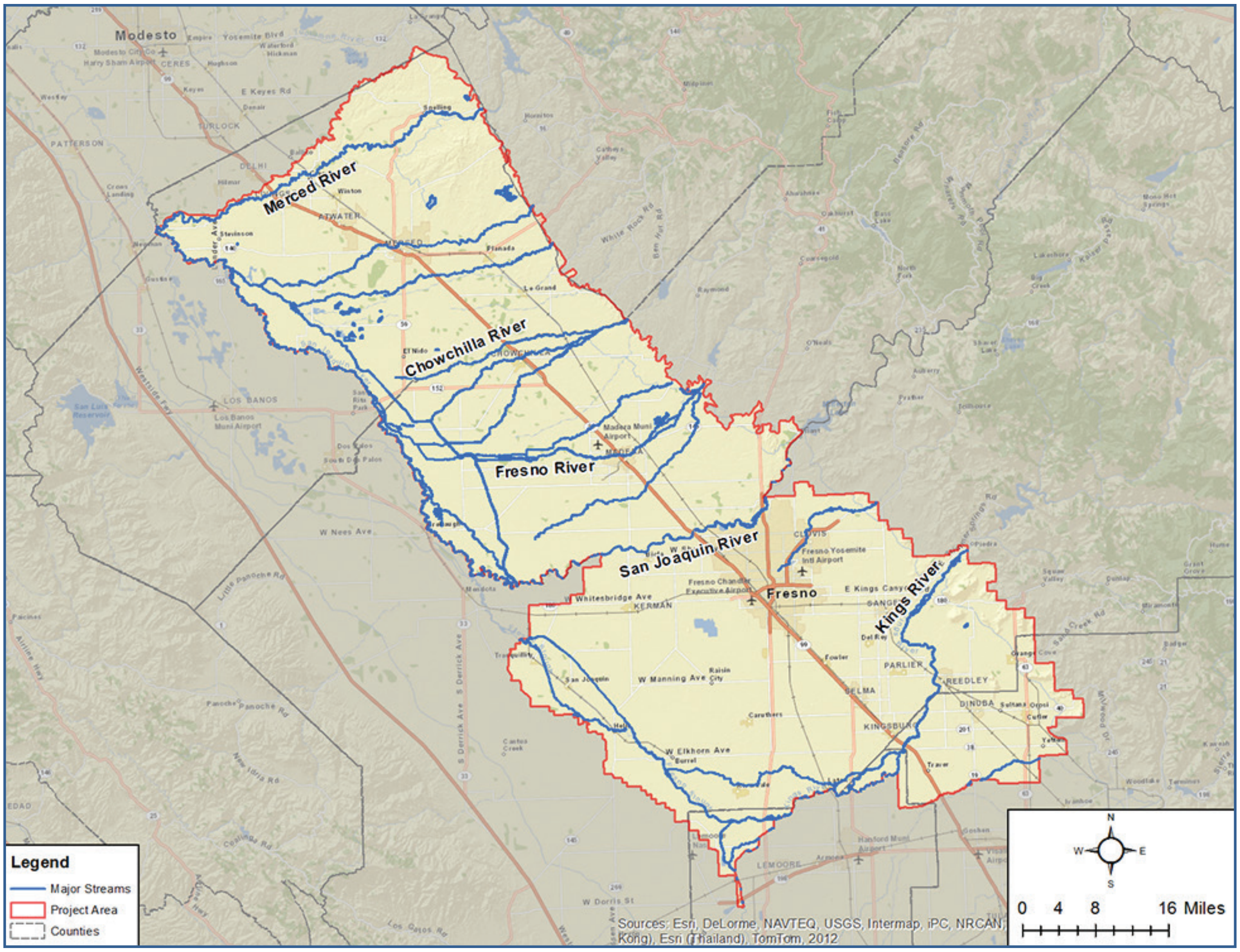


Figure 3: Major Rivers and Water Courses in the Project Area

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. Table 1 summarizes 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.

