Multi-Benefit Approaches to Sustainable Groundwater Management

A Framework for California's Groundwater Sustainability Agencies and Stakeholders

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As authors of this Group Project report completed in March, 2018, we archive this report on the Bren School's website such that the results of our research are available for all to read. Our signatures on the document signify our joint responsibility to fulfill the archiving standards set by the Bren School of Environmental Science & Management.

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The Group Project is required of all students in the Master of Environmental Science and Management (MESM) Program. The project is a year-long activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Group Project Final Report is authored by MESM students and has been reviewed and approved by:

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Abstract

Located in California's Central Valley, the San Joaquin Valley is one of the most agriculturally productive regions in the world, generating $31 billion in revenue annually. However, San Joaquin Valley agriculture is increasingly reliant on the region's diminishing groundwater supplies. As a result, groundwater overdraft has been responsible for valley-wide environmental damages, such as the drying up of streams, land subsidence, and community water supply contamination. To address this statewide crisis, California passed the Sustainable Groundwater Management Act (SGMA) in 2014, requiring groundwater basins be brought back into balance by 2040. Starting as soon as 2020, landowners will face tough decisions on how to decrease groundwater usage in the most cost-effective manner. This project explores the feasibility of ways landowners can save groundwater at minimal costs, while also analyzing the cost-differential for projects that generate multiple benefits, like creating endangered species habitat. Projects that can generate co-benefits may be eligible for incentive payments that can offset the costs of SGMA. The scope was narrowed to Kern County, a high-priority sub-basin under SGMA that generates $6.2 billion in agricultural revenues.

To evaluate the attractiveness of groundwater management options, cost-benefit analyses (CBAs) of several methods were performed. Results suggest that full agricultural production fed by groundwater generated the most benefit at the least cost for all crop types. With the advent of SGMA, however, landowners in the Central Valley can no longer pursue this option. Tasked with curtailing groundwater overdraft, the CBAs suggest higher profit margin crops benefit from maintaining full production with surface water irrigation supplied through in-lieu or on-farm recharge. Lower profit margin crops benefit more from multi-benefit replenishment projects, where landowners can offset costs of fallowing through incentive payments received for habitat creation. Supplemental societal impacts of multi-benefit projects include improvements in air quality and reduced pesticide use, as well as creating new restoration economy jobs to offset farm labor loss.

Lastly, a spatial analysis was performed to assess the spatial suitability of groundwater projects to determine differences in cost and groundwater savings between projects with and without co-benefit creation. Using the conservation-planning program Marxan, the siting of wetland and upland habitat groundwater replenishment projects was optimized subject to minimizing costs while achieving groundwater savings and habitat creation targets. Results indicate that when optimizing for water savings through upland habitat replenishment projects, 85,500 acres of endangered species upland habitat can be created with projects that achieve equal groundwater savings (426,670 AFY) for an additional cost of $3.9 million when compared to no habitat optimization. However, wetland habitat optimization results indicate 13,015 acres wetland habitat can be created, achieving 1 million AFY of groundwater replenishment, but at an additional cost of $262.3 million compared to optimizing only for groundwater replenishment targets. Thus, through CBA and spatial analysis, groundwater management projects that generate multiple benefits are feasible in the San Joaquin Valley—provided that landowners have access to sufficient incentive streams to offset additional costs for generating co-benefits.

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List of Acronyms

AF – Acre Feet

AFY – Acre Feet per Year

BDI – Bay-Delta Initiative

BLM – Boundary Length Modifier

BCR – Benefit-Cost Ratio

CARB – California Air Resources Board

CASGEM – California Statewide Groundwater Elevation Monitoring

CBA – Cost Benefit Analysis

CCED – California Conservation Easement Database

CDFW – California Fish and Wildlife Service

CEQA – California Environmental Quality Act

CF – Conservation Factor

CPAD – California Protected Area Database

CPI – Consumer Price Index

CRP – Conservation Reserve Program

CSP – Conservation Stewardship Program

CV – Central Valley

CVP – Central Valley Project

DAC – Disadvantaged Community

DOGGR – Division of Oil, Gas, and Geothermal Resources

DOT – Department of Transportation

DWR – Department of Water Resources

EAST – Ecoregional Assessment Status Tool

EDF – Environmental Defense Fund

EPA – Environmental Protection Agency

EQIP – Environmental Quality Incentives Program

ESA – Endangered Species Act

FCGMA – Fox Canyon Groundwater Management Agency

GDP – Gross Domestic Product

GIS – Geographic Information Systems

GPMS – Gas Pipeline Mapping System

GSA – Groundwater Sustainability Agency

GSP – Groundwater Sustainability Plan

HQT – Habitat Quantification Tool

MBOM – Multi-Benefit Optimization Model

MCA – Mitigation Credit Agreement

MCL – Maximum Contaminant Level

MESM - Master of Environmental Science and Management

NASS – National Agriculture Statistics Service

NEPA – National Environmental Policy Act

NOAA – National Oceanic and Atmospheric Administration

NPMS – National Pipeline Mapping System

NPV – Net Present Value

NRCS – Natural Resources Conservation Service

O&M – Operations and Maintenance

PUC – Public Utilities Commission

RCA – Regional Conservation Agreement

RCIS – Regional Conservation Investment Strategy

SAGBI – Soil Agricultural Groundwater Banking Index

SGMA – Sustainable Groundwater Management Act

SJV – San Joaquin Valley

SPMS – State Pipeline Mapping System

SW – Surface Water

SWID – Shafter-Wasco Irrigation District

SWP – State Water Project

SWRCB – State Water Resources Control Board

TNC – The Nature Conservancy

USDA – United States Department of Agriculture

USFWS-NAWCC – US Fish and Wildlife Service- North American Wetlands Conservation Council

WY – Water Year

Glossary of Terms

Conservation Easement: a legally binding agreement that limits certain types of uses or prevents development from taking place on a piece of land in perpetuity while it remains in private hands

Conservation: preservation, protection, or restoration of the natural environment, natural ecosystems, vegetation, and wildlife

Critically Overdrafted Basin: a basin defined by the Department of Water Resources as one wherein continuation of present water management practices would probably result in significant adverse overdraft-related environmental, social, or economic impacts

Fallowing: the permanent or temporary act of taking agricultural lands out of production

Groundwater Sustainability Agency: one or more local agencies that implement Sustainable Groundwater Management Act within a given basin or sub-basin

Groundwater Sustainability Plans: a plan of a groundwater sustainability agency proposed or adopted pursuant to the Sustainable Groundwater Management Act

In-Lieu Recharge: surface water use instead of groundwater for irrigation needs, also known as “passive” recharge

On-Farm Recharge: the application of available floodwater to active farmland for replenishment during the crop’s dormant season

Planning Unit: the spatial boundary unit in Marxan, defined as the agricultural field boundaries in the MBOM

Recharge Basin/ponds: constructed surface basins that allow water to slowly infiltrate through the soil into the underground aquifer

Reserve Network: a series of strategically placed reserves designed to connect habitats allowing animals to travel between protected areas through wildlife corridors

Restoration: the act or the process of returning land to its original condition, or to a state similar to its original condition

Safe Harbor Agreement: a voluntary agreement between the U.S. Fish and Wildlife Service and non-Federal landowners designed to benefit federally endangered and threatened species by giving landowners assurances that at no future time would the U.S. Fish and Wildlife Service impose restrictions on their land as a result of conservation actions on their part. These agreements essentially relieve landowners of liability under the Endangered Species Act if conservation practices on their land attract and/or perpetuate federally listed species

Species Range: the geographical area within which a species can be found
Sustainable Groundwater Management Act: California state law requiring groundwater basins achieve sustainable levels by 2040/2042

Upland Habitat Replenishment Project: the retirement of agricultural crops and subsequent restoration of these fallowed field to upland habitat.

Upland Habitat: dry land containing grasslands, scrublands and vernal pools suitable for terrestrial fauna

Irrigation Water Demand: the amount of water required for a certain crop that varies by crop type and by climate

Water Year: the period from October 1 through the following September 30, inclusive

Wetland Habitat Replenishment Project: the replacement of agricultural crops with a recharge pond that infiltrates surface water into the underlying groundwater table, while also serving as wetland habitat

Wetland Habitat: a land area saturated with water either permanently or seasonally suitable for plant-life and animals

Executive Summary

Located in the southern Central Valley of California, the San Joaquin Valley is home to a billion dollar agricultural economy. Agriculture in the San Joaquin Valley accounts for 15% of the gross domestic product (GDP), and comprises half of California's agricultural output.[1] Sixty percent of the land area in the San Joaquin Valley is dedicated to agriculture and produces a wide array of agricultural commodities from fruits to alfalfa, and dairy to cotton.[2]

Since it receives less than ten inches of rain per year, the San Joaquin Valley is technically a desert.[3] During dry years, groundwater accounts for 30-60% of the region's agricultural irrigation needs.[1] As a common pool resource, groundwater can be extracted to meet these needs with little to no regulation or limits on the amount of water pumped. Over the last century, agricultural landowners have become increasingly reliant on groundwater to supplement irrigation needs to a point of groundwater overdraft. During California's most recent drought, groundwater overdraft was largely responsible for extreme detrimental effects, including poor groundwater quality, land subsidence, and significant reductions in groundwater storage. These groundwater impacts have caused concomitant damages to community water supplies, water conveyance infrastructure, and the depletion of groundwater connected streams and wetlands.

In light of this crisis, California passed the Sustainable Groundwater Management Act (SGMA) in 2014. SGMA identifies groundwater basins in conditions of critical overdraft that would most likely generate in adverse environmental, social and economic impacts.[4] As home to many of these critically overdrafted basins, groundwater users across the San Joaquin Valley will be required to return them to balance and reverse decades of unregulated groundwater extraction by the year 2040.[5] Thus, landowners will be faced with tough and expensive groundwater management decisions to comply with rapidly approaching SGMA deadlines.

Traditional groundwater management strategies, such as recharge ponds and large-scale fallowing (i.e., the permanent retiring of agricultural land), will be the most commonly pursued groundwater management strategies to meet water savings at low-cost. However, there may be potential for other groundwater management strategies that achieve these same objectives while also providing auxiliary co-benefits, such as benefits to surrounding natural resources and communities. Multi-benefit replenishment projects offer landowners a means to conserve groundwater and mitigate negative land use impacts, while providing co-benefits at comparable costs. Additionally, multi-benefit replenishment projects have the potential to receive habitat market payments through programs like conservation and wetland mitigation banking. The potential for multi-benefit replenishment projects to offset the costs of SGMA has yet to be fully researched and analyzed. To determine the potential for multi-benefit replenishment projects in the San Joaquin Valley, two analyses were performed: (1) a socio-economic analysis to determine under what conditions landowners benefit from individual replenishment actions, and (2) a spatial analysis to determine where landowners can cost-effectively conserve groundwater while achieving additional habitat benefits at minimal costs.

Kern County, the southernmost county in the San Joaquin Valley, was selected as the specific region of interest due to its $6.2 billion agricultural economy and state of critical groundwater overdraft.[5,6] In 2016, Kern County was named the nation's top agricultural producing county. The Kern County sub-basin is also considered a SGMA high priority groundwater basin and will be managed by eleven separate Groundwater Sustainability Agencies (GSAs). Beneficial users of the sub-basin besides agricultural users include domestic well owners, municipal well operators, California Native American tribes, and wildlife refuges. Seventy-seven percent of residents in the Kern County sub-basin belong to disadvantaged or severely disadvantaged communities.[7] Thus, Kern County serves as an ultimate example of how different interests will come together to solve groundwater overdraft for the long-term sustainability of the basin.

In order to classify the conditions by which a landowner can benefit from groundwater replenishment actions, an economic CBA was performed on several agricultural groundwater management strategies, including fallowing, in-lieu recharge, on-farm recharge, and two multi-benefit replenishment strategies: upland habitat replenishment projects and wetland habitat replenishment projects. Habitat replenishment projects include the restoration of either upland shrub habitat or wetland habitat for endemic and endangered animal species on recharge ponds and fallowed fields. The CBA of multi-benefit replenishment methods revealed that drivers of project costs, operations and foregone crop revenue, could be slightly offset with habitat credit programs for both methods to have benefit-cost ratios (BCRs) greater than a baseline fallow groundwater management method.

Supplemental analysis was performed for 33 crops to explore how costs and benefits are accrued with changing profit margins and irrigation demands. High profit margin crops benefit more by staying in full production, whereas low profit margin crops may benefit economically from multi-benefit replenishment projects—so long as habitat credit programs provide a consistent source of monetary funding. Given the heterogeneous results of the CBA, a functional tool was designed so that individual landowners could adjust inputs (such as crop type, hydrologic variability, and operational costs) to match their circumstances. Apart from the CBA, societal implications were also analyzed for multi-benefit replenishment projects. Habitat creating multi-benefit replenishment projects offer societal benefits such as dust mitigation from restored vegetation, and job creation benefits as a new restoration economy potentially absorbs those who have lost their livelihood due to fallowing.

To complement the multi-benefit replenishment economic analyses, a spatial analysis of the potential for replenishment projects across Kern County was conducted using Geographic Information Systems (GIS) and the conservation-planning program, Marxan. The Multi-Benefit Optimization Model (MBOM) combines spatial data on species habitat ranges, groundwater and geologic conditions, conservation areas, crop revenue and crop irrigation demand to locate agricultural fields with the most potential for replenishment projects at minimal costs. For upland habitat replenishment projects, 129,950 acres of projects can restore 85,500 acres of designated endangered species habitat to save 426,670 AFY through irrigation savings at a total cost of $269.5 million. Compared to the baseline of not including habitat creation targets, this saves an equal amount of water for an additional cost of $3.9 million. Wetland habitat replenishment projects exceed water replenishment targets with the ability to replenish 1 million AFY when optimizing for habitat creation, but create habitat on less than 2% of the fields in Kern County (13,015 acres), for a total estimated cost of $711.8 million. Compared to the baseline of only optimizing for groundwater replenishment, this is an additional $262 million to create an additional 7,320 acres of wetland habitat. Less habitat is created because water replenishment targets can be fulfilled with less land area and high value agricultural in Kern County is co-located near prime habitat areas. Thus, the MBOM determined significant co-benefits can be derived from groundwater management strategies if strategically located to achieve groundwater reduction targets at minimal total costs.

Landowners in the San Joaquin Valley are currently facing significant land use change decisions on how to best and most efficiently comply with rapidly approaching SGMA deadlines. These economic and spatial analyses provide groundwater managers and landowners with information and support to make decisions that reduce groundwater pumping. These analyses further give landowners guidance on how to offset the costs of SGMA through engaging in alternative market mechanisms that benefit natural resources and local communities. Through this research, it has been shown that traditional groundwater management strategies can be reimagined to generate benefits for endangered species, disadvantaged communities, and other beneficiaries at marginal additional costs. The negative impacts from a century of groundwater overdraft can be rectified to raise groundwater tables through a variety of management strategies. The unique opportunity to additionally restore native habitats and improve quality of life in surrounding communities, however, should not be overlooked.

Both the spatial and economic analyses have been designed as functional tools for landowners, GSAs, and additional stakeholders to deliver specific recommendations at different spatial scales. This will encourage multi-benefit replenishment strategies throughout Kern County, the San Joaquin Valley, and other agricultural areas of California to meet groundwater sustainability goals. Information gathered through these analyses has been synthesized to generate a sample Groundwater Sustainability Plan chapter that can enable newly created GSAs to pursue multi-benefit groundwater management.

1. Significance and Background

1.1. Project Significance

Agriculture in the San Joaquin Valley generates billions in annual revenue, providing half of California's agricultural output. However, due to a variable climate, landowners in the San Joaquin Valley have become increasingly reliant on groundwater to supplement scare surface water supplies. This increasing reliance has led to extreme groundwater overdraft, with groundwater being extracted at rates exceeding natural replenishment. As seen in **Figure 1**, for nearly 65% of the groundwater wells in the Tulare Basin, groundwater levels have decreased by over 25 feet from Spring 2011 to Spring 2017.[8]

Negative impacts observed through the Valley due to overdraft include the dewatering of streams, land subsidence on the order of two feet per year, and groundwater supply contamination affecting domestic well use. To effectively mitigate the negative impacts of groundwater depletion and address unsustainable use of groundwater, California passed the Sustainable Groundwater Management Act (SGMA) in 2014. SGMA requires the formation of Groundwater Sustainability Agencies (GSAs) to develop and implement Groundwater Sustainability Plans (GSPs) that detail the means necessary for critically overdrafted basins to achieve sustainability by 2040. Sustainability is defined by SGMA as the avoidance of undesirable effects of reductions in groundwater storage, lower groundwater levels, degraded water quality, seawater intrusion, land subsidence and depletion of interconnected surface waters.[10] With GSAs pursuing different management approaches to achieve their 2040 goal, there is an opportunity to research, develop, and offer an alternative multi-benefit approach that achieves groundwater replenishment as well as improves local community welfare and natural resource values.

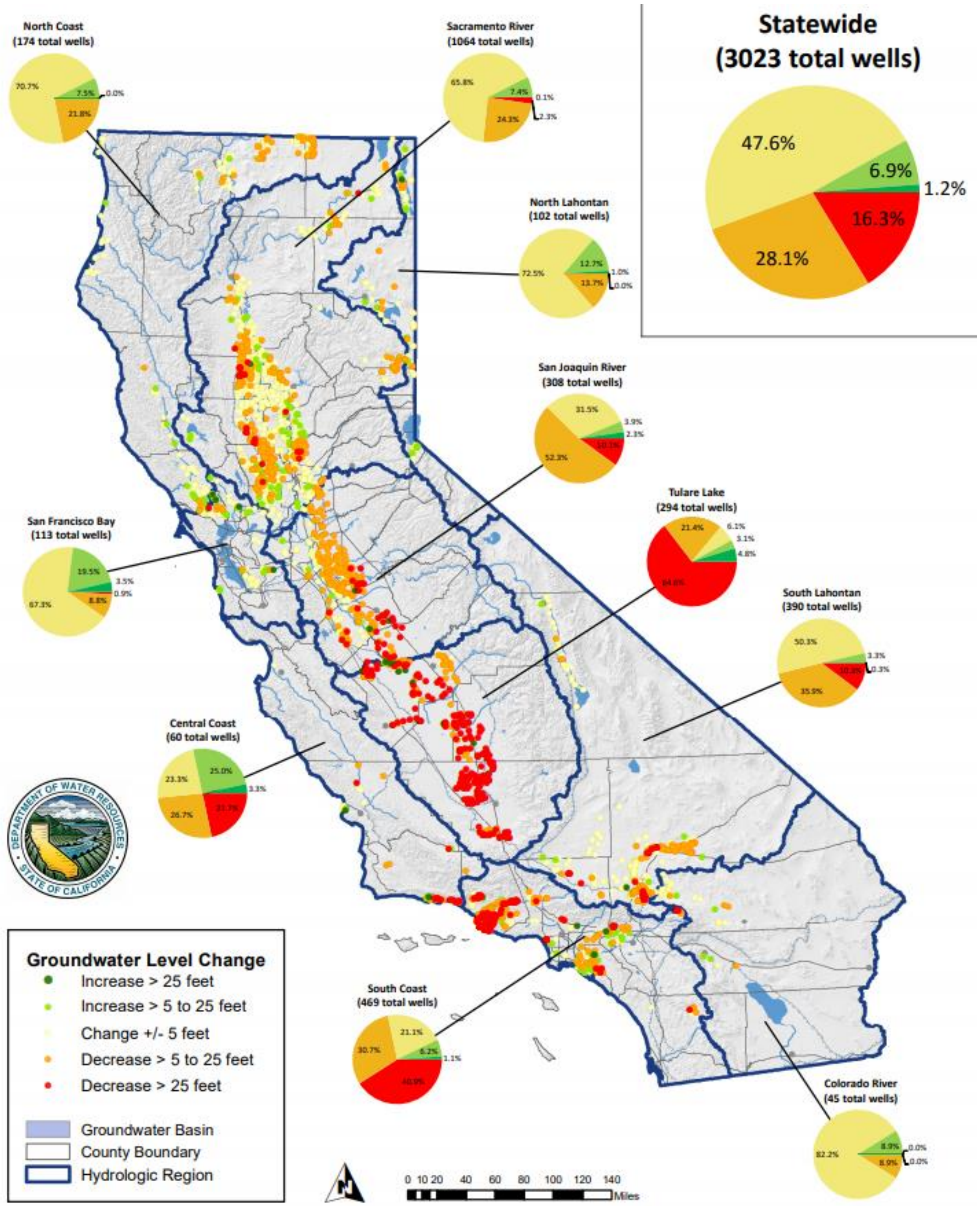


Figure 1: *Groundwater level change in California from Spring 2011 to Spring 2017.*[9]

The Environmental Defense Fund (EDF) has been working with Central Valley growers to develop and pilot solutions to groundwater management that support agricultural production, replenish aquifers, and benefit local communities and natural resources. These multiple benefits include improved air and drinking water quality, endangered species habitat creation, and native vegetation restoration. The foregoing report advances this objective and provides information to drive locally-based systems to facilitate the efficient consumption, exchange and/or banking of groundwater as important management tools. Partnerships with large-scale agribusinesses and landowners can provide a means of piloting such a system. The results of this project will inform EDF's emerging collaboration with landowners throughout the San Joaquin Valley.