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

Water Source	Recharge Period	Total Flood Flows	Historical Diversions	Flood Flows that can be Conveyed with Existing Capacity	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**	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**

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

Groundwater Recharge Benefits

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.

The analyses indicate the following increases in the average annual groundwater storage for the two scenarios evaluated. The Winter scenario assumed recharge between December and February, and the Extended Winter scenario assumed recharge between November and March:

- Winter: 31,000 AF/year increase in groundwater storage
- Extended Winter: 51,800 AF/year increase in groundwater storage

The following sections describe the methodology used to evaluate the scenarios.

C2VSIM Integrated Hydrologic Model

Integrated hydrologic modeling to evaluate the effectiveness of recharge through winter flooding was performed using the California Department of Water Resources' C2VSim model, which covers the entire Central Valley, including the full project area. It is a three-dimensional model that simulates monthly hydrologic processes in the surface and subsurface environments as one integrated system. The model simulates major rivers, including those being analyzed as part of this effort: Merced River, Chowchilla River, Fresno River, and Kings River.

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.

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.

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. The results of modeling analysis are presented in the following section.

Groundwater Level Benefits

The long-term effects of on-farm capture of excess winter flows on groundwater levels for both the Winter and Extended Winter recharge periods are illustrated in Figure 4 and Figure 5. The type and magnitude of recharge benefits change over, with initial increases in groundwater levels leading to reduced stream depletion. benefits are realized in the form of more moderate increases in groundwater levels over much larger geographic areas. The long-term and more moderate rises in groundwater levels have the following general benefits:

- Increased interaction between groundwater and surface water courses, resulting in lower stream depletion due to higher groundwater levels and therefore higher streamflows and potentially better ecosystem conditions.
- Lower lift at the pumping wells, resulting in less costs of pumping and more long-term savings in energy consumption.

Table 2 provides information on estimated increases in groundwater levels for different hydrologic conditions.

Table 2: Changes in Groundwater Elevation for Winter and Extended Winter Recharge Periods for Selected Years

Hydrologic Condition	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
Wet Year	50-75	>75	5-15	15-25	50-75	50-75
Dry Year	25-35	35-50	5-15	5-15	15-25	25-35
End of Simulation	25-35	35-50	5-15	5-15	5-15	15-25

Benefits to Groundwater Storage and Stream Capture

As groundwater elevations rise from the recharge, the interaction between the surface water and groundwater systems change. Stream capture is a term for the combination of increased recharge from a stream to groundwater and decreased discharge from groundwater to a stream. Stream capture 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 recharge program would benefit 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 project-related recharge of groundwater and resulting higher groundwater elevations will reduce stream capture. These changes may be due to reduced discharge of groundwater to surface water (gaining stream) and/or increased 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. Both increased groundwater in storage and decreased stream capture are beneficial to water resources conditions.

The effects of capturing excess winter flows for recharge on groundwater storage and stream capture were quantified by developing average annual summary of the key components of the groundwater budget.

The percentage of recharged water that results in increased groundwater storage, as opposed to reduced stream capture or subsurface flows to groundwater adjacent to the recharge area, is approximately the same (40%) for both Winter and Extended Winter. This suggests the ability to further expand the project within the footprint of the project area without significantly shifting benefits from groundwater storage to streamflow, should conveyance or other limitations be eased. Further, the results show significant long-term groundwater storage benefits. Shorter timeframes will likely result in higher percentages of benefits to groundwater storage relative to stream capture, as time is required for the recharged groundwater to interact with surface water courses.