SGMA will significantly curtail agricultural producers' access to groundwater. Many Central Valley landowners, already recognize this as a threat to long-term supply chain security and support efforts to meet mandated SGMA deadlines. If landowners could receive monetary benefits for enhancing groundwater sustainability while also achieving community and environmental co-benefits, they may be more likely to implement multi-benefit strategies to replenish aquifers. Providing analyses that identify and incentivize such actions would benefit these landowners and other stakeholders reliant upon groundwater resources. Similarly, a proposed framework of multi-benefit strategies and incentives will provide replicable models for GSAs to embed in GSPs throughout California.

1.2. California Sustainable Groundwater Management Act of 2014

Prior to the passage of SGMA, California lacked comprehensive and effective groundwater management regulations. With only patchwork oversight across the state, overdraft accumulated in many areas over decades of unrestricted urban and agricultural pumping, resulting in costly and sometimes irreversible impacts to the state's drinking water resources and ecosystems.[11] SGMA now applies to 127 groundwater basins that account for 96% of the groundwater used in California.[12] These basins are further prioritized by the California Department of Water Resources (DWR) into high and medium priority basins according to several factors (rate of population growth, groundwater reliance, and documented negative impacts, etc.).[13] High priority basins have been further divided into overdrafted or critically overdrafted. DWR has mandated that GSAs achieve sustainable groundwater management by 2040 or 2042. It is a unique and opportune time to pursue innovative, multi-benefit solutions to sustainable groundwater management.

As of January 2016, 21 of California's 515 groundwater basins were identified as "critically overdrafted" in California.[14,15] SGMA defines a critically overdrafted basin when "continuation of present water management practices would probably result in significant adverse overdraft-related environmental, social, or economic impacts."[14] These basins are most susceptible to the adverse effects of severe overdraft, including seawater intrusion and land subsidence and will need to implement the greatest reductions in groundwater use. In accordance with SGMA, these critically overdrafted basins must establish a GSP by January 31st, 2020. The majority of critically overdrafted basins are within the San Joaquin Valley.[16] This decision framework is designed for use by basin managers throughout California, but will be most useful for landowners and GSAs in overdrafted and critically overdrafted basins. Stakeholders in these basins will need to employ significant management strategies to achieve sustainable groundwater use by 2040.

SGMA is a novel law in California's history; never has such a large, comprehensive plan been set forth to combat groundwater depletion in the state. Importantly, issues of groundwater quantity and quality are addressed without modifying existing water rights. The act was devised to establish local and regional control over the management and use of groundwater basins, and passed as three separate bills in 2014.[17] Given the heterogeneity of the state in terms of groundwater users and resources, SGMA promotes local management through GSAs. These agencies must engage stakeholders within the planning area to develop a GSP that defines undesirable results for the planning area and sets forth actions to avoid those results. State agencies have defined roles in supporting this local management objective. With respect to SGMA, DWR manages the formation of GSAs and GSPs developed by local agencies. The California State Water Resources Control Board (SWRCB) acts as the enforcing entity, intervening in non-SGMA compliant basins to regulate groundwater use.

GSAs can come in many forms. A GSA can consist of a single local agency or multiple local agencies with jurisdiction over an entire basin. Alternatively, multiple local agencies can form multiple GSAs that coordinate to manage a basin. SGMA explicitly lays out procedures for stakeholder engagement in GSA and GSP development processes. Specific stakeholder groups are identified by SGMA and there are requirements for public notification and participation. Specific means of stakeholder engagement, however, are not delineated in SGMA and will vary throughout the state. This variation will be reflected in how effective certain GSAs are at bringing diverse groups and management schemes to the negotiating table.[18] The foregoing framework investigates how stakeholder concerns can be met with multi-benefit groundwater management embedded in GSPs.

1.3. The San Joaquin Valley

The San Joaquin Valley falls within eight inland counties: Fresno, Kern, Kings, Madera, Merced, San Joaquin, Stanislaus, and Tulare. Farms and manufacturing businesses account for 25% of revenue, 16% of local jobs, and 89% of annual net water usage in the region.[1] Over the past three decades, groundwater overdraft has averaged 2 million acre-feet per year (AFY), 15% of net water use. The San Joaquin Valley produces half of California's agricultural output. Since the early 1980s, growers have shifted toward perennial vineyards, orchards, and high-revenue annual specialty crops in response to rising agricultural commodity prices, technological innovation, low interest rates, and rising costs of land and water.[1] From 1980 to 2012, total acreage of orchards and vineyards grew from 21% to 36%. However, in 2015 San Joaquin Valley growers faced a 10% shortage of water leading them to fallow 8% of cropland.[1] Elsewhere in the American West, strategies are being developed to reduce net water use. Partial fallowing, or fallow-leasing, is a strategy now being piloted in the Colorado River basin to reduce net water use and provide assurances to landowners to lease water to municipalities in dry periods.[19] This framework details the benefits a landowner can derive from pursuing multi-benefit groundwater management strategies, particularly through methods of either groundwater replenishment or agricultural fallowing.

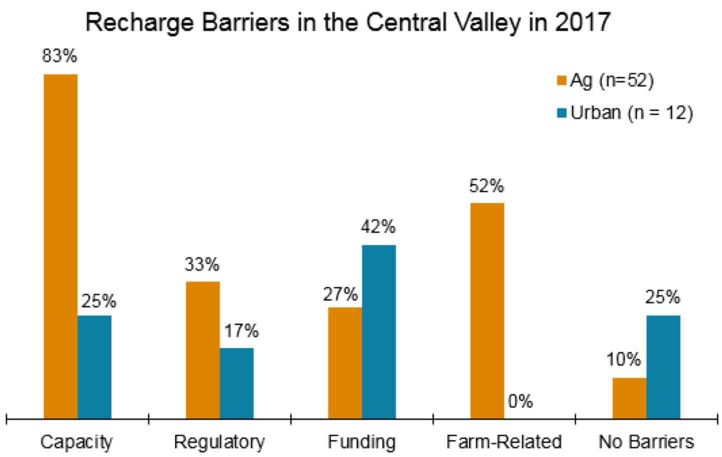
Agriculture and related processing provides over one-quarter of the employment in the San Joaquin Valley: 13% in crop and animal production, and 3% in food and beverage processing.[1] Other large industries include healthcare, retail and manufacturing.[20] Poverty levels are above average and there is a disproportionate amount of Disadvantaged Communities (DACs) in the San Joaquin Valley. While there is no universal definition for a DAC, the communities generally share the characteristics of having low-income levels, high levels of poverty, poor public health indicators, and high exposure to environmental hazards.[20] California specifically defines a DAC as the top 25% scoring areas from CalEnviroScreen through an evaluation process where communities are scored on a series of health, pollution and population characteristics.[20] Air and water pollution are of particular concern in the agricultural areas of the San Joaquin Valley.[21] SGMA implementation has the potential to mitigate damages to these communities and can lessen some environmental burdens for DACs, but will also likely result in economic hardships.

1.4. Groundwater Replenishment

1.4.1. *Current Efforts in California*

There have been an increasing number of efforts to develop farm-level groundwater management strategies that could facilitate groundwater replenishment through direct and in-lieu recharge. Sustainable Conservation began a partnership with the Kings River Conservation District and the Almond Board in 2011 to promote the application of available floodwater to active farmland for replenishment ("on-farm recharge").[22] In Kern County, the Shafter-Wasco Irrigation District allowed replenishment of unfarmed land for credit in advance of SGMA. This was consistent with Shafter-Wasco's future GSP, which will allow SGMA credits for the "offset" of groundwater pumping within or adjacent to its territory.[23] The Recharge Initiative at the University of California, Santa Cruz is collaborating with government agencies, municipalities and landowners, particularly in the Pajaro Valley groundwater basin, on groundwater recharge efforts that prevent future seawater intrusion.[24] Researchers at University of California, Davis (UC Davis) are also collaborating with the Scott-Valley Irrigation District and the Orland-Artois Water District to explore on-farm recharge opportunities.[25]

A recent study by the Public Policy Institute of California (PPIC) found that a majority of agricultural water districts, of those surveyed in the Central Valley, are currently operating or plan to operate groundwater replenishment projects.[26] The study also found that a portion of urban districts have also implemented or plan to implement groundwater replenishment strategies. Agricultural districts primarily use in-lieu recharge and unlined canal methods (~70% of districts), with the most future potential for open space-recharge, fallowed-land recharge, and recharge basins (each category expected to expand by 20%). The most popular replenishment method for urban districts has been recharge basins (~30% of districts), followed by in-lieu recharge (25% of districts), unlined canals (18% of districts), and open space recharge (15% of districts). PPIC found that over half of the replenishment efforts are being performed in the Kern basin and that recharge basins store the most water, but that several barriers exist when implementing replenishment projects. The following graphic highlights these barriers (**Figure 2**).[26]



Barriers to Recharge	Ag	Urban
Capacity Issues		
System Conveyance	37%	8%
District Basin Capacity	50%	25%
District Conveyance	44%	17%
Timing of Water	63%	8%
Regulatory Issues		
Construction Approvals	29%	8%
Water Rights	15%	0%
Conveyance Approvals	10%	0%
Water Quality	10%	8%
Funding Issues		
Proposition 218	17%	0%
Price of Water	12%	0%
Migration Out of District	0%	42%
Farm-Related Issues		
Irrigation System	46%	0%
Benefits for Farmers	13%	0%
Crop Health	29%	0%

Figure 2: *Barriers to recharge in the Central Valley.*[26]

** summarized survey results of water districts*

Despite these barriers, the interest to expand replenishment projects within the Central Valley is widespread. Water districts have indicated that they plan to prioritize capacity, regulatory, basin planning and management, funding, water availability, followed by farm-related barriers. [26]

In November 2017, the California DWR published a draft white paper that discusses the opportunities for using flood water for managed aquifer recharge (Flood-MAR).[27] Public benefits of replenishment projects include flood risk reduction, drought preparedness, aquifer replenishment, ecosystem enhancement, subsidence mitigation, water quality improvements, working landscape preservation and stewardship, climate change adaptation, and recreation and aesthetics. Additional private and local benefits of groundwater replenishment projects include water supply reliability and reduced groundwater pumping costs. The following figure is a conceptual display as to how replenishment projects can operate on working landscapes (**Figure 3**).[27]

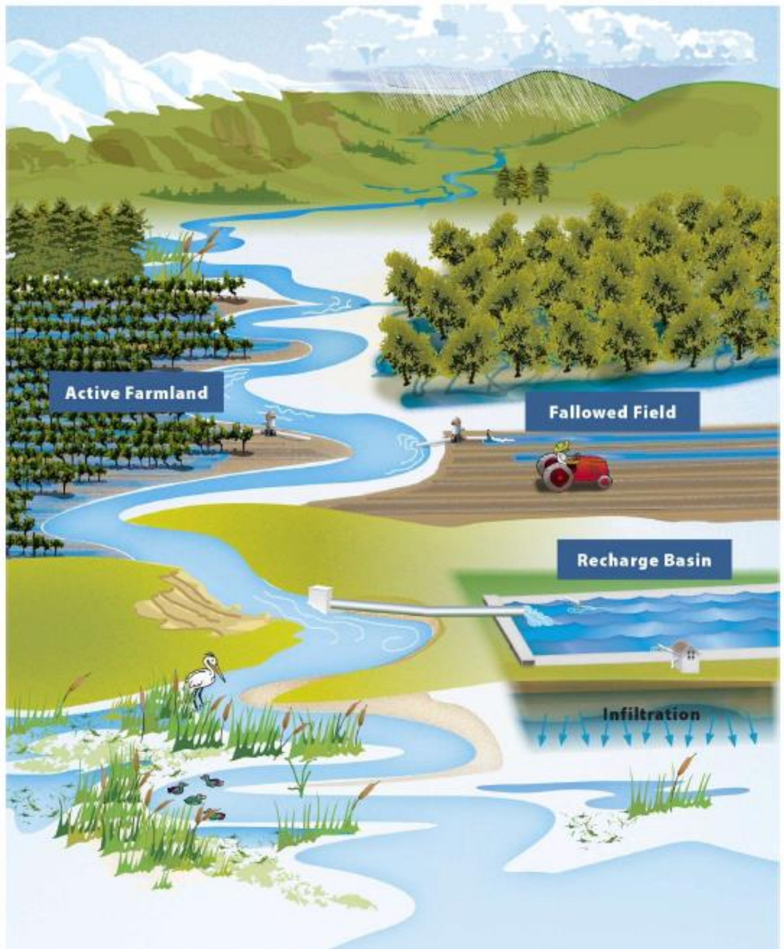


Figure 3: *Multi-Benefit recharge opportunities defined by the Department of Water Resources.*[27]

DWR identifies the following factors to consider for a Flood-MAR project, which can be also considered for replenishment projects more generally:[27]

- Site Suitability: landowner willingness, soil suitability, crop suitability, aquifer suitability, aquifer capacity, aquifer water quality, environmental considerations
- Source Water: high flows, reservoir reoperation, timing and quality of flows, future expectations of flows
- Conveyance: existing infrastructure, new infrastructure
- Governance and Coordination: beneficiaries, costs and risks, coordination of operations, project feasibility, state incentive programs
- Legal: water right considerations, regulatory standards

- Recharge Method: on-farm, fallows land, dedicated basin, in-lieu, direct injection
- Groundwater Use: groundwater extraction wells, beneficial uses, augmentation of groundwater for restoration.

DWR is expected to release an updated report on Flood-MAR in the spring of 2018, and is currently expanding partnerships with stakeholders involved in replenishment projects. Furthermore, DWR is developing a plan of study for a state program of public-private partnerships that will assess the potential for statewide flood flow replenishment projects, prioritize locations, identify applicable water management tools and techniques, develop economic quantification of groundwater replenishment benefits, and provide technical assistance to GSAs.[27]

1.4.2. *Groundwater Markets and Replenishment Crediting*

Two primary market mechanisms can be used to manage surface and groundwater consumptive uses in a basin: water markets and water banks. Water markets consist of voluntary exchanges of water rights or allocations. Transfers can be in the form of temporary leases, long-term leases, or permanent sales. Informal water markets can also arise, where users within a basin trade current water uses for future use.[28] Water banks store available surface water in aquifers during wet years for later extraction in subsequent dry years and are typically run by third-party entities, such as irrigation districts, private companies, or joint-power authorities. California possesses the largest water market in the western United States, with a traded value of $560 million and 793,000 AF exchanged in 2015 alone.[29] Currently, most of the market activity involves surface water rights, which are held based on seniority.[18] This creates incentives for trade, as users can obtain a higher value from water by exchanging water rights or allocations. The majority of surface water rights are held by local public water agencies and used primarily for irrigation.[18] The small proportion of groundwater market activity belies its importance in the state. Though transactions account for only 3% of all water trading in California, groundwater provides one-third to one-half of the state's total water supply.[30,31] Lack of groundwater market activity is due to undefined property rights, complex state and county regulations (e.g. SWRCB licensing and permitting terms, county ordinances prohibiting water from leaving the basin), as well as a lack of information and tracking tools, making it difficult to know who is using groundwater and in what quantities.[31,32] Absence of regulations and enforcement surrounding groundwater rights makes defining and exerting groundwater property rights difficult.[32]

In response to this regulatory uncertainty, and in the face of significant threats to water supply, some basins quantified and delineated groundwater rights through an adjudication process. There have been 24 adjudications completed in California—most with fully quantified rights, but a handful of basins with partial or unquantified rights.[33] While GSAs cannot determine or change water rights, they do have discretion under SGMA to determine an allocation structure that could involve a cap and assigning shares.

1.5. Habitat Market Incentives

EDF has also developed the Central Valley Habitat Exchange, which offers incentives for private landowners to create measurable improvements in habitat in the Central Valley. Through the exchange, private landowners earn revenue for implementing strategies that restore functional habitat on private lands, which account for 70% of the Central Valley. To support the program, EDF also developed the Habitat Quantification Tool for consistent calculations of species benefit.

Numerous financial assistance programs exist for private landowners to engage in habitat creation markets or habitat-friendly farming practices. Most programs include one or more of the following financial assistance structures:[34]

- Cost share: partial coverage of the cost to implement a conservation practices
- Rental payment: annual payments (e.g. for retired land) in lieu of foregone farming or ranching income.
- Incentive payment: for completing work early, working with neighbors, etc.
- Tax relief: federal income and estate tax programs; state property and income tax programs
- Technical assistance**:** for conservation planning, design of conservation practices or advice for implementing or installing practices on the ground
- Easement purchase: partial or complete funding for the value of purchasing a conservation easement
- Regulatory assistance: alternative compliance mechanisms, assistance with achieving compliance or assurances if regulations change

More detailed descriptions of landowner incentive programs and available funding are described below for the Environmental Quality Incentives Program, the Species Conservation and Wetland Banking Program, the Regional Conservation Incentive Strategy Program, and the Conservation Reserve Program.

1.5.1. *Environmental Quality Incentives Program*

The United States Department of Agriculture Natural Resources Conservation Services (NRCS) provides technical and financial assistance to landowners to encourage farmland conservation improvements.[35] Funding for these programs is included in the US Farm Bill, passed every five years (or so) by Congress. The Farm Bill encompasses amendments, provisions, and suspensions to farm commodity pricing, income support, agricultural conservation, farm credit, trade research, rural development, bioenergy, foreign food aid, and domestic nutrition assistance.[36] When each Farm Bill is renewed, the funding for agricultural conservation programs (to incentivize environmental farming improvements) is reviewed for continuation, expansion, or suspension.[36] Included in the Farm Bill is funding for the Environmental Quality Incentives Program (EQIP). EQIP is a voluntary conservation program that compensates landowners for investing in solutions that benefit natural resources. A complete list of fundable conservation practices is provided by NRCS, along with technical guides localized by geographic area.[37] One such practice is "Early Successional Habitat Development/Management" defined as "managing plant succession to develop and maintain early successional habitat to benefit desired wildlife and/or natural communities" (practice code 647).[38] Additional conservation practices with regard to habitat creation include:

- Restoration and management of rare or declining habitats (643)
- Wetland wildlife habitat management (644)
- Upland wildlife habitat management (645)
- Wetland restoration (657)
- Wetland creation (658)
- Wetland enhancement (659)

Specific funding pools in EQIP are also set aside for specific initiatives. One such initiative is the Bay-Delta Initiative (BDI) where NRCS and its local partners aim to address water quantity, quality and habitat restoration needs of the California Bay-Delta watershed by implementing conservation practices on private lands.[39] Specifically in 2017, the BDI allocated funding for the Sothern Tulare Basin in the San Joaquin Valley to enhance surface and groundwater conservation efforts.[39]

Total EQIP monetary obligations for California have varied yearly, but have been increasing since 2009 (**Table 1**):[40]

Table 1: *EQIP total funding obligations by fiscal year.*[40]

Year	Obligation (in thousands)
2009	$69,871.2
2010	$91,860.1
2011	$90,102.6
2012	$116,559.8
2013	$96,880.0
2014	$114,702.2
2015	$123,665.0
2016	$109,010.3

The unit cost for each practice code is detailed in the EQIP payment schedules. For example, seasonal flooding under the Wetland Wildlife Habitat Management practice (644) is eligible for $99.70 per acre.[41]

According to data in 2014, the EQIP demand in California was an average contract incentive of $40,812; 34.2% of 9,423 applications received funding.[42] According to the

2016 financial report, $18.3M was allocated to California for private lands conservation operations, $20M for watershed and flood prevention operations, and $1,000 for watershed rehabilitation.

NRCS reevaluates the amount of financial assistance available to the EQIP and other related conservation improvement programs according to current costs for material and labor by state. Therefore, it is recommended that California's payment schedules for the EQIP program be checked annually, along with the renewal of the Farm Bill, to assess the total amount of funding being channeled for habitat conservation improvements.

1.5.2. *Species Conservation and Wetland Banking*

Conservation banking is an economic mechanism that allows for the permanent conservation of species, habitat or wetlands in exchange for satisfying legal requirements.[43] Conservation banks are designed to protect threatened and endangered species, and credits are generated based on the amount of habitat conserved.[44] These credits are purchased by entities, which are required to mitigate or compensate for environmental impacts of development projects. Agencies that participate and monitor these programs include the US Fish and Wildlife Service, National Oceanic and Atmospheric Administration-National Marine Fisheries Service, and the California Fish and Wildlife Service (CDFW). These entities also participate in wetland banking along with the Army Corps of Engineers and the Environmental Protection Agency (EPA).

Seventy-nine conservation banks are currently operating in California, with eight operating in the San Joaquin Valley.[45] In 2017, Coles Levee Ecosystem Preserve sold 5,446 credits for San Joaquin Valley endangered and threatened species, Kern Water Bank sold 1,321 credits for San Joaquin Valley kit fox (SJV kit fox), Tipton kangaroo rat and Blunt-nosed leopard lizard, and Palo Prieto Conservation Bank sold 3,225 credits for SJV kit fox.[45] Each fall, CDFW determines the fees for the following year that will be applied to banks to cover the reasonable costs of CDFW for review, implementation and compliance.[43] Because conservation banking in California is funded primarily by the conservation bank and the developer purchasing the credit, funding for the program itself comes through application and credit fees. As of January 2017, the California Conservation and Mitigation Banking Program had observed a decline in applications and associated fees such that the CDFW has stated it will work with the community to assess ways to support and further encourage banking.[45]

Demand for the credits depends on the enforcement of environmental protection and impact laws, and the subsequent mitigation required.[46] Strict development laws and enforcement in California have created a steady stream of demand for credits, unlike in other states where demand for credits is limited.[46] Furthermore, California has 300 federally listed species with an additional 50 state protected species, both eligible for species and wetland conservation banking.[46] Thus the demand for these credits is steady and the longevity of species conservation and wetland banking in California is assured.

1.5.3. *Regional Conservation Incentive Strategies Program*

The Regional Conservation Investment Strategy (RCIS) pilot program was created by California's Assembly Bill 2087, is administered by CDFW, and went into effect on January 1, 2017.[47] The RCIS Program consists of three major components: (1) Regional Conservation Assessments (RCAs); (2) Regional Conservation Investment Strategies (RCISs); and (3), Mitigation Credit Agreements (MCAs). RCAs are voluntary, non-binding conservation assessments that include analyses on species and ecosystems to support RCISs. An RCIS is developed by a public agency to establish biological goals and objectives at a species level to inform conservation investments, such as land acquisition or restoration, and can be approved for up to ten years by CDFW. MCAs are developed under approved RCISs to conserve or mitigate actions identified therein. Any person or entity can enter into an MCA with CDFW to create credits. The RCIS program is entirely fee-based, determined by CDFW each year. The current 2017-18 fiscal year fees are:

- RCA Review and Approval: $22,000
- RCIS Review and Approval: $28,500
- MCA Review and Approval: to be determined

Even if the person or entity was not involved in the development of the RCIS, it may enter into an MCA to create credits.[48] Program development itself is funded by the public agency that creates these components.[48]
Due to the recent approval of the RCIS program, the demand for MCA credits has yet to be determined. Four pilot RCISs are currently being developed in California in the following regions:[49]

- Santa Clara County
- Antelope Valley in Los Angeles County
- East Bay covering Alameda and Contra Costa Counties
- Yolo County

Thus, there is still potential for an RCIS to be developed and implemented in the San Joaquin Valley.

1.5.4. *Conservation Reserve Program*

The Conservation Reserve Program (CRP) is managed by the USDA Farm Service Agency. Through CRP, landowners are eligible to receive payments for removing environmentally sensitive lands from agricultural production and subsequently plant vegetation that will improve ecosystem health and quality.[50] The average contract term is 10 to 15 years, but the goal of the program to reduce the loss of wildlife habitat over time. Other co-benefits from enrolling in CRP include reduced soil erosion, improved water quality, and increased habitat for threatened and endangered species.[50] CRP initiatives include:

- Duck Habitat
- Floodplain Wetland
- Pollinator Habitat
- State Acres for Wildlife Enhancement
- Upland Bird Habitat

Other than these specific initiatives, lands can be eligible for payment fallowing for the purposes of:

- Buffers for wildlife habitat
- Wetlands buffer
- Riparian buffer
- Wetland restoration
- Filter strips
- Grass waterways
- Shelter belts
- Living snow fences
- Contour grass strips
- Salt tolerant vegetation
- Shallow water areas for wildlife *(list not exhaustive)*

Cost-share payments can be made for 50% of the eligible cost of establishing a CRP practice.[51] In addition, there is a one-time payment for enrolling at $10 per acre for each full year of fallowing. The maximum annual non-cost share payment is $50,000 per fiscal year and payment rates for fallowed land vary by county (**Figure 4**).[51]

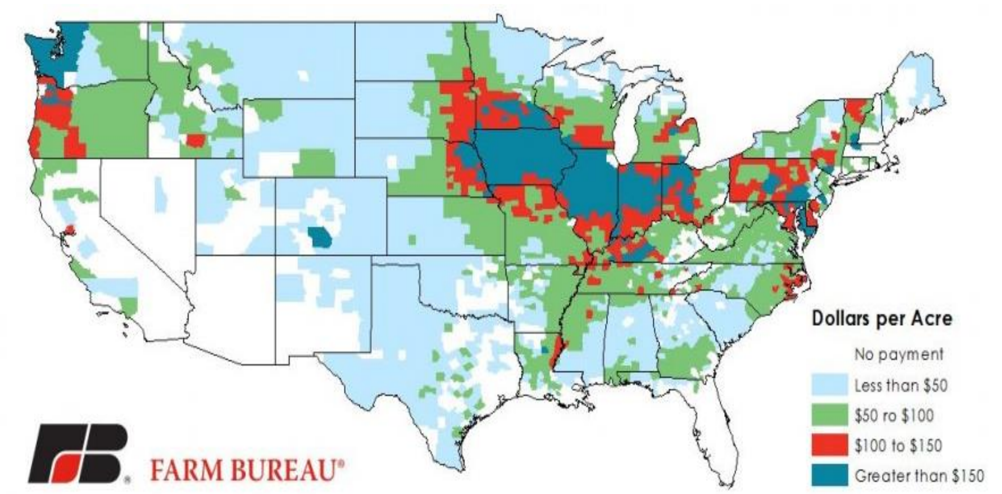


Figure 4: *Conservation Reserve Program rental rates (2016 Fiscal Year). The average rental rate was $72.61.*[52]

In 2013 in the San Joaquin Valley, acres enrolled included: 5,366 acres in Kern County, 4,839 acres in Merced County, and 587 acres in Stanislaus County.[53] Statewide, 91,088 acres were enrolled in 2013. However, California's participation rate in CRP is low compared the Plains states (**Figure 5**).

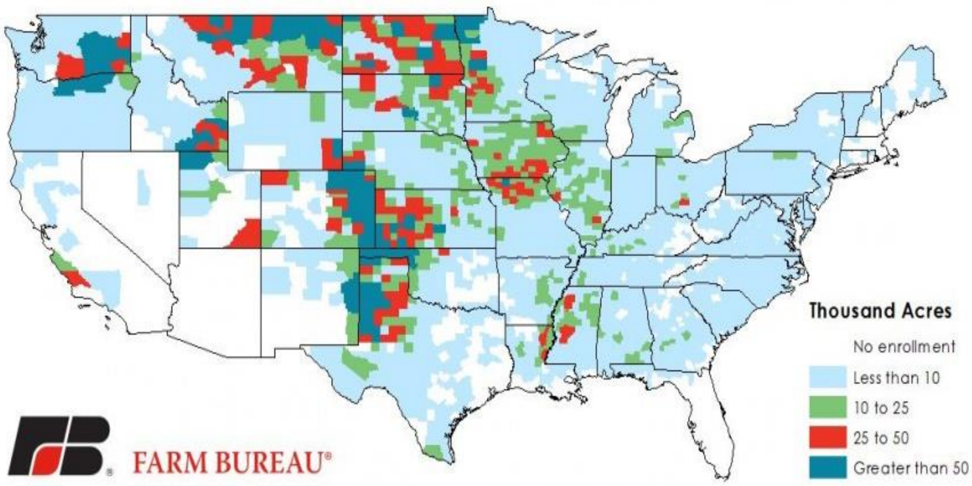


Figure 5: *Conservation Reserve Program enrollment (2016 Fiscal Year). Total enrollment was 23.9 million acres.*[52]

1.5.5. *Habitat Quantification Tool*

To help promote, monitor, and assist in habitat market transactions in California's Central Valley, EDF developed the Central Valley Habitat Exchange Program. The program aims to help compensate landowners for sustainable management practices and restoration activities that result in species and habitat benefits. To support this program, EDF developed a Habitat Quantification Tool (HQT) that allows for consistent and unbiased calculation of species benefits. Landowners can use the HQT to help focus their conservation efforts in order to maximize potential habitat and mitigation credits generated. Currently, the HQT is calibrated to measure habitat benefit for Chinook salmon, Swainson's hawk, riparian songbirds, giant garter snakes, and monarch butterflies, but can be adapted in the future to quantify habitat for more species. Through use of the HQT, EDF hopes to bring greater accountability and transparency to conservation investments in the Central Valley and foster a healthy and efficient habitat trading market that maximizes species and social benefits. EDF's Central Valley Habitat Exchange program and HQT are well suited to work with multi-benefit groundwater management strategies to help quantify habitat credits in a consistent manner.[54]

1.6. Multi-Benefit Approach to Groundwater Management

Implementation of SGMA will entail drastic land use changes over the next 20 years. GSAs will be tasked with defining and achieving sustainable yield for their water basins to avoid the undesirable effects of groundwater depletion. Many of these basins are already critically overdrafted and will require a certain degree of groundwater replenishment to achieve sustainable levels. Given agriculture's heavy reliance on groundwater, particularly in the San Joaquin Valley, landowners will be faced with the difficult decision of how to comply with replenishment requirements.

SGMA also presents a unique opportunity to improve natural ecosystems and surrounding communities. Certain groundwater management strategies can mitigate the social and environmental damages from groundwater overdraft through the generation of multiple benefits. These multi-benefit groundwater management strategies seek to achieve groundwater savings at low-costs, while also simultaneously attaining environmental and social co-benefits. The foregoing framework seeks to provide research, data, and economic and spatial analyses to advise landowners, GSAs and stakeholders of potential options when pursuing groundwater replenishment under SGMA.

1.6.1. *Multi-Benefit Recharge Ponds – Wetland Habitat*

One of the most traditional methods for complying with SGMA will be the infiltration of surface water to the underlying aquifer via artificially constructed recharge ponds (also known as managed aquifer replenishment).[55] According to a Public Policy Institute of California survey (2017), 75% of respondents in the San Joaquin Valley reported active engagement in managed aquifer recharge.[56] Agricultural irrigation districts play a large role in these activities, with half of them directing surface water to dedicated recharge basins; or flooding irrigated cropland, fallowed land, or open space.[56] Other methods reported include "in-lieu recharge" where surface water use displaces groundwater irrigation needs.[56] Per the survey, landowners are already recharging 4,000,000 AF through these methods, though actual replenishment volumes is hard to measure.[56] Landowners have additionally cited difficulties in securing the appropriate funds for recharge pond projects.[56]

A multi-benefit approach designs the recharge pond to co-function as a seasonal wetland that supports migratory waterfowl and endangered species habitat, making it eligible for funding to offset costs. These constructed wetlands would incorporate appropriate vegetation and topography to encourage species establishment, while still achieving groundwater replenishment goals. The costs of removing agriculture, constructing the wetland recharge pond, and the forgone revenues from fallowing can be potentially offset through engaging in habitat markets.[57] By doing so, landowners commit to building and preserving habitat to provide benefits for relevant species. Monetary funds for habitat restoration could come from land retirement grants and habitat market programs, such as the EQIP, CRP and state conservation banking programs, as discussed above. This report aims to explain how much groundwater management costs can be offset by habitat market incentives, while still achieving replenishment goals in light of rapidly approaching SGMA deadlines.

1.6.2. *Multi-Benefit Fallowed Fields – Upland Habitat*

Apart from active groundwater replenishment, aquifers can be passively replenished through forgoing extraction, allowing groundwater that would have been pumped to remain in ground. Passive replenishment is traditionally performed through fallowing. The decision to fallow agriculture is typically a result of limited access to (or funds to purchase) surface water.[58] When groundwater extractions for agricultural irrigation are limited, landowners can manage water supplies by fallowing the least productive, lowest revenue acreage.[58] During the height of the 2011-2016 California drought in 2015, landowners fallowed approximately 5% of active cropland costing $2.2 billion in farm revenues and 17,000 jobs economy-wide.[59] Fallowed acreage by county ranked the highest in Fresno, Kern, Kings, and Tulare Counties, all within the San Joaquin Valley.

The costs of fallowing can be offset by the potential for agricultural producers to engage in supplemental environmental markets. To participate in these programs, landowners create and restore fallowed fields to San Joaquin Valley grassland and scrubland habitat for upland wildlife species. To create habitat, landowners topographically redesign fields for burrows, plant native vegetation, as well as provide establishment irrigation. Incentive programs for this type of habitat restoration include the EQIP, CRP, conservation banking and other programs (described above). This report researches the extent to which restoring fallowed land to habitat can offset the costs of fallowing for passive replenishment, and under what conditions landowners can benefit from these programs.

1.7. Kern County Scope

To thoroughly analyze the potential for multi-benefit groundwater management in the San Joaquin Valley, this framework narrowed its economic and spatial analyses to Kern County (**Figure 6**). In 2016, Kern County was ranked the number one agricultural producer in the country, leading the state in pistachio and almond production.[60] However, Kern County retired almost 350,000 agricultural acres during the drought. Empty, dust-generating fields exacerbate health problems in a county that has been consistently ranked as the worst in the US for people at risk from short-term particle pollution (24-hour $PM_{2.5}$).[61] Additionally, Kern County once supported one of the most diverse and productive grasslands in temperate North America, as well as enormous populations of wintering waterfowl along the Pacific Flyway.[62] As such, Kern County potentially stands to benefit the most from multi-benefit groundwater management.

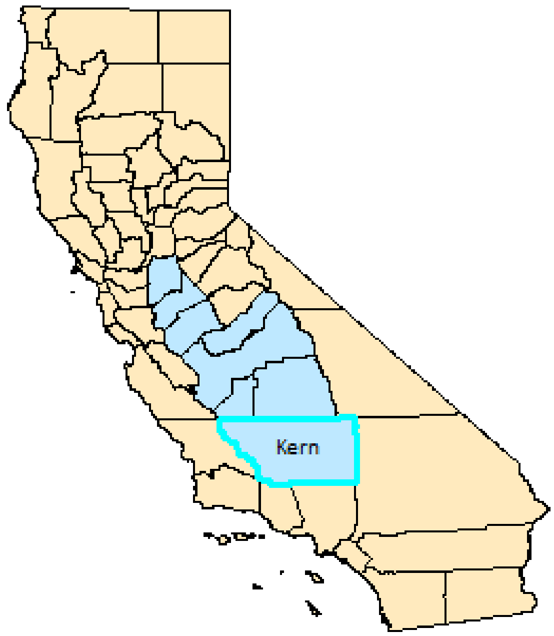


Figure 6: *Kern County is one of eight counties located in the San Joaquin Valley of California.*

2. Objectives

California’s overreliance on groundwater has created a need for scalable, replicable models for reducing overdraft prior to the deadlines established in SGMA. The objective of this report is to develop a framework for analyzing landowner actions and incentives to enhance groundwater resources in accordance with SGMA, as well as create natural resource and community co-benefits.

Specifically, this framework meets the following objectives:

1. Identify the necessary incentives for landowners to make land use decisions at the farm level that increase groundwater sustainability while creating measurable improvements in natural resources and communities,
2. Identify areas potentially suitable for multi-benefit replenishment projects, and
3. Provide a mechanism to embed this framework within GSPs.

Meeting these objectives and developing a multi-benefit groundwater replenishment framework will facilitate the establishment of multi-benefit strategies, providing flexibility and resiliency in sustainable groundwater management.

3. Cost-Benefit Analysis of SGMA Compliance Methods

This section seeks to advise a landowner pursuing groundwater replenishment as a compliance method for SGMA, of cost and benefit estimates for different options. Two conventional replenishment methods as well as two multi-benefit (i.e., habitat + replenishment) methods are analyzed against a baseline fallow scenario, allowing a landowner to make an informed decision. These options are also compared to a "pre-SGMA" scenario where a landowner does not face a requirement to reduce groundwater use, and therefore operates at full production with groundwater.

A dynamic cost-benefit analysis (CBA) tool was developed in order to estimate the net present value (NPV) of different replenishment project options borne by a Kern County landowner across the 2018-2045 timeframe. This timeframe was chosen to reflect a landowner who initiates a replenishment project today (2018), through five years after her GSA must reach sustainable yield targets (2045). The CBA tool allows for user input of a discount rate, crop type, crop acre revenue, crop operational cost by acre, crop applied water, groundwater depth, and groundwater pumping electricity cost ($/kWh). Thirty-two crop types are available to select in the tool. Crop revenue prices were obtained from the USDA NASS and the 2016 Kern County Agricultural Report, crop operational costs were obtained from UC Davis cost study reports, and applied water amounts were obtained from the DWR.[63] To demonstrate the purpose of the tool, this section will discuss a representative case of an almond producer in Kern County. This landowner must replenish her aquifer by 1,000 AFY to be compliant with SGMA. This CBA analysis only takes into account the benefits and costs borne by the landowner, and do not take into consideration broader societal impacts or the impacts of collective action. Further research on the societal impacts of SGMA is discussed in Section 3.6. These broader costs and benefits are difficult to estimate per capita, and would likely not be of immediate concern to a landowner making a personal financial decision. The four replenishment projects are: (1) in-lieu recharge, (2) on-farm recharge, (3) recharge pond for wetland habitat, and (4) fallowed land for upland habitat. These projects are also compared to the NPV of a pre-SGMA "full production" scenario and a post-SGMA "baseline fallow" scenario. Costs and benefits were normalized to 2018 dollars using the Bureau of Labor Statistics Consumer Price Index (CPI) Inflation Calculator.[64] NPV of costs and benefits accrued between 2018-2045 was determined using the USDA recommended discount rate of 4.4%.[65] Climatic variability was estimated during this time using historical precipitation data and Central Valley Project Friant Division surface water allocations data. Surface water pricing was varied to reflect scarcity using multipliers from the 2016 California Water Commission's "Water Storage Investment Program."[66–68]

Of the four methods, plus the full-production and baseline fallowing scenarios, analyzed for the almond producer, the recharge pond with wetland habitat resulted in the highest benefit cost ratio. This is due to the fact that a wetland recharge pond only requires 42 acres of almonds to be fallowed, and the almond producer accrues habitat payments through state and federal funding programs. To ensure the success of multi-benefit options, further research should be conducted on ecosystem and societal benefits generated and the potential to monetize such benefits and reward landowners.

3.1. Analysis Scope and Assumptions

In order for California's groundwater basins to achieve sustainable yield by 2040, GSAs will be designing GSPs that restrict excessive pumping. In Kern County and elsewhere in the Central Valley, landowners will have to decide how to implement projects that significantly reduce groundwater extractions while still maximizing economic value of their properties. Groundwater replenishment projects currently being pursued in the Central Valley in advance of SGMA requirements largely include in-lieu surface water purchases, groundwater recharge ponds, and land fallowing.

Although research is developing on the aggregate impact of SGMA to the Central Valley and the cumulative economic impacts of removing agriculture from production, economic analyses on an individual landowner scale are lacking.[69] This report provides a CBA of four landowner-scaled SGMA compliance projects, in comparison to full-production and baseline fallow scenarios. These projects effectively reduce groundwater extractions and are exemplary of those currently being pursued in the Central Valley.

Cost-benefit analysis is an economic technique for evaluating a project or investment by comparing the direct and indirect economic costs and benefits of the activity.[70] This CBA evaluates two traditional (in-lieu, and on-farm recharge) and two multi-benefit groundwater replenishment projects (recharge pond with wetland habitat, and fallowing with upland habitat) against full-production (pre-SGMA) and baseline fallowing (assumed to be the post-SGMA default) scenarios. Apart from the traditional projects that singularly achieve groundwater replenishment, the multi-benefit project approaches to SGMA compliance achieve ecosystem benefits through habitat creation. These projects are eligible for monetary payments through habitat incentive-programs available to participating landowners. In this report, the economic viability of these multi-benefit methods are analyzed under the aegis of SGMA.

The purpose of this analysis is to deliver a CBA of traditional and multi-benefit replenishment projects at the individual landowner level in Kern County (**Table 2**).