Table 3: Average Annual Potential Recharge Effects

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%
Net Increase in GW Storage	31,000	39%	51,800	40%

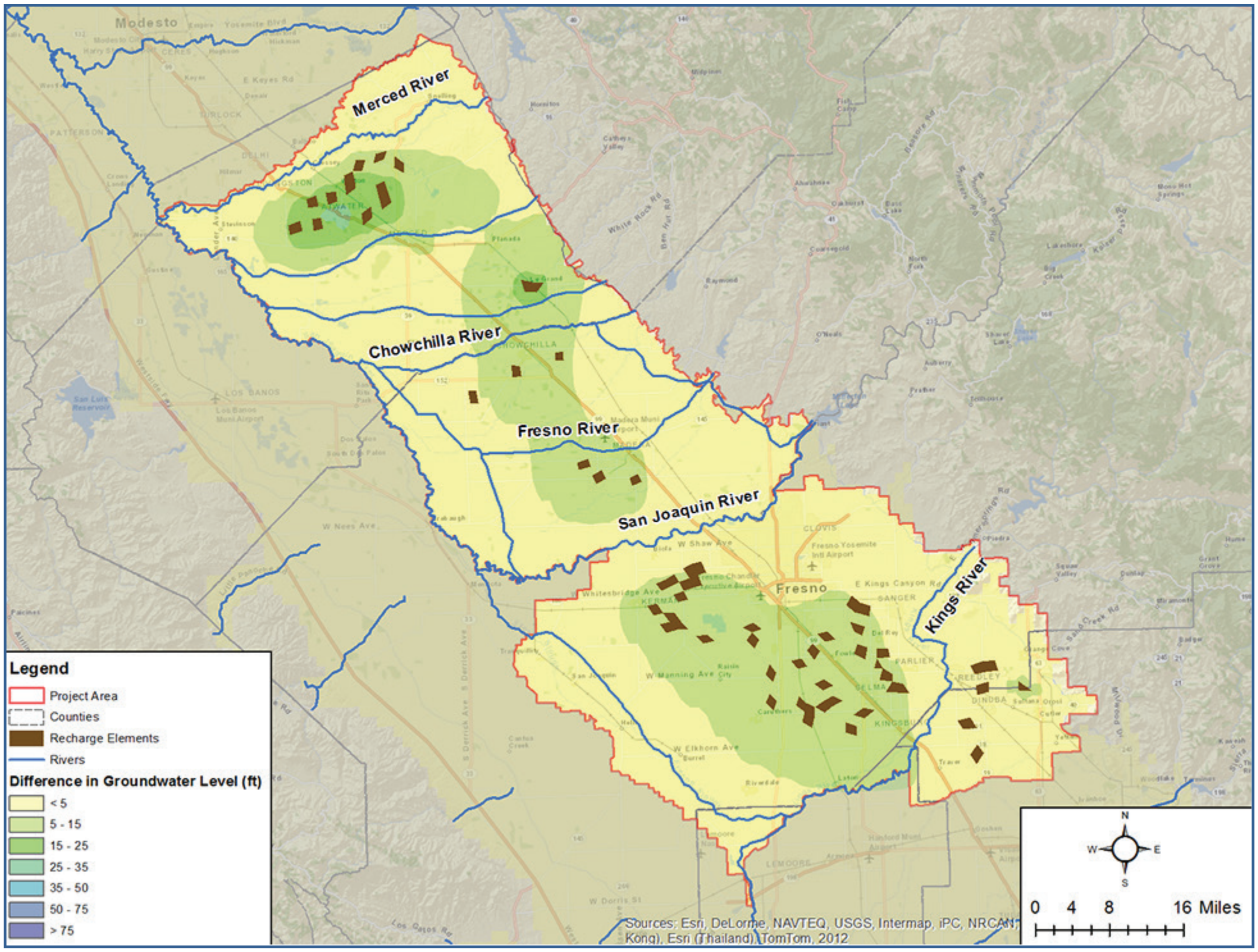


Figure 4: Groundwater Level Changes for the Winter Recharge Scenario

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.