***Table 2**: Cost-benefit analyzed methods.*

SGMA COMPLIANCE METHOD	DESCRIPTION
BASELINE FALLOW	The permanent retirement of land from agricultural production in order to conserve water.
IN-LIEU RECHARGE	The transfer or purchase of surface water to be used in in-lieu of groundwater irrigation.
ON-FARM RECHARGE	The use of excess flood waters or controlled reservoir releases to flood cropland in the crop's dormant season.
RECHARGE POND FOR WETLAND HABITAT	The construction of a dedicated recharge pond designed to also provide habitat for wetland species.
FALLOWED LAND FOR UPLAND HABITAT	The removal of crops and subsequent habitat restoration for upland species.

3.1.1. *Analysis Scope*

In order to provide the most functional CBA, scope is limited to a single landowner faced with the decision of how to comply with her GSP's sustainable yield targets. Therefore, the landowner is the single beneficiary and the costs and benefits outlined in the report are those only accrued to her. For the purposes of providing a representative CBA, the scope is limited to an almond grower in Kern County tasked with lessening groundwater extraction by 1,000 AFY— which equates to a 4.4% reduction to her current irrigation amount.

Prior to the passage of SGMA, this characteristic almond grower irrigated 5,000 acres of almonds with 100% groundwater production. To lessen groundwater pumping by 1,000 AFY, the landowner's chosen SGMA compliance methods must achieve 1,000 AFY of groundwater replenishment through year 2045 (five years after her GSA must reach sustainable yield targets). This CBA, therefore, projects out costs and benefits over a 28-year timeline (2018-2045).

It is important to note that the scope of CBAs can exceed that of a single landowner, and can be expanded to include the costs and benefits to society. The purpose of this CBA, however, is to deliver digestible costs and benefits to an individual landowner audience. A landowner does not bear the indirect costs and benefits to society. For example, if a landowner removes 300 acres of agriculture and lays off twenty agricultural workers living in the nearby community, there are potential economic losses to society through lack of available employment, potential reduction of available labor to landowners in the future, and possible loss of tax funding in the community.[69] Additionally, this CBA does not quantitatively evaluate cumulative impacts of SGMA compliance methods across multiple growers. Cumulative costs could include emigration of available labor, degradation of air-quality from fallowed fields, increased demand for surface water, and increased water scarcity, among others.[58] Aggregated implementation of multi-benefit projects could also generate cumulative benefits, such as improved air quality, greenhouse gas reductions, and carbon sequestration from wetland restoration. These are all important considerations recommended for future analysis, as they are beyond the scope of this CBA. Some of these costs and benefits are addressed qualitatively following the discussion of the results.

3.1.2. *Assumptions*

This CBA utilizes several assumptions specifically regarding groundwater replenishment and groundwater savings, conveyance and infrastructure, beneficial uses of water, access to available incentive payment programs, and groundwater quality. The most basic assumption is that without these analyzed SGMA compliance methods, the landowner would have fallowed the number of agricultural acres equivalent to a total crop demand of 1,000 AFY, presently estimated to be 220 acres for almonds (a 4.54 AF/acre water demand).

It is also assumed that the amount of land to take out of production is a function of saved applied irrigation water. “Applied water” data was obtained from the DWR which considers: crop water demand (evapotranspiration), evaporative losses, irrigation efficiencies, and, effective precipitation.[71] The amount of saved irrigation water is also considered in the amount of surface water needed to purchase for in-lieu recharge, and the amount of water needed for infiltration in the recharge pond and recharge pond size.

Additionally, it is assumed that the landowner does not have ready access to surface water conveyance. These infrastructure costs have been included in the CBA and are according to an average farm to canal distance of 400 meters.[72] This analysis assumes that purchased surface water for the use of groundwater replenishment will be considered a beneficial use of water in California. The State Water Resource Control Board’s decision on the beneficial use of water for groundwater replenishment is currently pending as of March 2018.[73]

In order to best analyze the potential for habitat development and corresponding habitat incentive payments, the analysis assumes the available funding of existing local, state and federal habitat payment programs, and that a landowner has access to conservation banking credit monetary payments. Existing local, state, and federal funds for habitat programs may be susceptible to political pressures in future years. Additionally, the actual number of credits for conservation banking for a conservation project will vary significantly based on the restoration project implementation and the population of bank-considered species that become established on the property. This CBA along with the spatial optimization portion of this research (in Section 4 of this report), can work in tandem with programs such as EDF’s Central Valley HQT. The HQT allows for better science-based quantification of functional acres for habitat conservation, which will be helpful to participating landowners.[74]

Costs and benefits were normalized to 2018 dollars using the Bureau of Labor Statistics Consumer Price Index (CPI) Inflation Calculator.[64] NPV of costs and benefits accrued between 2018-2045 was determined using the USDA recommended discount rate of 4.4%.[65]

Lastly, the CBA assumes no changes in the quality of both groundwater and surface water; no costs for water treatment are included. Also, the analysis does not address the costs of potential non-compliance of neighboring landowners, nor the SGMA enforcement costs of the DWR, SWRCB, and local GSAs. All other method-specific assumptions are further described within each of the replenishment strategy descriptions below.

3.2. Cost-Benefit Analysis Approach

3.2.1. *Cost & Climate Methodology*

Costs for each of the methods are estimated based on historical transactions or market prices, then aggregated across time for each SGMA compliance method scenario. Each method has unique cost elements but some cost elements are relevant across all four scenarios. Surface water acquisition prices and associated costs were obtained from the UCSB Bren School's Water Transfer Records Database,[75] the California SWRCB fee schedule,[76] and expert advice from New Current Water Law.

Water acquisition costs are dependent upon source type (Post-1914 Right Purchase, State Water Project (SWP) contract, Central Valley Project (CVP) contract, or 1-Year Water Lease), as well as climatic conditions. For instance, if the Central Valley is in a drought and/or the Sierra snowpack is below normal, scarcity of the water supply will cause an increase in acquisition prices. To account for climatic variably and its impact on surface water pricing, the analysis collected the previous 49 years of annual precipitation data from the National Oceanic and Atmospheric Administration's (NOAA) weather station in Bakersfield, California in addition to historical annual CVP water supply allocations from 1998 to 2017 obtained from the United States Bureau of Reclamation.[68]

For both the Kern and Sierra water scenarios, "Very Dry," "Dry," "Normal," and "Wet" categories were determined based on historical occurrences. The Kern categories were based on percentiles of precipitation per Water Year (WY) (September – October) from 1969-2017. Sierra conditions were grouped based on the percent of annual CVP allocations from 1998 to 2017 to Friant Division Class 1 (C1) and Class 2 (C2) contract holders (**Table 3**).

Table 3: *Kern (per Bakersfield precipitation) and Sierra (per CVP allocations) climatic conditions.*

Kern		
Climatic Code		**Define**
1	Very Dry	5th percentile (< 2.9 in/WY)
2	Dry	25th percentile (2.9< x <4.6 in/WY)
3	Normal	50th percentile (4.6< x < 7.0 in/WY)
4	Wet	75th percentile (> 7.0 in/WY)

Sierras (per CVP allocations)		
Climatic Code		**Define**
1	Very Dry	C1: <=30% C2: 0%
2	Dry	C1: 30% < x <= 65% C2: 0% < x <= 8%
3	Normal	C1: 65% < x < 100% C2: 8% < x <= 18%
4	Wet	C1: 100% C2: >18%

Historically, the majority of years appear to have faced "normal" climatic conditions (**Figure 7**). The historical climate patterns were reiterated over the 2018-2045 project timeframe, which for Kern resulted in 6 Very Dry years 3 Dry years, 11 Normal years and

8 Wet years. To account for climate change (estimated future drier weather conditions) it is assumed that two projected Wet years will become Normal years, two projected Normal years become Dry years, and two projected Dry years become two Very Dry years. This assumption produces a more conservative cost estimate to avoid understating costs of future surface water shortages. The model projects 8 Very Dry years, 3 Dry years, 11 Normal years and 6 Wet years for Kern.

Reiterating the CVP historical allocation pattern over the 2018-2045 timeline results in an estimate of 7 Wet years, 19 Normal years, and 2 Very Dry years. The same climate modeling assumptions described above were applied to the Sierra climate scenario. Projected Sierra snowpack climate conditions according to climate-factored historical patterns result in 5 Wet years, 17 Normal years, 2 Dry years, and 4 Very Dry years. The accompanying CBA model can be referenced for further detail on climatic assumptions and projections.

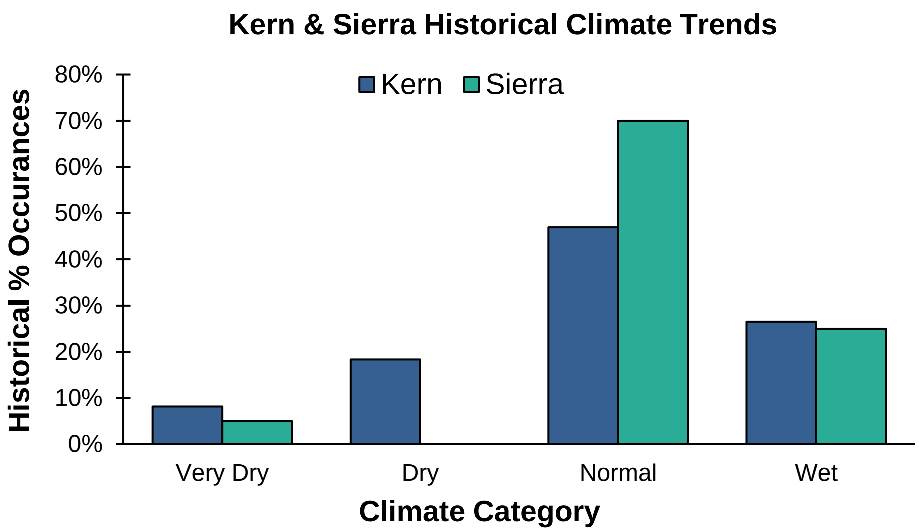


Figure 7: *Historical occurrences of "Very Dry," "Dry," "Normal," and "Wet."*

Climate projections are further grouped into "Wet Kern – Wet Sierra," "Dry Kern – Wet Sierra," "Wet Kern – Dry Sierra," and "Dry Kern – Dry Sierra" categories. Because the "Wet Kern – Dry Sierra" scenario is highly unlikely, it was replaced by "Dry Kern – Dry Sierra." Using cost projections from the Water Storage Investment Program's Technical Reference, the following price increases were applied to several cost elements of the four surface water supply acquisition options (**Table 4**):[66]

Table 4: *Price increases of surface water acquisition and relevant associated costs based on climate condition.*

Climate Scenario	Wet Kern – Wet Sierra	Dry Kern – Wet Sierra	Dry Kern – Dry Sierra
% of base water pricing	100%	144%	260%

The climatic condition projections impact costs for In-Lieu Recharge, On-Farm Recharge, and Recharge Pond + Wetland Habitat, as these options involve purchasing additional water supplies in the “Dry Kern – Wet Sierra” and “Dry Kern – Dry Sierra” years, when excess floodwaters and water from controlled reservoir releases are not available. Out of the 28 years in this CBA analysis, 13 of these years (46%) are projected to be “Wet Kern – Wet Sierra” years. This is consistent with Kocis and Dahlke’s determination of there being 4.7 out of 10 years in the San Joaquin-Tulare Basin with high magnitude stream flows (resulting from 5-7 1-day peak events) for 25-30 days in the winter months.[77]

Different cost elements apply to each SGMA compliance method (**Table 5**). In addition to the surface water acquisition costs mentioned, active replenishment methods face costs of surface water conveyance and irrigation system construction. In-lieu and on-farm recharge face agricultural operations costs (farming machinery and production inputs, labor) to prevent 220 acres from being fallowed (which otherwise would have occurred through a 1,000 AF reduction of groundwater pumping). The multi-benefit methods consider costs for crop removal, habitat restoration and maintenance, safe harbor agreement establishment, and foregone crop revenue.

Costs that were not calculated but are relevant for state-wide analysis of the economic impacts of SGMA, include societal costs and penalties of non-compliance. Such penalties have yet to be determined at the landowner level, since GSAs are in the initial stages of developing GSPs. Another aspect of non-compliance includes third-party landowners free-riding on the efforts of those who replenish. These third party may either not reducing their groundwater pumping or increasing their pumping. Such free riding can be mitigated through stringent GSPs that call for groundwater use metering and enforcement actions for non-compliance.

Table 5: *Cost elements for the four groundwater replenishment options assessed (and not assessed). Applicable costs are indicated in green.*

		SGMA Compliance Methods					
Costs	**Full Production w/ Groundwater**	**Method 0: Baseline Fallow**	**Method 1: In-Lieu Recharge w/ SW Import**	**Method 2: On-Farm Recharge**	**Method 3: Fallow + Wetland Habitat**	**Method 4: Fallow + Upland Habitat**	**Not Captured in Analysis**
Water Acquisition + Associated Costs	(green)	(green)	(green)	(green)	(green)		
Conveyance + Irrigation System Construction			(green)	(green)	(green)		
Agricultural Operations	(green)	(green)	(green)	(green)			
Crop Removal + Restoration Install					(green)	(green)	
Restoration Maintenance					(green)	(green)	
Safe Harbor + Associated Costs					(green)	(green)	
Foregone Crop Revenue		(green)			(green)	(green)	
Societal Impacts (Labor Market, Farm Inputs, etc.)							(green)
Penalties of Non-Compliance							(green)

3.2.2. *Benefits Methodology*

Benefits are estimated based on observed market transactions. Different replenishment methods accrue different types of benefits (**Table 6**). The five compliance scenarios receive the benefit of avoided groundwater pumping costs. All methods also benefit from total crop revenues. All 5,000 acres of almonds are kept in production in pre-SGMA Full Production and compliance methods in-Lieu and on-farm recharge. For the Baseline Fallow scenario Fallow + upland habitat creation method, 4780 acres are kept in production. When constructing a recharge pond to serve as wetland habitat, 4958 acres are kept in production. Active replenishment methods involve the purchase of surface water in dry years (or no-cost excess flood flows and controlled reservoir releases in wet years) for irrigation.

For the purposes of this CBA, the number of acres kept in production or fallowed is a function of how much irrigation water is saved by retiring the crop and the corresponding applied water per crop. Given the assumption that almonds demand 4.54 AFY of applied water, 220 acres of almonds would need to be fallowed in both the baseline scenario and in the fallowing + upland habitat method. When fallowing to create wetland habitat, the assumption was that 42 acres would need to be taken out of production, based on a 5.04

mm/h percolation rate and 60 days of flooding per year. Converting these 42 acres saves 191 AFY of groundwater extractions, which more than offsets the evaporation that would occur in the application of 1,000 AFY of water in a wetland pond. Multi-benefit replenishment methods also allow the landowner to benefit from habitat incentive payments.

Considering that many different landowners will partake in replenishment under SGMA, benefits will also occur on an aggregated level. Though not included in this analysis due to lack of available data on direct payments to landowners, these benefits may include: dust mitigation, greenhouse gas reductions, carbon sequestration payments, avoidance of land subsidence, and the avoidance of replacing or deepening wells.

Table 6: *Benefits accrued by the four SGMA compliance options assessed (and not assessed). Applicable benefits are indicated in green.*

		SGMA Compliance Methods					
Benefits	**Full Production w/ Groundwater**	**Method 0: Baseline Fallow**	**Method 1: In-Lieu Recharge w/ SW Import**	**Method 2: On-Farm Recharge**	**Method 3: Fallow + Wetland Habitat**	**Method 4: Fallow + Upland Habitat**	**Not Captured in Analysis**
Avoided Groundwater Pumping Costs							
Avoided Crop Revenue Loss							
Irrigation/ Water District Cost Shares							
USDA EQIP Grant Funding							
Central Valley Habitat Restoration Program							
USFWS-NAWCC, birds							
Wetland Banking Credit							
USDA CRP							
Conservation Banking (various species)							
Air Quality Control (Dust Mitigation)							
Greenhouse Gas Reductions							
Carbon Sequestration Payments							
Avoidance of Land Subsidence							
Avoidance to Replace or Deepen Wells							

3.3. Summary Results

Our results indicate that fallowing and creating upland habitat, is the best option for the landowner in terms of BCR and NPV. To ensure that costs were not undercounted, a sensitivity analysis was performed to assess costs at 200% and 300% increases (**Table 7**). All compliance methods cease to be beneficial to the landowner (i.e., BCR<1) at 200% cost.

Table 7: *Benefit Cost Ratio across all scenarios, sensitivity analysis performed on costs.*

Benefit Cost Ratio - Sensitivity Analysis	Full Production w/ Groundwater	Method 0: Baseline Fallow	Method 1: In-Lieu Recharge w/ SW Import				Method 2: On-Farm Recharge	Method 3: Fallow + Wetland Habitat	Method 4: Fallow + Upland Habitat
			Post-1914	SWP	CVP	1-Year Lease			
BCR	2.04	1.90	1.99	1.94	1.74	1.95	1.98	1.99	1.93
BCR (2x cost)	1.02	0.95	1.00	0.97	0.87	0.97	0.99	0.99	0.96
BCR (3x cost)	0.68	0.63	0.66	0.65	0.58	0.65	0.66	0.66	0.64

The following sections detail the assumptions as well as cost and benefit breakdowns of each of the five SGMA compliance methods.

3.4. Methods for Multi-Benefit SGMA Compliance

3.4.1. *SGMA Methods Description*

Many opportunities exist for how landowners can meet SGMA compliance targets by 2040. To comply with SGMA, agricultural landowners can use groundwater replenishment to retain or infiltrate water in an aquifer that would otherwise not occur. Traditional replenishment methods largely include in-lieu recharge – the supply of surface water to users who would otherwise rely on groundwater for irrigation.[78] Managed aquifer recharge is another tool used to actively replenish aquifers either through surplus surface water spreading or dedicated recharge basins.[78] However, an alternative to these traditional replenishment methods are more innovative and multi-beneficial approaches to reach groundwater sustainable yield targets. On-farm recharge offers an alternative means for surface water spreading by leveraging excess storm water flows and reservoir storage releases for surface spreading on agricultural fields.[78] Additionally, traditional recharge ponds may be reconsidered as wetlands to allow landowners to leverage recharge ponds for aquifer replenishment benefits and habitat market benefits. Lastly, landowners retiring low-revenue and least-productive cropland are leveraging similar habitat market payments by restoring retired agricultural land for either temporary or permanent upland habitat.

Based on research into the suite of methods being pursued for SGMA compliance and groundwater replenishment, this analysis selected five that span traditional, innovative, and multi-beneficial approaches to sustainable groundwater management. First, a baseline fallow scenario is presented below. Next, four replenishment project options are analyzed as singular options to achieve the same amount of groundwater replenishment at the landowner scale. However, these projects do not need to be mutually exclusive. GSAs can cooperatively pursue these projects with landowners and agricultural producers to optimize groundwater replenishment.

3.4.2. *Baseline Fallow*

3.4.2.1. Description and Assumptions

A baseline fallow scenario requires a landowner to replenish 1,000 AFY of groundwater and assumes that a landowner does not pursue a replenishment project. In the case of almonds, a hypothetical landowner will fallow 220 acres of the 5000 acre almond operation to achieve the 1,000 AFY replenishment target.

3.4.2.2. Costs

Costs include tree removal, field clean up, the operational cost of almonds for the 4780 acres that remain in production, the groundwater pumping cost to irrigate these 4780 acres, and the lost revenue of the 220 acres of almonds that are removed from production. The present value of costs across the 2018-2045 time period is $250.9M.

3.4.2.3. Benefits

The benefits of the baseline fallow scenario include almond revenue for the 4780 acres in production, the avoided operational cost of the 220 acres that are fallowed, and the avoided groundwater pumping cost for the 220 fallowed acres. The present value of benefits across the 2018-2045 time period is $477.6M.

3.4.2.4. Benefit-Cost Ratio

The NPV total amounts to $226M over the 28 years, based on revenue generated from remaining acres in production and avoided production costs of fallowed acres less the costs associated with production and fallowing (**Equation 1**). This results in a benefit cost-ratio of 1.90. The NPV of a baseline fallow scenario, without pursuing an accompanying replenishment project, is $22M less than the present value the landowner would have achieved had there been no groundwater restrictions or disruptions in groundwater supply. A summary of costs and benefits considered is presented below (**Table 8**).

Equation 1. *Net Present Value calculation of Baseline Fallow method.*

$$NPV_{Baseline} = PV_{Revenue}(4780) - PV_{Costs}(4780) - PV_{Fallowing\ Costs}(220) + PV_{Avoided\ Production\ Costs}(220)$$

***Table 8**: Summary of Method 0: Baseline Fallow costs and benefits.*

Costs

Tree Removal and Grind	$	87,010
Field Clean Up	$	31,821
Almonds Operational Cost (4780 Acres)	$	373,955,652
Groundwater Pumping Cost (4780 Acres)	$	12,350,179
Almonds Revenue Loss (220 Acres)	$	36,208,310
TOTAL COSTS	$	422,632,972
PV TOTAL COSTS	$	250,928,221

Benefits

Almonds Revenue (4780 Acres)	$	786,707,819
Avoided Almonds Operational Cost (220 Acres)	$	17,211,348
Avoided Groundwater Pumping Cost (220 Acres)	$	568,418
TOTAL BENEFITS	$	804,487,586
PV TOTAL BENEFITS	$	477,553,344

NPV TOTAL	*$*	***226,625,123***
Benefit-Cost Ratio		***1.90***

3.4.3. *In-Lieu Recharge*

3.4.3.1. Description and Assumptions

In-Lieu Recharge consists of substituting groundwater extraction with the use of surface water. In California, there are several ways for a landowner to acquire surface water. For the purposes of this analysis, the following were considered as potential surface water acquisition sources:

(a) Acquire a post-1914 water right
(b) Seek a short-term (1 year) lease of water
(c) Purchase of Central Valley Project (CVP) water
(d) Purchase of State Water Project (SWP) water

The purchase of a post-1914 water right would give the landowner access to this surface water in perpetuity. A water lease would allow the landowner access to another actor's water for a short amount of time (in this case one year). The landowner can also acquire 1,000 AFY from the SWP, operated and maintained by DWR, or the CVP, operated and maintained by the US Bureau of Reclamation.

These surface water acquisition types each have different associated transaction and acquisition costs. This analysis assumes sufficient surface water for these options is available each year for each method. Pricing of acquisition costs and raw water costs vary depending on climatic conditions as described above.

3.4.3.2. Costs

Given the different assumed ways to acquire surface water, four cost analyses were performed. Costs universal across all acquisition methods are surface water conveyance construction, pumping costs and agricultural costs (e.g., planting and harvesting).

For post-1914 water right purchases and 1-year leases, the acquisition costs were estimated using publicly available data on agriculture-agriculture sales of rights in California from 1987-2005. This yielded a price of $496.64/AF for water right purchases and $131.20/AFY for 1-year leases. These estimates were reviewed by industry experts who deemed them too low, and the prices were revised to $1,200/AF and $280/AF accordingly. Post-1914 water right purchases also incur hefty transaction costs as well as trigger CEQA/NEPA requirements.[79] Water right leases do not trigger CEQA/NEPA fees, but face the same high transaction costs.[80] Additionally, leasing water annually will trigger these fees on a recurring basis. Post-1914 water right transfers and temporary water leases are governed by the SWRCB, which charges a fee to determine whether there is harm to downstream users.[79] This fee is variable in accordance with the amount of water being transferred. All remaining costs are fixed.

For both CVP and SWP water, there is a lower transaction cost for acquiring a contract,[80] and annual water rates are set by the governing bodies. SWP prices were acquired from the Berrenda Mesa Water District, located in northwestern Kern County, which provides a rolled up cost for raw water and conveyance as between $218.71-268.71/AF.[81] For the purposes of the analysis, an average price of $243.71/AF was used. For CVP water, historical data on the average cost of raw water and conveyance was used, yielding an average price of $886.40/AF.[82] These annual water costs varied in accordance with the climate projected as referenced above.

Table 9 provides a summary of the capital and operational expenses incurred when engaging in different surface water acquisition scenarios. The total present value costs over the 2018-2045 period range from $245M (post-1914 water right purchase) to $280M (CVP).

3.4.3.3. Benefits

The primary benefit of in-lieu recharge is the ability to keep all land in production. While revenue is dependent on harvest conditions, pests, and market pricing, the 2016 Kern County Agricultural Report published the per acre value of almonds to be $5,878 (normalized to 2018 dollars). A secondary, though not insignificant benefit to the landowner is the avoided cost of pumping 1,000 AFY of groundwater. Groundwater pumping cost savings were estimated assuming an average groundwater depth of 100 feet, an energy value of $0.10 per kWh, and pressurizing drip irrigation at 30psi.[83,84] Almond operational cost savings were determined using the 2016 UC Davis Almond Cost Study File for the San Joaquin Valley South region.[85] These two categories of benefits remained constant through all four surface water purchase scenarios, generating a present value total of $488.8M over the 28 year time period.

3.4.3.4. Benefit-Cost Ratio

Given that in-lieu recharge allows the landowner to avoid losses in almond production, the BCR is greater than 1 regardless of type of surface water purchased (**Table 9**). The greatest benefit offered by this option is the ability to maintain all lands in production, despite the costs of surface water acquisition (**Equation 2**).

Equation 2. *Net Present Value calculation of In-Lieu Recharge.*

$$NPV_{InLieu} = PV_{Revenue}(4780) + PV_{Revenue}(220) + PV_{AvoidedGWPumping}(220) - PV_{Costs}(4780) - PV_{Costs}(220) - PV_{Surface\ Water\ Costs}(220)$$

Although the purchase of a post-1914 water right has the highest BCR (1.99), the availability of these water rights for purchase is minimal. The most likely scenario that a landowner will pursue are 1-year leases across the 28 year time period (2018-2045), which yield a BCR of 1.95.

Table 9*: Summary of Method 1: In-Lieu Recharge costs and benefits.*

Costs	**Post-1914**	**SWP**	**CVP**	**1 Year Lease**
Capital Costs	$ 2,817,287	$ 6,727,990	$ 727,990	$ 13,325,940
Acquisition Cost (cost of surface water right)	$ 2,016,000	$ -	$ -	$ 11,636,800
Price of Purchasing Entitlement	$ -	$ 6,000,000	$ -	$ -
Transaction Cost	$ 35,000	$ 18,000	$ 18,000	$ 980,000
CEQA/NEPA	$ 40,000	$ -	$ -	$ -
SWRCB Fee per for Water Right or Transfer	$ 17,147	$ -	$ -	$ -
CDFW Review	$ -	$ 850	$ 850	$ -
Conveyance Construction	$ 709,140	$ 709,140	$ 709,140	$ 709,140
Operations & Maintenance Costs	$ 408,278,701	$ 413,709,579	$ 471,659,348	$ 408,790,811
Conveyance Fee	$ 4,691,680	$ -	$ 34,039,178	$ 4,760,000
SWRCB Fees	$ 6,030	$ -	$ -	$ 449,820
Full water cost (including raw water and conveyance)	$ -	$ 10,128,588	$ 34,039,178	$ -
Lift Pump Power	$ 63,812	$ 63,812	$ 63,812	$ 63,812
Almonds Operational Cost (4780 Acres)	$ 373,955,652	$ 373,955,652	$ 373,955,652	$ 373,955,652
Groundwater Pumping Cost (4780 Acres)	$ 12,350,179	$ 12,350,179	$ 12,350,179	$ 12,350,179
Almonds Operational Cost (220 Acres)	$ 17,211,348	$ 17,211,348	$ 17,211,348	$ 17,211,348
TOTAL COSTS	$ 411,095,988	$ 420,437,569	$ 472,387,338	$ 422,116,751
PV TOTAL COSTS	$ 245,176,351	$ 252,204,199	$ 280,174,126	$ 250,739,106

Benefits				
Almonds Revenue (4780 Acres)	$ 786,707,819	$ 786,707,819	$ 786,707,819	$ 786,707,819
Avoided Almonds Revenue Loss (220 Acres)	$ 36,208,310	$ 36,208,310	$ 36,208,310	$ 36,208,310
Avoided Groundwater Pumping Cost (220 Acres)	$ 568,418	$ 568,418	$ 568,418	$ 568,418
TOTAL BENEFITS	$ 823,484,547	$ 823,484,547	$ 823,484,547	$ 823,484,547
PV TOTAL BENEFITS	$ 488,830,165	$ 488,830,165	$ 488,830,165	$ 488,830,165

NPV TOTAL	$ 243,653,813	*$ 236,625,965*	*$ 208,656,039*	*$ 238,091,059*
Benefit-Cost Ratio	*1.99*	*1.94*	*1.74*	*1.95*

3.4.4. *On-Farm Recharge*

3.4.4.1. Description and Assumptions

On-farm recharge is a water supply strategy currently being studied and tested by universities, NGOs, and landowners in the Central Valley. Technical considerations for on-farm recharge projects include site suitability, water availability, infrastructure and conveyance. Agricultural lands are the most probable areas for groundwater replenishment due to their large acreage, proximity to surface water supply systems, high infiltration capacity soils, and connection to aquifers. However, physical feasibility can be limited by cropping season times, surface water sources, storm and floodwater conveyance to fields, "recoverability" of replenished water, and water quality implications. Most importantly, not all crop types are suitable for flood irrigation via on-farm recharge. Researchers at UC Davis are testing crop performance under different flood durations, crop stages, soils, and climatic and biogeochemical conditions for alfalfa, irrigated pasture, and tree and vine crops.[86]

Pertinent assumptions for the on-farm recharge scenario in this analysis include the following:

- Water acquisition occurs through excess floodwaters or controlled reservoir releases, and is provided by the irrigation district at no extra cost
- The landowner will plan for one flood event each year in which she receives 1,000 AF of water from the irrigation district. The landowner will flood 1,000 of 5,000 acres with 12 inches of water
- There will be no crop damage or impacts to crop quality from engaging in on-farm recharge (i.e. 0% losses in crop revenue)
- The historical drip irrigation system is removed (not compatible with flood flows) and replaced with a border irrigation system with the following assumptions:
    - A border irrigation system includes square basins, contour basins, contour checks, border checks, and furrows
    - The average distance from irrigation ditch or floodway is 1/4 mile
    - The average size of turnout gate & pipelines is 15"
    - Lift pumps needed because waterways are lower than surrounding lands
    - Maximum on-farm distribution pipeline size is 24"
    - New/replacement irrigation systems are PVC pipe with dimension ratio of 51 (as recommended by NRCS standards)
    - At an infiltration rate of 3" per day (an average considering climate and soil variations), it will take 4 days to drain 12 inches of water.
    - The landowner will purchase short term leases for the years floodwaters are not available

3.4.4.2. Costs

Capital costs include furnishing and installing pipelines and lift pumps to deliver the floodwater from the irrigation ditch or floodway to the farm.[72] Operating costs cover soil preparation, irrigation labor, pumping energy, and temporary border checks.[72] Capital costs also include application for a Temporary Permit from the SWRCB (pursuant to Water Code 1425 to divert to underground storage during high flow events).[76] Finally, in years where excess flood flows are not available, the landowner will purchase 1-year water leases.

The total present value of capital costs over the 2018-2045 time period amount to $9.6M. Additionally, the landowner will have to pay operations and maintenance (O&M) costs. O&M costs include: the construction of berms to contain the floodwater; lift pump power to pump water from the irrigation ditch to the farmland; irrigator labor; gypsum application (a soil additive to improve its receptivity to replenishment); surface water conveyance fees; agricultural operational costs for 5,000 acres of almonds; and, groundwater pumping electricity costs for 4780 acres of almonds. Together, capital costs and O&M costs amount to a present value of $247.2M over 2018-2045 time period.

3.4.4.3. Benefits

Benefits that accrue to a landowner pursuing on-farm recharge as a SGMA compliance method include avoided groundwater pumping costs the almond revenue of 5000 acres kept in production. These benefits are calculated using the same assumptions in Method 1 above. The landowner may also benefit from a cost-share opportunity with the irrigation or water district, which can cover 25% of the construction costs. Water districts have a vested interest in raising groundwater levels and can offer incentive payments to landowners who are willing to undertake an on-farm recharge project on their land. Total benefits amount to a present value of $489M over a 2018-2045 time period.

3.4.4.4. Benefit-Cost Ratio

Pursuing on-farm recharge has benefits for the landowner, which exceed the costs of undergoing the project. The NPV to a landowner, with 5000 acres of almonds and a 1,000 AFY replenishment target, pursuing an on-farm recharge project is $241.8M over 28 years (**Equation 3**).

Equation 3. *Net Present Value calculation of On-Farm Recharge.*

$$\begin{aligned} NPV_{OnFarm} = {} & PV_{Revenue}(4780) + PV_{Revenue}(220) + PV_{AvoidedGWPumping}(220) \\ & + PV_{WaterDistrictCostShare} - PV_{Costs}(4780) - PV_{Costs}(220) \\ & - PV_{Surface\ Water\ Costs}(220) - PV_{Costs}(FloodPreparation) \end{aligned}$$

The analysis predicts a BCR of 1.98 (**Table 10**).

***Table 10**: Summary of Method 2 On-Farm Recharge costs and benefits.*

Costs

Capital Costs	**$ 9,556,285**
Remove Existing Irrigation System	$ 84,270
Furnish & Install 24" Canal Gate	$ 3,710
Furnish & Install 24" PVC Pipe	$ 539,540
Furnish & Install Irrigation Valves	$ 91,690
Furnish & Install 13 cfs Lift Pump	$ 26,500
Furnish & Install Lift Pump Stands	$ 21,200
Furnish & Install Electrical Service & Control Panel	$ 26,500
Application for Temporary Permit	$ 100
*1 Year Water Lease Acquisition, Transaction & Fees**	$ 8,762,775
Operations & Maintenance Costs	**$ 406,800,911**
Build Temporary Berms 2 Times Per Year	$ 76,320
Lift Pump Power	$ 63,812
Irrigator Labor	$ 213,696
Gypsum Application	$ 379,904
*1 Year Water Lease Conveyance Fee**	$ 2,550,000
Almonds Operational Cost (4780 Acres)	$ 373,955,652
Groundwater Pumping Cost (4780 Acres)	$ 12,350,179
Almonds Operational Cost (220 Acres)	$ 17,211,348
TOTAL COSTS	**$ 416,357,196**
PV TOTAL COSTS	**$ 247,193,542**

**assuming no cost for water in wet-wet years; one-year lease purchase in dry years*

Benefits

Almonds Revenue (4780 Acres)	$ 786,707,819
Avoided Almonds Revenue Loss (220 Acres)	$ 36,208,310
Avoided Groundwater Pumping Cost (220 Acres)	$ 568,418
Water District Cost Share	$ 198,353
TOTAL BENEFITS	**$ 823,682,900**
PV TOTAL BENEFITS	**$ 489,028,517**

NPV TOTAL	***$ 241,834,975***
Benefit-Cost Ratio	***1.98***

3.4.5. *Recharge Pond for Wetland Habitat*

3.4.5.1. Description and Assumptions

One of the more traditional methods for complying with SGMA is the construction and infiltration of water via recharge ponds. In this case, surface basins are designed to infiltrate surface water to replenish the underlying aquifer.[55] Alternatively, recharge ponds can be designed to function as constructed wetlands by incorporating appropriate vegetation, as well as providing vegetated pond borders similar to those of natural ponds.

For this analysis, the constructed recharge pond is designed to also function as a wetland habitat. Therefore, the pond must have the capacity to replenish 1,000 AFY. The total recharge pond area depends on the soil infiltration rate and the timing of when the wetland needs to be flooded for migratory birds and other relevant species. For this analysis, 60 days of flooding is calculated to achieve the 1,000 AFY.[87] Based on the analysis, 42 acres of land are needed and are assumed to come from fallowed cropland. Further, the wetland is assumed to be flooded with excess flood flows and controlled reservoir releases when available, which will only happen when Kern County experiences a wet year in the climate model analysis previously described in Section 3.2.1.

The costs of fallowing orchards, constructing the wetland recharge pond, and forgone revenues can be potentially offset by landowners by engaging in habitat markets.[57] By doing so, landowners commit to building and preserving habitat to provide benefits for relevant species. Landowners can opt to acquire funds from land retirement grants and habitat market programs, such as the San Joaquin Valley Cropland Environmental Quality Incentives Program (EQIP) Grant Funding Program, the California Conservation Stewardship Program (CSP), and state conservation banking, which provide funds for habitat restoration.

For the present analysis, it is assumed that the landowner will fallow land equivalent to the surface area needed for the recharge pond, hire a third-party to construct and maintain the wetland, and will work with the US Fish and Wildlife Service to develop a Safe Harbor Agreement to avoid regulatory pressures from the Endangered Species Act (ESA). A Safe Harbor Agreement, included as a cost in this analysis, allows landowners whose actions contribute to the recovery of an ESA species to be given formal assurances that no additional or different management activities are applied without consent, thus protecting the landowner from potential species takings or harms.[88] Therefore, the analysis assumes the landowner constructs the wetland recharge pond specifically for the benefit of endangered species recovery and receives monetary payment for those actions in addition to indirect benefits of groundwater replenishment and basin sustainability.

3.4.5.2. Costs

Direct capital costs include land preparation, engineering and surveying, wetland construction, legal fees, development of a safe harbor agreement, and conveyance construction (**Table 11**). Annual reporting and monitoring occur from year 2 onwards, while permit fee and wetland development accrue during the first year of the project. Operations and maintenance costs include maintenance of the wetland, the purchase of 1-year surface water leases in dry years with the associated fees, lift pump power, the operational cost and groundwater pumping electricity cost for 4958 acres of almonds, and the foregone revenue of 42 acres of almonds. The present value of total costs of fallowing 42 acres of almonds to conversion to wetland habitat is $250M across the 2018-2045 time period.

3.4.5.3. Benefits

Benefits of fallowing to wetland habitat conversion include almond revenue for 4958 acres, avoided operational costs of groundwater pumping and almond operations, habitat restoration grant funding, and habitat payments.

Operational benefits include the forgone costs of almond production and pumping operations. Groundwater pumping cost savings were estimated assuming an average groundwater depth of 100 feet, an energy value of $0.10 per kWh, and pressurizing drip irrigation at 30psi.[83,84] Almond operational cost savings were determined using the 2016 UC Davis Almond Cost Study File for the San Joaquin Valley South region.[85]

Regarding habitat benefits, the San Joaquin Valley Cropland EQIP Grant Funding Program and California Conservation Stewardship Program (CSP) programs provide funding for construction and maintenance of wetlands. The EQIP program is assumed to provide funding for the first ten years, while the CSP program provides funding for the remaining time, due to constraints in contract durations.[41,89]

The remaining benefits accrue from the sale of conservation banking credits. Conservation credits were exclusively considered, excluding conservation easements, due to the highly variable nature of the latter making reliable estimations unlikely.[90] In this case, wetland habitat credits have been estimated in $100,000 per acre based on information from USDA and Ducks Unlimited.[91–93]

Lastly, the Central Valley Project Restoration Program is designed to protect species and habitat impacted by the Central Valley Project and could provide funding to preserve Giant Garter Snake habitat, at a value of $4,680 per acre.[94] The US Fish and Wildlife Service provides grants to protect wetland bird habitat, valued at $92 per acre.[95] The total present value of benefits, from 2018-2045, for a replenishment project that involves conversion to a recharge pond with wetland habitat is $497M.

3.4.5.4. Benefit-Cost Ratio

The BCR of pursuing a recharge pond with wetland habitat is 1.99, and a landowner with 5000 acres of almonds and a 1,000AFY groundwater replenishment target will receive a NPV of $246.8M across 2018-2045 (**Equation 4**).

Equation 4. *Net Present Value calculation of Recharge Pond with Wetland Habitat.*

$$\begin{aligned} NPV_{WetlandHabitat} & \\ &= PV_{Revenue}(4958) - PV_{Costs}(4958) - PV_{Fallowing\ Costs}(42) \\ &- PV_{SurfaceWater}(42) - PV_{HabitatCreation\ and\ Preparation}(42) \\ &+ PV_{Avoided\ Production\ Costs}(42) + PV_{HabitatCredits}(42) \end{aligned}$$

Table 11 summarizes the costs and benefits associated with this method.