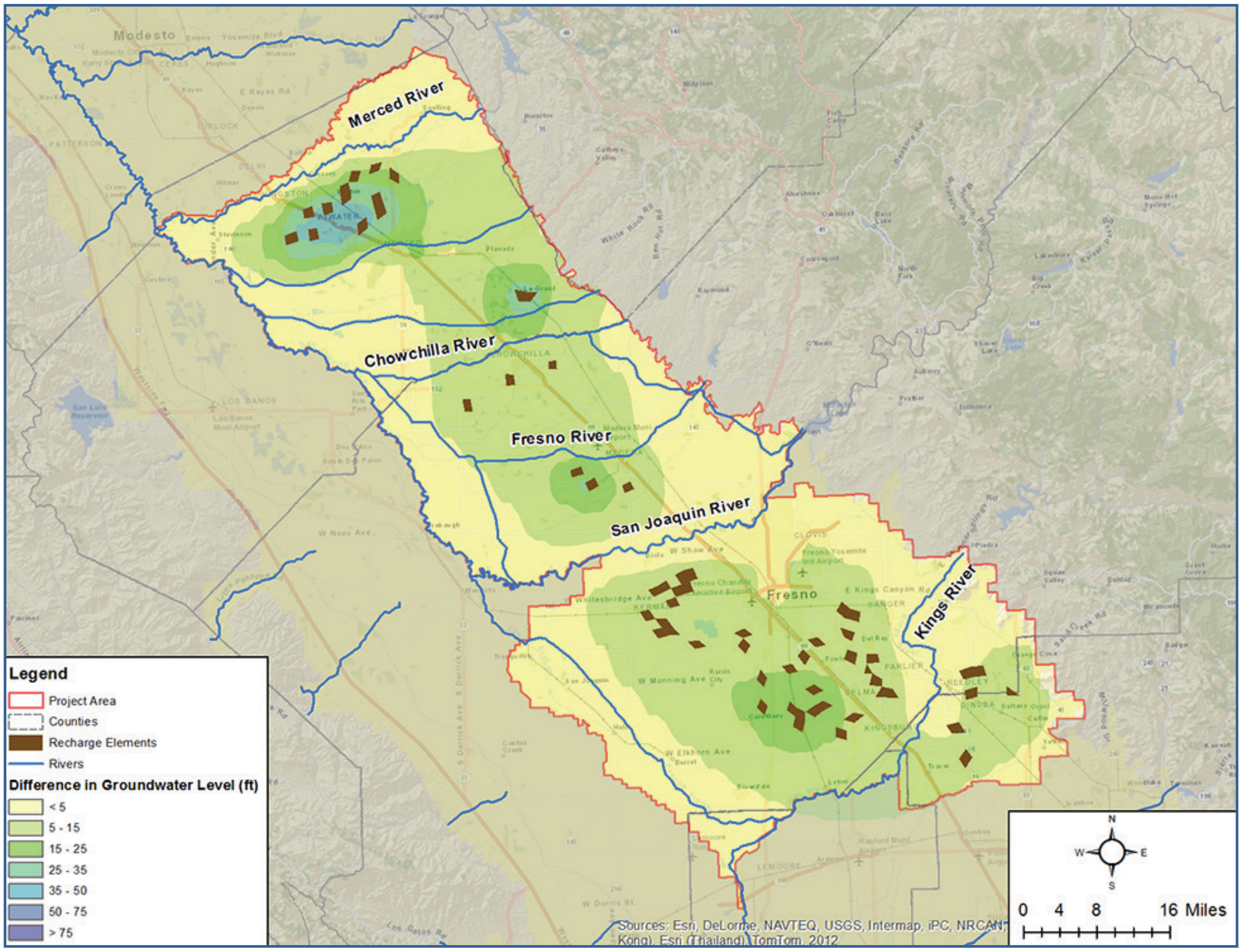


Figure 5: Groundwater Level Changes for the Extended Winter Recharge Scenario

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 would be sufficient for delivery of water. 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.