Table 11: *Summary of Method 3: Fallow + Wetland Habitat costs and benefits.*

Costs

Capital Costs	$	1,592,614
Tree Removal and Grind	$	14,700
Field Clean Up	$	5,376
Construction	$	467,754
Legal Fees	$	6,500
Engineering + Surveying	$	150,444
Conveyance Construction	$	709,140
Safe Harbor Agreement	$	238,700
Development	$	22,650
Permit Fee	$	50
Annual Reporting	$	108,000
Monitoring	$	108,000
Operations & Maintenance Costs	$	419,359,242
Maintenance Costs	$	378,881
*1 Year Water Lease Conveyance Fee**	$	2,550,000
*1 Year Water Lease Acquisition, Transaction & Fees**	$	8,762,775
Lift Pump Power	$	63,812
Almonds Operational Cost (4958 Acres)	$	387,881,197
Groundwater Pumping Cost (4958 Acres)	$	12,810,081
Almonds Revenue Loss (42 Acres)	$	6,912,495
TOTAL COSTS	$	420,951,856
PV TOTAL COSTS	$	250,150,616

**assuming no cost for water in wet-wet years; one-year lease purchase in dry years*

Benefits

Almonds Revenue (4958 Acres)	$	816,003,634
Avoided Operational Costs	$	3,394,319
Avoided Groundwater Pumping Cost (42 Acres)	$	108,516
Avoided Almonds Operational Cost (42 Acres)	$	3,285,803
Habitat Restoration Grant Funding	$	1,222,479
EQIP - Wetland Construction	$	1,200,907
EQIP - Wetland Management	$	15,411
California Conservation Stewardship Program - Wetland Wildlife Habitat Management ($/ac-yr), after EQIP	$	6,161
Habitat Payments	$	4,861,401
Wetland Banking Credit	$	4,200,000
USFWS-NAWCC, Birds	$	104,464
Central Valley Habitat Restoration Program: Giant Garter Snake	$	200,986
Conservation Banking: Swainson's Hawk	$	355,950
TOTAL BENEFITS	$	825,481,832
PV TOTAL BENEFITS	$	496,998,268

NPV TOTAL	***$ 246,847,651***
Benefit-Cost Ratio	***1.99***

3.4.5.1. Recharge Pond without Habitat Creation Alternative

It is possible, and likely, that landowners will also pursue SGMA compliance by constructing recharge basins that do not have a habitat function. The following table displays the corresponding costs and benefits of doing so. Included in the wetland habitat scenario, but excluded in this non-habitat alternative, are the cost of a safe harbor agreement and the benefits of habitat payment opportunities. The NPV of the non-wetland habitat recharge basin option is $236.4M across 2018 – 2045, which is $10M less than the NPV of the recharge pond as wetland habitat option (**Equation 5**) and (**Table 12**).

Equation 5. *Net Present Value calculation of recharge pond without habitat creation.*

$$NPV_{RechargePondOnly} = PV_{Revenue}(4958) - PV_{Costs}(4958) - PV_{Fallowing\ Costs}(42) - PV_{SurfaceWater}(42) + PV_{Avoided\ Production\ Costs}(42)$$

Table 12: *Summary of recharge pond without wetland habitat costs and benefits.*

Costs

Capital Costs	**$ 1,353,914**
Tree Removal and Grind	**$ 14,700**
Field Clean Up	**$ 5,376**
Construction	**$ 467,754**
Legal Fees	**$ 6,500**
Engineering + Surveying	**$ 150,444**
Conveyance Construction	**$ 709,140**
Operations & Maintenance Costs	**$ 419,359,242**
Maintenance Costs	**$ 378,881**
*1 Year Water Lease Conveyance Fee**	**$ 2,550,000**
*1 Year Water Lease Acquisition, Transaction & Fees**	**$ 8,762,775**
Lift Pump Power	**$ 63,812**
Almonds Operational Cost (4958 Acres)	**$ 387,881,197**
Groundwater Pumping Cost (4958 Acres)	**$ 12,810,081**
Almonds Revenue Loss (42 Acres)	**$ 6,912,495**
TOTAL COSTS	**$ 420,713,156**
PV TOTAL COSTS	**$ 250,002,947**

**assuming no cost for water in wet-wet years; one-year lease purchase in dry years*

Benefits

Almonds Revenue (4958 Acres)	**$ 816,003,634**
Avoided Operational Costs	**$ 3,394,319**
Avoided Groundwater Pumping Cost (42 Acres)	**$ 108,516**
Avoided Almonds Operational Cost (42 Acres)	**$ 3,285,803**
TOTAL BENEFITS	**$ 819,397,953**
PV TOTAL BENEFITS	**$ 486,404,314**

NPV TOTAL	***$ 236,401,366***
Benefit-Cost Ratio	***1.95***

3.4.6. *Fallowed Land for Upland Habitat*

3.4.6.1. Description and Assumptions

Apart from the groundwater replenishment methods described in this analysis, the decision to fallow agriculture is typically a result of limited ability to purchase and convey surface water.[58] When groundwater extractions for agricultural irrigation are limited, producers can manage water supplies by fallowing the least productive, lowest revenue acreage.[58] Fallowing cropland is inexpensive in practice but is much more costly for perennial crops, such as vineyards and orchards, than field crops because of the perennials' high investment costs and vulnerability to water scarcity.[58] In 2014, California landowners fallowed approximately 5% of mostly low-value cropland, costing $2.2 billion in farm revenues and 17,000 jobs economy-wide.[59] The decision to fallow agriculture for groundwater management has consequences, but may be optimal for producers with low-value crops and limited access to surface water.

The costs of fallowing can be offset by the potential for agricultural producers to engage in supplemental environmental markets. This CBA calculates the costs and benefits of retiring an agricultural field and subsequently restoring native vegetation to create upland species habitat. For the creation of habitat, landowners can hire a restoration manager to oversee topographic preparation, restoration plan designs, locally sourced seed collection, and planting techniques. To offset these costs, landowners can participate in land retirement grants and habitat market programs, such as the San Joaquin Valley Cropland EQIP Grant Funding Program and conservation banking, which provide funds for habitat restoration.

This analysis operates under the assumption that the landowner will restore the property to San Joaquin Valley upland vegetation to attract Federal and State endangered and threatened species. Private lands make up 70% of the Central Valley, and private landowners can invest in habitat like a new crop by "growing" habitat to sell to private and public investors.[96] Similar to Method 3, a landowner can work with US Fish and Wildlife Service to develop a Safe Harboring Agreement. This analysis assumes the landowner fallows lands specifically for the benefit of endangered species recovery and receives monetary payment for those actions in addition to indirect benefits of groundwater replenishment and basin sustainability.

3.4.6.2. Costs

Direct costs included the upfront capital, operations, and maintenance costs for fallowing agriculture and restoring idled fields to native species habitat. Capital costs, including orchard removal, topographic preparation, restoration project management, planting and supplemental irrigation, all occur in the first two years of the project, assuming orchards are removed in year 1 and restoration is completed in year 2. Capital costs for creating habitat account for 0.18% of the overall costs of the almond producer, totaling $0.75M discounted over 28 years.

Capital costs also partially include the development of a conservation plan, specifically a Safe Harboring Agreement, which occurs in year 1 to ensure it protects successful habitat restoration developed in year 2. The Safe Harbor Agreement development accounts for $0.24M, 0.06% of total discounted costs. Safe Harbor Agreements require annual reporting and monitoring, where costs occur every year (23 years to year 2040). Habitat operations and maintenance costs, largely vegetation monitoring and weed abatement, comprise 0.27% of the total costs at $1.13M.

Lastly and most significantly, the landowner bears the direct cost of foregone crop revenue. Over the analysis timeline, $36.2M in discounted almond revenues is lost from the fallowing of 220 acres of almonds.

3.4.6.3. Benefits

Benefits from fallowing agricultural land can be directly accrued from foregone agricultural operational costs and foregone groundwater pumping costs (as described above), almond revenue from the 4780 acres remaining in production, habitat restoration grant funding, and habitat payments.

Habitat specific benefits were analyzed based on observed transactions and payments schemes available to the private landowner in the San Joaquin Valley. First, the landowner can receive grant funding for upfront habitat restoration costs through programs like EQIP or the Central Valley Project Restoration Program.[97,98] The Central Valley Project Restoration Program is designed to protect species and habitat impacted by the Central Valley Project. In 2016, the program provided $1.6M total to three restoration projects.[99] Through grant funding programs like these, landowners can cost share up to 50% of the costs for habitat restoration efforts. Grant funding totals up to $0.59M across the 28-year timeframe.

Upland habitat creation from fallowed agriculture could either be temporary or permanent based depending on whether the landowner wishes to convert land back to agriculture. Because the decision of converting back to agriculture largely depends on the outcomes of SGMA, the landowner’s particular GSA and associated GSP, and agricultural commodity markets, two benefits analyses were performed. The first assumes a temporary project through 2040 with land going back into production thereafter, and the second assumes a permanent project through 2045. Benefits between these two options change based on available habitat payment schemes for either temporary or permanent restoration projects. Landowners pursuing temporary restoration projects can participate in the USDA Conservation Reserve Program, which gives a sign-up payment and annual rents to landowners for retiring agriculture. The incentive payments gained through temporary restoration projects amount to $1.26M. Alternatively and more favorable, a landowner can retire and restore upland habitat permanently to be eligible for species conservation credits. Like wetland credits, species conservation credits allow landowners to create habitat for endangered species. Endangered species conservation credits included in this analysis are SJV kit fox, Tipton kangaroo rat, Valley Elderberry Longhorn Beetle, and Swainson's Hawk. For the purposes of the analysis, it was assumed that the landowner would create 220 acres of species conservation credits with the exception of the beetle at 50 acres. With these assumptions, the permanent habitat restoration generates a discounted benefit of $8.6M.

3.4.6.4. Benefit-Cost Ratio

The BCR of fallowing 220 acres of land and creating upland habitat upon it is 1.93 or 1.90, for permanent or temporary restoration projects, respectively (**Table 13**). A landowner with 5000 acres of almonds and a 1,000AFY groundwater replenishment target will receive a NPV of either $234.2M (permanent project) or $226.7M (temporary project) across 2018-2045 (**Equation 6**).

***Table 13**: Summary of Method 4 Fallow for Upland Habitat costs and benefits.*

Costs	Permanent Restoration Project	Temporary Restoration Project
Captial Costs	**$ 747,040**	**$ 747,040**
Orchard Removal	$ 118,831	$ 118,831
Land Preparation	$ 151,646	$ 151,646
Restoration Project Management	$ 112,463	$ 112,463
Seeding	$ 100,320	$ 100,320
Establishment Irrigation	$ 25,080	$ 25,080
Safe Harbor Agreement	$ 238,700	$ 238,700
Operations & Maintenance Costs	**$ 423,651,611**	**$ 423,651,611**
Almond Operational Cost (4780 Acres)	$ 373,955,652	$ 373,955,652
Groundwater Pumping Cost (4780 Acres)	$ 12,350,179	$ 12,350,179
Almond Revenue Loss (220 Acres)	$ 36,208,310	$ 36,208,310
Maintenance Costs	$ 1,137,470	$ 1,137,470
TOTAL COSTS	**$ 424,398,651**	**$ 424,398,651**
NPV TOTAL COSTS	**$ 252,155,413**	**$ 252,155,413**
Benefits		
Almond Revenue (4870 Acres)	$ 786,707,819	$ 786,707,819
Avoided Operational Costs	$ 17,779,766	$ 17,779,766
Habitat Restoration Grant Funding	$ 586,500	$ 586,500
Habitat Payments - Temporary Restoration	$ -	$ 1,260,213
Habitat Payments - Permanent Restoration	$ 8,564,830	$ -
TOTAL BENEFITS	**$ 813,638,916**	**$ 806,334,298**
NPV TOTAL BENEFITS	**$ 486,343,704**	**$ 478,887,921**
NPV TOTAL	**$ 234,188,291**	**$ 226,732,508**
Benefit-Cost Ratio	**1.93**	**1.90**

Equation 6. *Net Present Value calculation of Fallowing for Upland Habitat.*

$$
\begin{aligned}
NPV_{UplandHabitat} &= PV_{Revenue}(4870) - PV_{Costs}(4870) - PV_{Fallowing\ Costs}(220) \\
&- PV_{HabitatCreation\ and\ Preparation}(220) + PV_{Avoided\ Production\ Costs}(220) \\
&+ PV_{HabitatCredits}(220)
\end{aligned}
$$

3.5. Cost-Benefit Analysis Recommendation

The enactment of SGMA will increase the resiliency of agricultural production to future water shortages and a changing climate. It may also provide a unique opportunity to positively impact California's natural ecosystems.[59] In order to reach sustainability targets laid out in SGMA by 2040, GSAs and participant landowners will pursue a suite of groundwater replenishment options. Cost-benefit analyses performed on four replenishment methods, plus a baseline fallow scenario, for an almond producer yielded varying results (**Table 14**). None of the compliance methods brings the landowner back to her pre-SGMA BCR. The landowner's "willingness to accept" a SGMA compliance measure (assuming lack of enforcement or non-compliance penalty) is the NPV difference between the pre-SGMA full production with groundwater and the baseline fallow scenario. This amounts to $22 million for an almond producer over 2018-2045

In an era of SGMA, however, each of the four groundwater replenishment analyzed outperform a simple fallow scenario. Based on discussion with subject matter experts, it is predicted that the most easily accessible in-lieu recharge option will be to procure 1-year water leases. With this surface water source designated, a comparison across all groundwater replenishment methods can be made. Comparing BCRs, the almond producer's best option would be to fallow and create wetland habitat on 42 acres of land (BCR = 1.99). The habitat payments that can be garnered by the landowner for wetland habitat mitigate the small amount of fallowing necessary to pursue this method.

Table 14: *Comparison of all replenishment methods including previous full production with groundwater.*

CBA Comparison (Almonds)	Full Production w/ Groundwater	Method 0 Baseline Fallow	Method 1 In-Lieu Recharge w/ SW Import **	Method 2 On-Farm Recharge	Method 3 Fallow + Wetland Habitat	Method 4 Fallow + Upland Habitat
COSTS						
Capital Costs			$ 8,076,046	$ 5,767,373	$ 1,501,583	$ 640,650
Operations & Maintenance	$ 239,869,989	$ 250,928,221	$ 242,663,059	$ 241,426,169	$ 248,649,033	$ 251,514,763
TOTAL PV COSTS	**$239,869,989**	**$250,928,221**	**$250,739,106**	**$247,193,542**	**$250,150,616**	**$252,155,413**
BENEFITS						
TOTAL PV BENEFITS	**$488,492,745**	**$477,553,344**	**$488,830,165**	**$489,028,517**	**$496,998,268**	***$486,343,704***
NPV TOTAL *	***$248,622,756***	***$226,625,123***	***$238,091,059***	***$241,834,975***	***$246,847,651***	***$234,188,291***
BENEFIT COST RATIO	***2.04***	***1.90***	***1.95***	***1.98***	***1.99***	***1.93***

CBA Comparison (Almonds) - Sensitivity Analysis, 2x Costs						
TOTAL PV COSTS	**$479,739,978**	**$501,856,442**	**$501,478,211**	**$494,387,084**	**$500,301,233**	**$504,310,825**
TOTAL PV BENEFITS	**$488,492,745**	**$477,553,344**	**$488,830,165**	**$489,028,517**	**$496,998,268**	**$486,343,704**
NPV TOTAL	***$8,752,767***	***-$24,303,098***	***-$12,648,047***	***-$5,358,567***	***-$3,302,965***	***-$17,967,122***
BENEFIT COST RATIO	***1.02***	***0.95***	***0.97***	***0.99***	***0.99***	***0.96***

CBA Comparison (Almonds) - Sensitivity Analysis, 3x Costs						
TOTAL PV COSTS	**$719,609,966**	**$752,784,663**	**$752,217,317**	**$741,580,626**	**$750,451,849**	**$756,466,238**
TOTAL PV BENEFITS	**$488,492,745**	**$477,553,344**	**$488,830,165**	**$489,028,517**	**$496,998,268**	**$486,343,704**
NPV TOTAL	***-$231,117,222***	***-$275,231,319***	***-$263,387,152***	***-$252,552,109***	***-$253,453,582***	***-$270,122,534***
BENEFIT COST RATIO	***0.68***	***0.63***	***0.65***	***0.66***	***0.66***	***0.64***

** Costs and benefits normalized to 2018 dollars, and displayed as a Present Value (r=4.4%), over a 2018 - 2045 timeframe.*

*** Method displays 1-Year Water Lease Option*

Since the types of crops grown in Kern County vary greatly in their operational costs and profitability, it remained unknown if fallowing plus wetland habitat creation would be preferable for all landowners. The 33 crops grown in Kern County were run through the CBA tool, assuming 1-year water leases were available across the entire timeline (**Table 15**). Using NPV, a pattern emerged regarding when multi-benefit replenishment methods are favorable to traditional replenishment methods. Crops with the highest profit margins are best suited for methods that allow the lands to remain in full production—in these cases, habitat credits and foregone groundwater pumping costs could not outweigh foregone revenue. For lower profit margin crops, however, multi-benefit methods are preferable, since the earnings from habitat payments exceed the loss of revenue from fallowing.

Table 15: *NPV of the top 33 Kern County crops if faced with saving 1,000 AFY of groundwater assuming a 5,000 acre farm size.*

	Net Present Value of Groundwater Replenishment Options					
Crop Type	**Full Production**	**(0) Baseline Fallow**	**(1) In-Lieu Recharge**	**(2) On-Farm Recharge**	**(3) Fallow + Wetland Habitat**	**(4) Fallow + Upland Habitat**
Flowers, Nursery and Christmas Tree Farm	$ 1,830,319,117	$ 1,314,520,995	$ 1,819,788,015	$ 1,823,531,931	$ 1,801,971,514	$ 1,320,945,993
Grapes	$ 1,080,225,799	$ 930,103,029	$ 1,069,694,480	$ 1,073,438,396	$ 1,064,479,763	$ 937,367,546
Peppers	$ 1,098,511,464	$ 788,790,377	$ 1,087,980,361	$ 1,091,724,278	$ 1,082,458,229	$ 795,215,375
Bush Berries	$ 1,027,009,098	$ 737,423,077	$ 1,016,477,995	$ 1,020,221,911	$ 1,012,157,102	$ 743,848,075
Peaches/Nectarines	$ 792,781,491	$ 705,426,988	$ 782,249,422	$ 785,993,338	$ 781,864,519	$ 712,860,819
Olives	$ 749,867,370	$ 664,829,524	$ 739,335,802	$ 743,079,718	$ 739,671,356	$ 672,244,543
Avocados	$ 713,874,477	$ 632,911,027	$ 703,342,909	$ 707,086,825	$ 704,283,144	$ 640,326,045
Cherries	$ 625,393,008	$ 556,451,239	$ 614,860,940	$ 618,604,856	$ 617,288,164	$ 563,885,070
Citrus	$ 547,105,410	$ 485,020,218	$ 536,573,842	$ 540,317,758	$ 540,315,797	$ 492,435,236
Pomegranates	$ 523,839,102	$ 464,387,656	$ 513,307,533	$ 517,051,449	$ 517,440,363	$ 471,802,674
Apples	$ 517,522,194	$ 460,446,214	$ 506,990,125	$ 510,734,041	$ 511,229,579	$ 467,880,045
Onions and Garlic	$ 425,270,390	$ 375,270,440	$ 414,738,916	$ 418,482,832	$ 420,527,605	$ 382,661,942
Potatoes and Sweet Potatoes	$ 402,984,370	$ 311,604,723	$ 392,453,518	$ 396,197,434	$ 398,615,990	$ 318,356,592
Pistachios	$ 336,719,089	$ 306,968,978	$ 326,187,392	$ 329,931,308	$ 333,463,965	$ 314,532,146
Almonds	$ 248,622,756	$ 226,625,123	$ 238,091,059	$ 241,834,975	$ 246,847,651	$ 234,188,291
Pears	$ 228,383,330	$ 203,112,625	$ 217,851,261	$ 221,595,177	$ 226,948,247	$ 210,546,456
Plums, Prunes and Apricots	$ 179,545,850	$ 159,647,268	$ 169,013,782	$ 172,757,698	$ 178,931,238	$ 167,081,099
Tomatoes	$ 96,714,557	$ 81,730,239	$ 86,184,238	$ 89,928,155	$ 97,491,510	$ 88,912,450
Cole Crops	$ 110,875,356	$ 79,272,597	$ 100,344,254	$ 104,088,170	$ 111,414,408	$ 85,697,595
Cotton	$ 85,183,407	$ 74,176,313	$ 74,651,521	$ 78,395,437	$ 86,154,083	$ 81,509,025
Melons, Squash and Cucumbers	$ 71,833,750	$ 58,602,065	$ 61,302,135	$ 65,046,051	$ 73,028,701	$ 65,619,664
Carrots	$ 80,179,451	$ 57,220,659	$ 69,648,349	$ 73,392,265	$ 81,234,194	$ 63,645,657
Safflower	$ 55,249,046	$ 46,328,982	$ 44,718,674	$ 48,462,590	$ 56,722,620	$ 53,482,973
Kiwis	$ 34,317,034	$ 30,279,486	$ 23,785,466	$ 27,529,382	$ 36,142,266	$ 37,694,504
Walnuts	$ 27,538,612	$ 24,360,826	$ 17,006,544	$ 20,750,460	$ 29,477,721	$ 31,794,657
Corn, Sorghum and Sudan	$ 22,900,479	$ 20,038,881	$ 12,369,626	$ 16,113,542	$ 24,917,508	$ 27,425,680
Alfalfa and Alfalfa Mixtures	$ 7,983,618	$ 7,248,101	$ (2,546,755)	$ 1,197,162	$ 10,251,251	$ 14,865,356
Idle	$ -	$ -	$ -	$ (7,237,105)	$ 2,421,834	$ 8,080,519
Wheat	$ (4,232,121)	$ (3,611,964)	$ (14,762,547)	$ (11,018,631)	$ (1,759,263)	$ 3,203,398
Beans (Dry)	$ (5,646,449)	$ (5,118,888)	$ (16,176,781)	$ (12,432,865)	$ (3,149,831)	$ 2,239,692
Lettuce/Leafy Greens	$ (31,391,329)	$ (22,931,790)	$ (41,922,432)	$ (38,178,516)	$ (28,462,197)	$ (16,506,792)
Mixed Pasture	$ (29,371,072)	$ (26,938,873)	$ (39,901,708)	$ (36,157,792)	$ (26,475,880)	$ (19,368,650)
Strawberries	$ (110,889,829)	$ (80,043,512)	$ (121,420,931)	$ (117,677,015)	$ (106,625,122)	$ (73,618,514)

If the landowner wanted to think beyond her personal profits and losses, she may consider the loss of labor income to the local community of different replenishment projects. This cost is a direct function of amount of acres that must be taken out of production and the foregone cost of harvesting those acres. The different water demands of each crop type dictate how many acres must be fallowed to achieve targeted water savings. For the top 10 crops by acreage in Kern County, carrots require the greatest area fallowed to save 1,000 AFY (**Figure 8**).

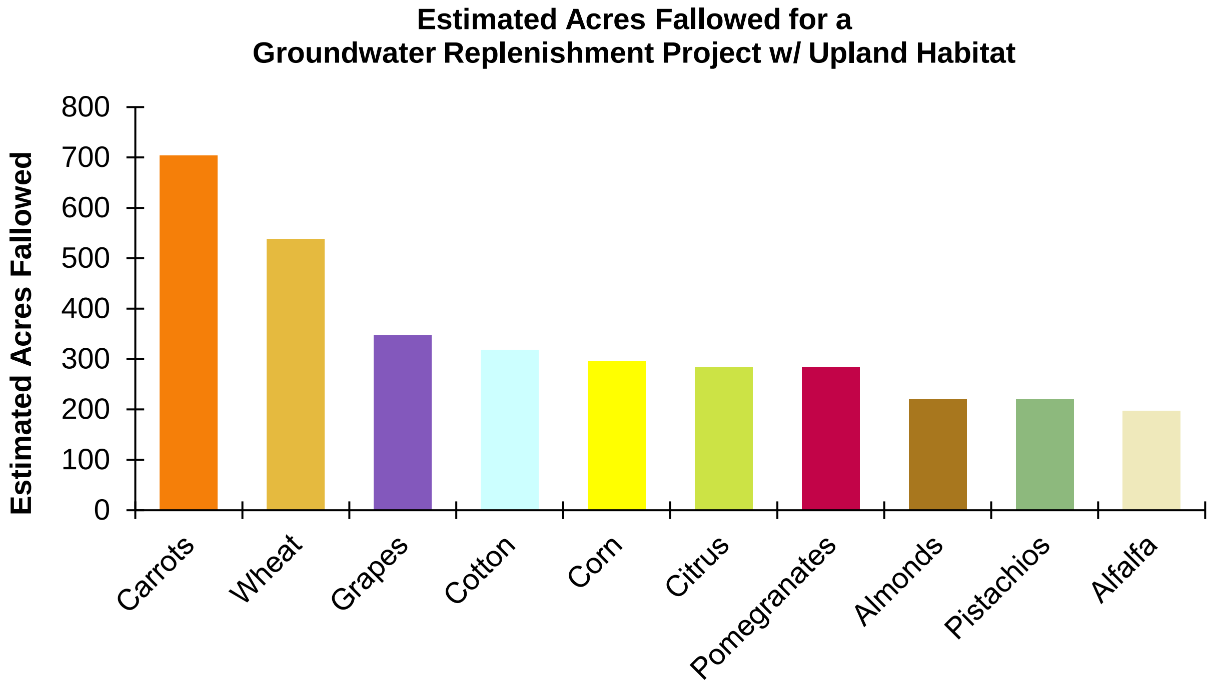


Figure 8: *Cost-benefit analysis results indicating the acres fallowed by crop for upland habitat replenishment projects generating 1,000 AFY of water savings.*

The type of habitat restoration (wetland or upland) also determines the magnitude of foregone labor wages. Wetland habitat restoration requires that less land be fallowed than upland habitat restoration, as water is being actively replenished to achieve a targeted savings of 1,000 AFY (**Figure 9**).

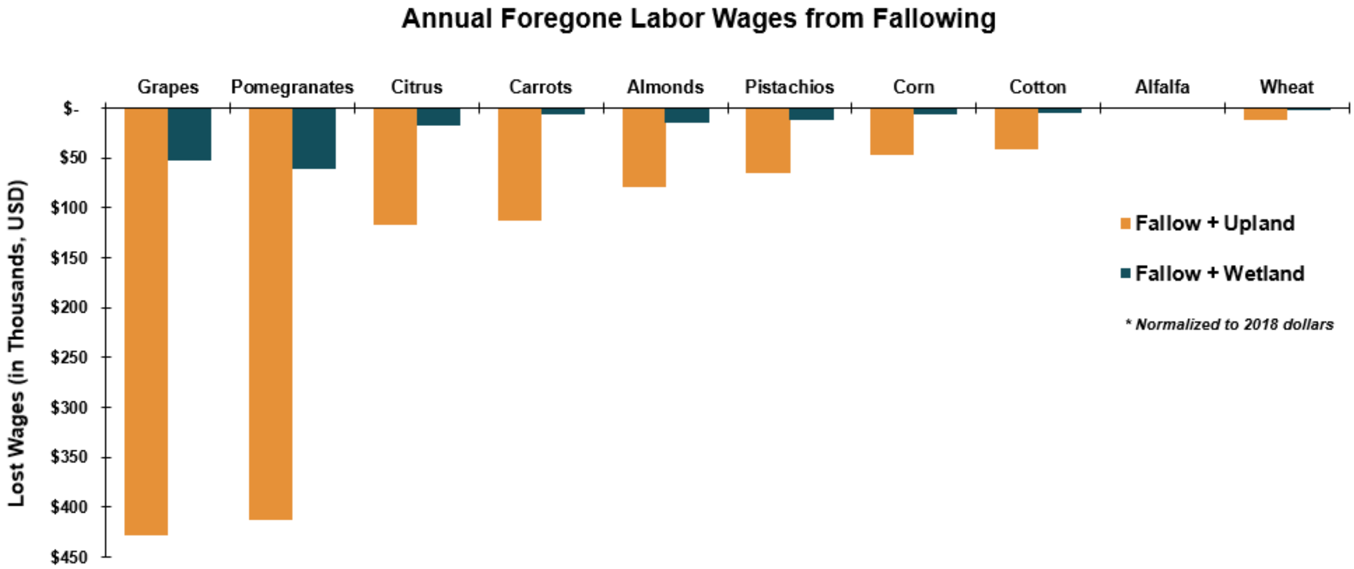


Figure 9: *Foregone labor wages from the amount of land fallowed required to achieve groundwater savings (1,000AFY).*

3.6. Societal Impact of Including Restoration

Given the heavy reliance of Kern County's economy on agriculture, any widespread land use change could have a dramatic effect on society. Rural and disadvantaged communities particularly will be hit hard if jobs dry up along with the fields. As outlined above, agricultural producers will have to decide how to comply with their GSPs based on personal costs and benefits. The number of jobs that could be lost if fields are retired from production depends on the amount of acres fallowed and the labor intensity of the crops in question. Labor costs per acre were collected for the top 30 crops in Kern County. This cost data combines wages from both non-skilled laborers (crop workers) and semi-skilled laborers (machine operators). Pomegranates and table grapes are the most labor intensive of the top 10 crops by acreage, requiring 100 hours and 75 hours per acre to harvest, respectively.[100,101] Many of the most labor intensive crops also boast the highest profit margins. Profit margin per acre and labor cost per acre are positively correlated (**Figure 10**). Given the CBA findings above, namely that high profit margin crops show the most benefit when kept in full production, fields that provide a large amount of local jobs should not be fallowed.

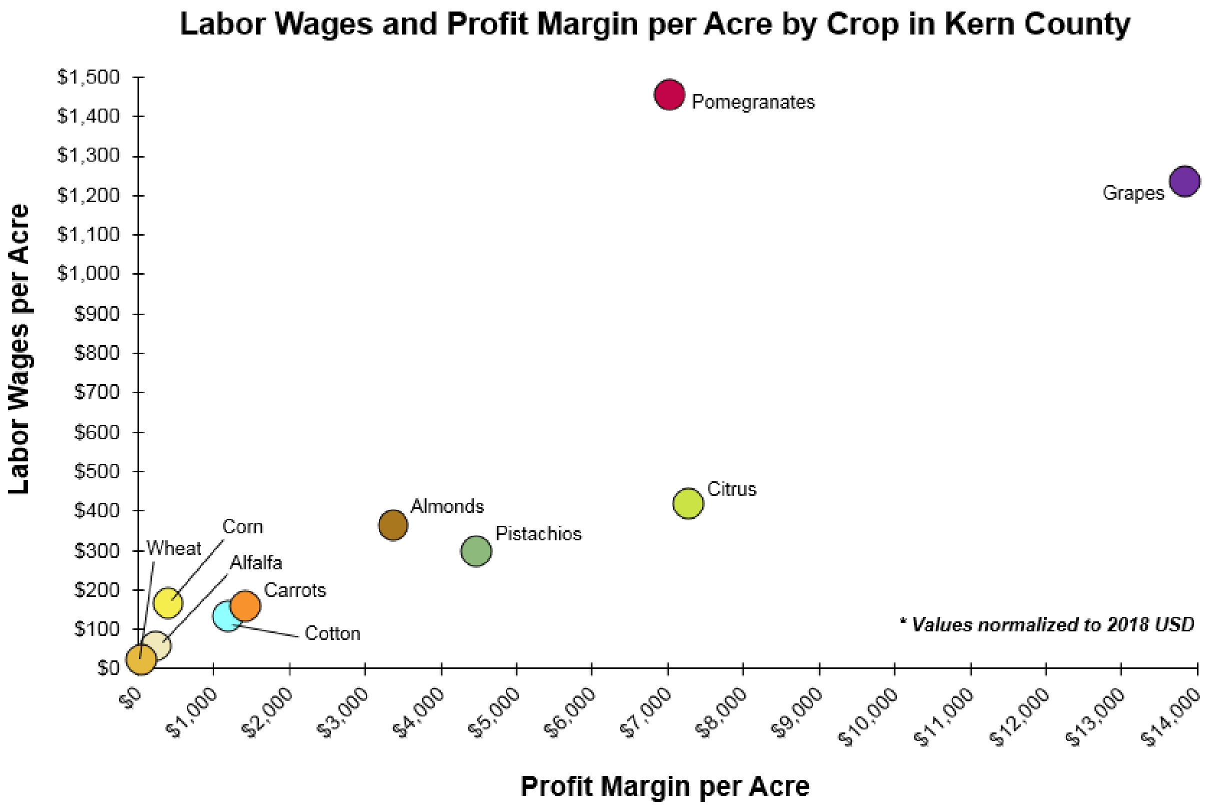


Figure 10: *Crop profit margins against labor costs per harvested acre.*

As indicated in the cost-benefit recommendations above, corn, alfalfa and wheat—three lower profit margin crops with a large presence in Kern County, are recommended for fallowing and upland habitat creation. These crops generate less than 10 hours of work per acre.[102–104] Thus from an individual landowner vantage point and a local employment vantage point, keeping high value crops in production is desirable.

3.6.1. *Wide-Scale Fallowing Could Hurt the Most Vulnerable*

Though the CBA cannot estimate the total amount of acreage that will be fallowed in Kern County because of SGMA, fallowed acreage during recent droughts can be used as proxy values. It was estimated that 10,100 seasonal agricultural jobs were lost state-wide in 2015, during the height of the most recent drought.[105] According to the 2014 Agricultural Worker Survey, the typical California hired farmworker is a foreign born (91%) male (74%) between the ages of 25-45 (52%) with little to no speaking or reading English ability (74% and 77%, respectively).[106] Over one-quarter live below the poverty line, and plan to continue working in agriculture until they are no longer able.[106] Most crop workers are local, 86% of those surveyed live within 75 miles of their primary farm of employment.[106] Only 24% of respondents believed they could find employment outside of the sector in one month.[106] If Kern County's crop workers share the traits of the typical California crop worker, then fallowing may result in a loss of agricultural jobs who have little social or economic safety net.

3.6.2. *Habitat Creation Can Mitigate Negative Externalities*

Habitat creation on already fallowed land can provide the opportunity for at least some gainful employment to the same workers who lost their jobs. In 2015, the national "restoration economy" was estimated to produce $9.6 billion per year. Restoration was defined as "any combination of activities intended to result in ecological uplift, improve ecosystem health, and result in a functioning ecosystem that provides a suite of ecosystem services."[107] It was estimated that the national restoration economy was responsible for 126,000 jobs in 2014.[107] Of those, nearly a quarter are physical restoration jobs (for example, earth moving, planting, maintenance).[107] Crop workers would be well suited for these physical restoration jobs. The number of jobs created appears to depend on the type of restoration project. At a county level, wetlands have been cited as creating 6.8 jobs per $1 million invested, while grasslands can create 13.[108] There were no estimates found for jobs created by restoring desert shrub land habitat. Restoration jobs tend to be seasonal, but well paid.[108]

Further supporting communities closely tied to agricultural fields, habitat creation has the potential to improve air quality. If native vegetation is planted, erosion due to wind is reduced. This could be especially helpful in a county that consistently has some of the worst particulate matter pollution in the country.[109] Planting native desert scrub can help to desalinate soils as well. After extensive agriculture, high salt content is a problem for many fields in Kern County. Other traditional benefits from habitat restoration include storm water management and water quality improvement. Further research should be conducted to determine if additional incentive programs and/or markets can be developed that can compensate landowners for restoration work based on the other benefits multi-benefit replenishment provides.

4. Multi-Benefit Projects: Spatial Optimization

Although the costs and benefits of multi-benefit replenishment projects have been detailed above, the question remains on where these multi-benefit projects can be strategically located to achieve groundwater replenishment targets.

Many private, academic, and non-profit groups have provided siting tools for the installment of groundwater banking, strategic fallowing, and endangered species habitat.[110–113] UC Davis designed a suitability index for groundwater replenishment on California agricultural land based on geologic and hydrologic characteristics.[110] The Nature Conservancy (TNC) has identified the potential of suitable habitat for strategic fallowing of agricultural land in the San Joaquin Desert for endangered species habitat creation.[111] Some tools in California have been designed to include multiple spatial layers of information as a comprehensive approach to land management. TNC assessed and identified the least conflict lands with the potential for solar energy development in the Western San Joaquin Valley.[113]

However, there has yet to be a comprehensive model that gathers spatial information from geologic conditions, replenishment suitability, groundwater quality, endangered species habitat, agricultural commodity pricing, irrigation demand and the factors necessary to best inform landowners on where to site multi-benefit replenishment strategies. Additionally, a tool has yet to be provided that dynamically optimizes siting for these projects. The Multi-Benefit Optimization Model (MBOM) presented in this report leverages existing spatial research on groundwater replenishment and endangered species habitat and combines it with crop irrigation demand and agricultural pricing to locate agricultural fields most suitable for multi-benefit groundwater replenishment projects. Further, the MBOM leverages an approach commonly used by conservation planners when designing reserve networks to achieve habitat goals. Marxan, a free conservation planning software, optimizes land units recommended for species conservation to meet defined-targets at the least cost or budgeted cost. In the MBOM, Marxan was utilized to select agricultural fields that meet defined groundwater savings targets, species conservation targets, at the least cost calculated as lost crop revenue. This approach allows landowners and stakeholders to prioritize different project goals, achieve groundwater savings at the least cost, and site projects that generate some additional co-benefits.

4.1. Motivation and Purpose

The San Joaquin Valley is technically a desert in that the valley receives less than ten inches of rain per year.[3] During dry years, groundwater accounts for 30-60% of agricultural irrigation needs in the region, which accounts for half of California's agricultural production.[1] As a common pool resource, groundwater has been extracted to meet agricultural needs to the point of significant groundwater overdraft, putting a billion dollar agricultural economy at risk. In 2014, California passed SGMA to identify basins most vulnerable to detrimental damages caused by groundwater overdraft (undesirable results). Of these 21 critically overdrafted basins, ten are within the San Joaquin Valley and namely.[14] Thus, agricultural landowners will be faced with tough and expensive groundwater management decisions to comply with SGMA deadlines in a way that does not further damage the natural environment.

SGMA positions agricultural landowners as water managers and, indirectly, as land use planners. Groundwater pumpers will face new decisions on how to manage their landscapes to enhance groundwater sustainability. With these decisions being made across the San Joaquin Valley, there may be potential for growers to optimally locate areas suitable for replenishment such that lands also generate benefits for natural resources and local communities.

Natural resource and community benefits include the benefits generated for the environment and ecosystems, as well as the societies and neighborhoods that depend on the health of the San Joaquin Valley. Natural resource benefits identified through the implementation of multi-benefit replenishment strategies include the benefits derived from endangered species habitat creation. Thirty endangered and threaten species exist in the San Joaquin Valley, and therefore there is significant potential for landowners to take advantage of species habitat markets and conservation banking to offset the costs of SGMA compliance. Community benefits can also be derived from the mitigation of adverse environmental health effects. The restoration of fallowed fields can mitigate dust particle generation and create a new potential job sector to mitigate farm labor loss. Further, groundwater recharge ponds can be potentially sited to avoid domestic well groundwater contamination. These benefits are therefore accrued by society. The landowner is compensated directly through monetary benefits derived from existing habitat market mechanisms.

The MBOM performs spatial and economic analysis to inform landowners on potential locations for multi-benefit replenishment projects the is cost-effective in achieving groundwater replenishment goals, while also siting the potential generating co-benefits specifically in California's San Joaquin Valley.

4.2. MBOM Description

The MBOM considers spatial parameters for replenishment suitability; upland and wetland habitat potential; current species ranges; existing and potential conservation areas; groundwater quality and contamination areas; and, crop value and irrigation demand. Combined with the CBA, this research informs landowners of the difference in costs between traditional and multi-benefit strategies to achieve groundwater reduction targets. Further, the goal of the MBOM is to maximize the total net benefits that can accrue for multi-benefit replenishment projects across different spatial scales. Goals of maximizing groundwater reductions in isolation may otherwise lead to different spatial distributions of management activities. Thus, the MBOM recommends fields for multi-benefit management projects that achieve multiple objectives to maximize the total net benefit.

The MBOM selects potential areas of greatest (net) value upland and greatest (net) value wetland benefits for multi-benefit groundwater replenishment projects on agricultural fields by minimizing costs subject to a variety of conservation targets. The MBOM is designed for landowner input and can be processed for different geographic regions within the San Joaquin Valley given the user's field outlines available for projects. This report presents a specific analysis within the area of Kern County that is encompassed within the San Joaquin Valley, which is otherwise defined in SGMA as the Kern County sub-basin.

4.3. Methodology

The MBOM considers many factors to determine which agricultural fields can be prioritized for groundwater replenishment projects by using the conservation-planning program, Marxan. Marxan is designed to achieve conservation targets at the lowest possible cost. The MBOM uses GIS spatial processes to score fields based on the field's ability to provide species habitat, its proximity to existing habitats, irrigation water savings, as well as a score based on groundwater replenishment suitability. These scores are inputted into Marxan along with each field's cost based on foregone crop revenue. Then, Marxan processes field scores to determine the least-cost reserve network possible that achieves habitat and groundwater savings targets.

Due to the differentiation between upland and wetland habitat suitability, the MBOM considers different variables and produces different outputs for the greatest value upland habitat benefits and greatest value wetland benefits.

4.3.1. *Upland Habitat Replenishment Projects*

The MBOM defines an upland habitat replenishment project as the retirement of agricultural crops and the subsequent restoration of the fallowed field to upland habitat. Upland habitat in the San Joaquin Valley is comprised of more than 325 species of plants and animals that occur in arid grasslands, scrublands and vernal pools.[114] Of the 325 wildlife species that occur in San Joaquin Valley upland habitats, eleven species are listed as threatened or endangered by the US and California Fish and Wildlife Services.[114] In order to help recover these species, agricultural lands can be fallowed and restored to upland habitat to curtail groundwater usage, support habitat, and in turn, potentially receive a monetary benefit from habitat incentive credit programs. The upland habitat replenishment model assumes that fallowed fields had been irrigated with groundwater, and that by no longer extracting groundwater for the irrigation of these crops, the groundwater table is passively replenished. In the MBOM, the costs do not include restoration and maintenance due to the wide-ranging fixed and variable costs by acre and by crop. However, these costs were explored in the CBA. The MBOM optimizes a recommended reserve network that achieves upland habitat conservation targets defined by species ranges and conserved areas, water savings targets calculated as forgone crop irrigation, at a minimal cost calculated as the annual foregone crop revenue.

4.3.2. *Wetland Habitat Replenishment Projects*

A wetland habitat replenishment project is defined in the MBOM as the replacement of agricultural crops with a groundwater recharge pond that infiltrates surface water into the underlying groundwater table, while also serving as wetland habitat. As the most common method for increasing groundwater storage, a recharge pond is a constructed surface basin that allows water to slowly infiltrate through the topsoil layer into the underground aquifer.[55] These ponds most typically use surface water supplies or excess storm flows for groundwater replenishment. Though most often constructed for maximum infiltration, these recharge ponds can also be designed to support wetland plant and animal species by selecting sites with moderate infiltration rates and allowing for depth heterogeneity and vegetation growth. As described in the CBA, a wetland habitat replenishment project offers landowners financial incentives to maintain wetland habitats through state and federal wetland mitigation bank credits upwards of $100,000 per acre.[93] Thus, a wetland habitat replenishment project considers wetland species ranges, proximity to existing wetland areas, groundwater infiltration capacity, at a minimal cost calculated as the foregone crop revenue. Because the MBOM does not currently account for the cost of acquiring surface water in its optimization, the cost is calculated as a secondary calculation at an average annual cost of $665/AF, according to the CBA.

These replenishment projects are assessed separately through two different models to determine a field's suitability for either an upland habitat replenishment project or a wetland habitat replenishment project. The following sections describe the decisions made while processing spatial data and the conservation factors considered for suitable replenishment projects.

4.3.3. *Model Scope*

The MBOM scope for this report is constrained to Kern County, California to be aligned with the results from the CBA. Because the MBOM focuses on upland and wetland habitat types that occur in the San Joaquin Valley, the study area in Kern County was constrained to only the portion of Kern County that exists within the San Joaquin Valley (**Figure 11**). This was further determined to be an appropriate study region as most of agriculture in Kern County is grown within the portion of the county that intersects the San Joaquin Valley.

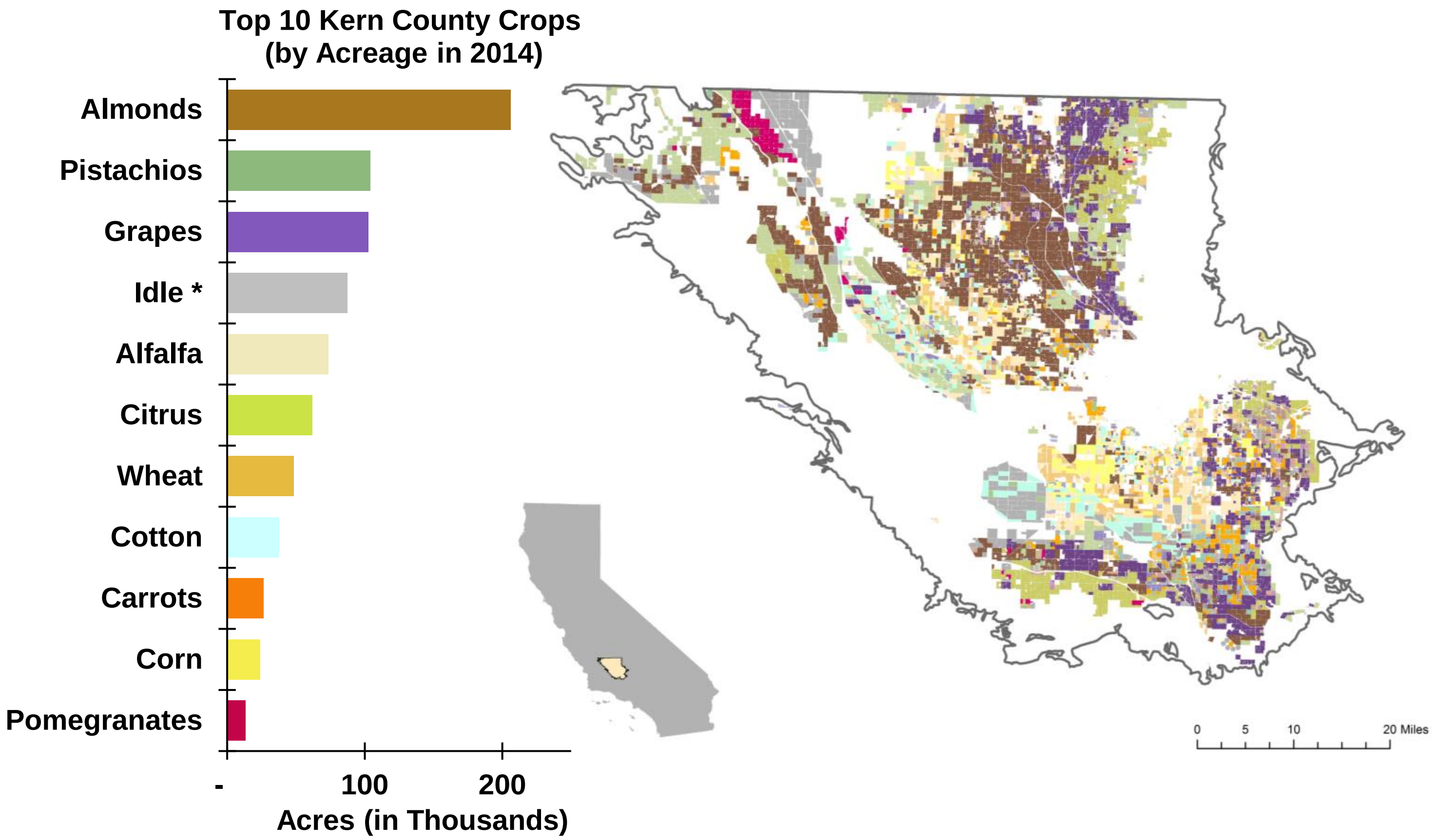


Figure 11: *Agricultural fields in the area of Kern County within the San Joaquin Valley in 2014.*[115]

Though the analysis presented in this report focuses on this region within Kern County, spatial data on habitat species ranges, conservation areas and geologic conditions were collected for the entire San Joaquin Valley in efforts to ease the expandability of the MBOM to other counties of interest for future applications.

4.3.4. *Marxan*

Marxan is a conservation planning software that recommends potential reserve networks that aim to meet conservation targets at minimal cost. It is readily available via the Internet at no cost (Marxan.org). To determine lowest cost reserve networks, Marxan considers the reserve's planning units, planning unit costs, and Conservation Factors, targets, and penalties. Planning units are the agricultural fields that could be included in the reserve network. Conservation targets are the goals that the reserve needs to meet based on the Conservation Factors. Conservation Factors are the reserve's suitability inputs, such as various species ranges or agricultural water consumption. Marxan can also considers other user objectives, such as budget constraints or the desire to minimize fragmentation of the reserve.

Marxan operates by considering different potential reserves networks. Each potential reserve network is a selection of planning units. In the MBOM, these planning units are the agricultural field boundaries. Marxan then creates a selection of planning units and calculates the total cost associated with it and repeats the process a pre-defined amounts of times. To select the planning units, Marxan implements a "simulated annealing" site optimization algorithm, where it attempts to minimize the reserve's total cost while meeting conservation targets.[116] After repeating this procedure for a defined number of reserve combinations, Marxan identifies the reserve system that comes closest or achieves all conservation targets at the lowest cost according to the following objective cost function (**Equation 7**).

Equation 7*: Marxan objective cost function.*

$$
\begin{aligned}
Total\ Cost = {} & \Sigma\, Planning\ Unit\ Cost + \Sigma(Conservation\ Factor\ Target \\
& - Conservation\ Target\ delivered) \\
& \times Penalty\ inccured\ for\ unmet\ targets + (Boundary\ Length\ Modifer \\
& \times Reserve\ Boundary\ Length)
\end{aligned}
$$

Where 'Total Cost' is the objective to be minimized, the 'Planning Unit Cost' is a cost assigned to each planning unit, 'Penalty Factors' are the costs imposed for not meeting conservation target goals, and 'Boundary Length Modifier' is the multiplier applied to the 'Boundary Length of the Reserve" determined by the total boundary length of planning units in the reserve network.[116] The Boundary Length of the Reserve is otherwise interpreted as the cost of planning unit fragmentation within the reserve.

4.3.4.1. Planning Unit Cost

The Planning Unit Cost is the cost of including a single planning unit in the reserve. The MBOM uses agricultural fields as the planning unit for analysis. Agricultural field spatial data was collected from CADWR: Land Use Viewer LandIQ Crop Data.[115] The LandIQ spatial data includes the boundaries for agricultural fields in California and the associated crop being grown in 2014.

The MBOM uses a one-year foregone crop revenue as the cost for each planning unit. Data on the annual revenue from Kern County crops was collected from the USDA's National Agricultural Statistics Service (NASS) Pacific Regional Field Office. Field costs are mandatory for Marxan to operate. More information on cost methodology is described in Section 4.3.6 below.

4.3.4.2. Conservation Factor Target and Penalties

Conservation Factor Penalties are the sum of the penalties for reserve planning units not meeting the reserve's aggregate conservation targets. Conservation Targets are defined by the user for each Conservation Factor. Through conservation targets, the user specifies how much of each Conservation Factor to protect in recommended network. MBOM's conservation targets are species range habitat, proximity to protected areas, and water savings targets. Conservation targets are essential and mandatory for each Conservation Factor.

Next, Marxan weights the user's given conservation targets by having the user assign specific penalties for not meeting the conservation targets, i.e., the conservation factor penalty. Penalties are the relative importance of each conservation factor defined by the user. When a planning unit fails to meet a conservation target, Marxan applies the conservation penalty factor (assigned by the user) to that planning unit. This will increase the total cost of the planning unit by the magnitude of the conservation penalty factor. In other words, a higher penalty will place a greater importance on solutions to meet that conservation target (versus other conservation targets).

Penalties are multiplied by the difference between the conservation target and the actual conservation factor achieved (i.e., the deficit between the goal and the actual achieved, **Equation 8**).

Equation 8: *Marxan penalty incurred for unmet targets.*

$$Penalty\ inccured\ for\ unmet\ targets = (Conservation\ Factor\ Target - Total\ Conservation\ Factor\ Achieved) \times Conservation\ Factor\ Penalty$$

4.3.4.3. Boundary Length Modifier and Boundary Reserve Length

The Boundary Length Modifier and Boundary Reserve Length are how Marxan quantifies the connectivity of a configuration of planning units. The Boundary Length Modifier is the weight chosen by the user that translates to the importance value of the reserve minimizing its total boundary reserve length. Marxan calculates the Boundary Reserve Length as the total perimeter length or boundary length of each planning unit included in the simulated reserve. If recommended fields are adjacent to each other, Marxan instead calculates the total perimeter boundary length around the aggregated fields. Thus, fields that are aggregated or connected will have a less total boundary length than fields scattered individually. The Boundary Reserve Length is multiplied by the Boundary Length Modifier (user-defined), where a greater value modifier will instruct Marxan to weight connectedness more heavily.

4.3.4.4. Marxan Algorithm

During each run, Marxan starts with an initial reserve network and an initial calculated total cost. Planning units (the MBOM's agricultural fields) are then added and removed through multiple iterations to evaluate and lessen the total cost of the reserve while seeking to achieve all conservation targets.[117,118] Throughout the run, Marxan becomes stricter by only accepting planning unit changes that achieve targets at minimal costs.[118] By performing multiple runs, Marxan calculates the number of times a particular planning unit is chosen, offering the user a potential measure of frequency for each planning unit in the reserve.

4.3.5. *Replenishment Project Suitability Factors and Spatial Data Sources*

In order for the MBOM to recommend networks and various fields for upland and wetland replenishment projects, fields need to be scored according to important conservation factors. A field is defined as the boundary available for a replenishment project. A field can be an individual parcel, multiple parcels aggregated together, or an agricultural field defined by the landowner.

In this model, conservation factors are defined as crucial factors in determining the suitability of a field for either and upland or wetland habitat replenishment project. Conservation factors include habitat suitability, proximity to conserved lands, habitat corridors, replenishment suitability and other factors. Selected conservation factors important for upland habitat replenishment projects are different than the wetland habitat replenishment projects. Upland habitat replenishment projects include conservation factors such as upland species habitat ranges, conservation and protected area proximity, and fallowed water savings. Wetland habitat replenishment projects instead include wetland species habitat ranges, proximity to wetland areas in addition to conservation and protected area proximities, and groundwater replenishment or infiltration suitability.

Using conservation factor spatial layers, the weighted average by area is determined for each field's percent overlap with species ranges, conservation areas, or geologic conditions. Therefore, a score is assigned to each field as the ability of the field to achieve each conservation factor: the greater the score, the greater the suitability for an upland or wetland habitat replenishment project. Calculations for conservation factor scores are different according to the specific conservation factor. Descriptions of scoring decisions are summarized below.

4.3.5.1. Species Habitat Range Scoring

Both the upland habitat model and wetland habitat model include conservation factors for species habitat ranges. For upland habitat, species conservation factors include SJV kit fox and Tipton kangaroo rat (**Figure 12**). The SJV kit fox is a federal and state endangered species that has been identified as an umbrella species for the San Joaquin Valley's upland habitat ecoregion. The requirements of the kit fox have been show to encapsulate the needs of other species.[66] A US Fish and Wildlife generated species boundary map was used to determine which areas provided SJV kit fox Habitat.[119] The Tipton kangaroo rat, both federal and state endangered species, is also argued as focal species shown to play key roles in upland ecosystem structure and composition.[67] A Maxent generated species distribution model that utilized 12 predictor variables was used to determine which areas may provide the most suitable habitat for Tipton kangaroo rats.[112] For wetland species habitat, the Giant garter snake is listed as a federal and state threatened species that depends on wetland ecosystems for species survival, while also being important prey for wetland bird species (**Figure 13**).[68]

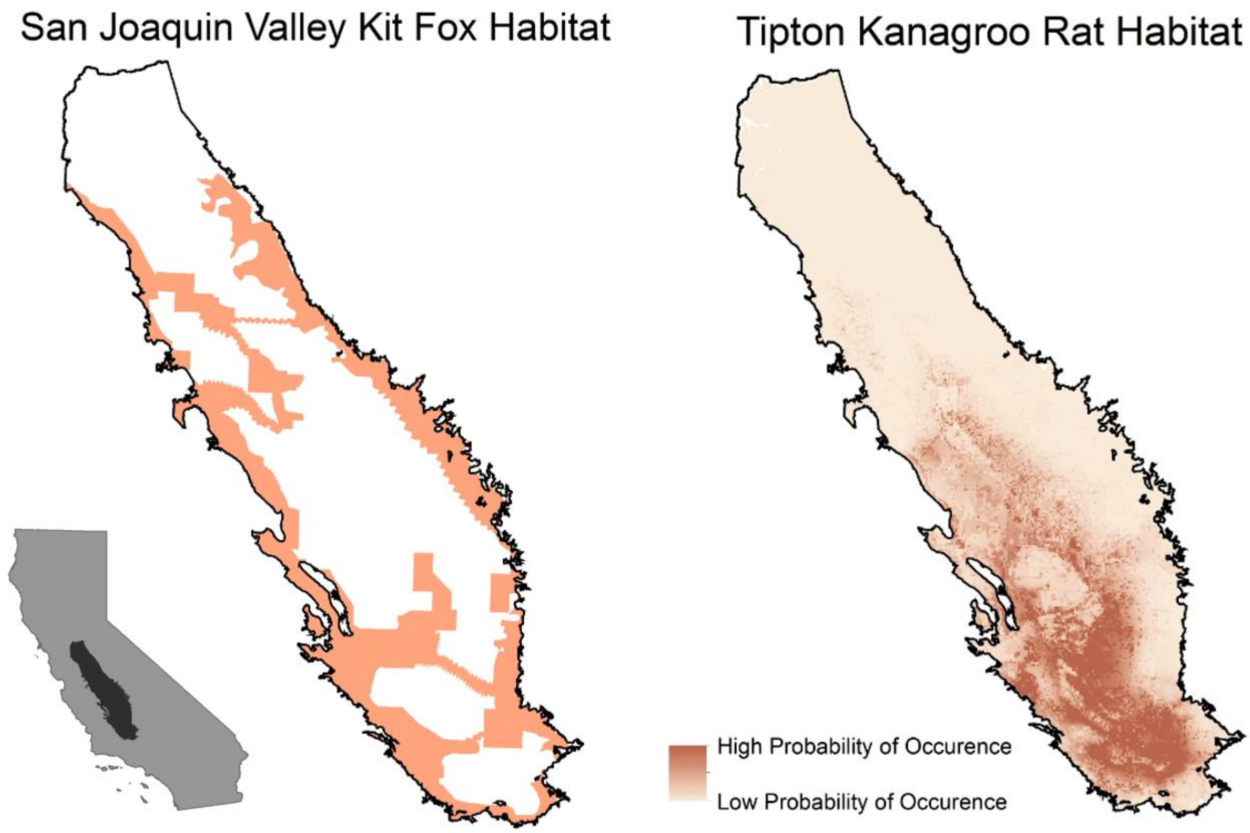


Figure 12: *Species habitat ranges for the San Joaquin Valley kit fox and Tipton kangaroo rat.*

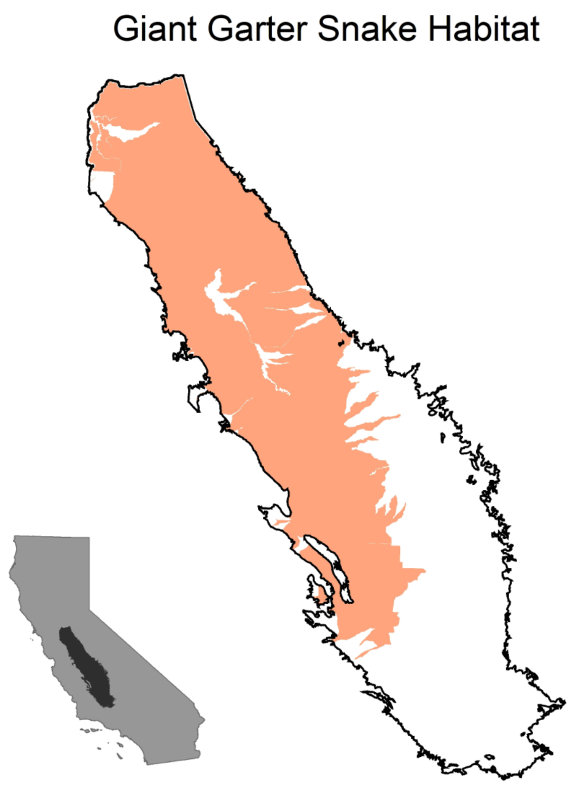


Figure 13: *Giant garter snake species range in the San Joaquin Valley.*

Each agricultural field planning unit was assigned a score equal to the percent of total species range in the San Joaquin Valley in the planning unit. Because spatial data collected on Tipton kangaroo rat designated areas on a scale of low to high probability of occurrence rather than suitable or not suitable habitat, the habitat was transformed into a binary score then normalized from 0-10.

This is a common approach used in Marxan where the area of a given conservation factor in a planning unit (agricultural field in the MBOM) is proportional to the total area of the conservation factor in the network (**Equation 9**).[116,120]

Equation 9: *Species habitat conservation factor score.*

$$Species\ Habitat\ Conservation\ Factor\ Score = \frac{Species\ Habitat\ Area\ in\ Planning\ Unit}{Species\ Habitat\ Area\ in\ San\ Joaquin\ Valley}$$

4.3.5.2. Existing Conservation Areas Scoring

In addition to species habitat ranges, the MBOM considers proximity to existing conserved and protected areas, as well as potential important conservation areas as additional suitability criteria for both upland and wetland habitat replenishment projects.[121]

Spatial data was collected for existing conserved and protected areas from the California Conservation Easement Database (CCED) and the California Protected Area Database (CPAD).[122,123] These two layers were joined with an additional five kilometer buffer assuming five kilometer dispersal distances for upland mammal and wetland bird species are appropriate (**Figure 14**).[124] This allows agricultural fields within close proximity to established wildlife species populations to have a greater score due to the ability for species to migrate to multi-benefit replenishment projects.

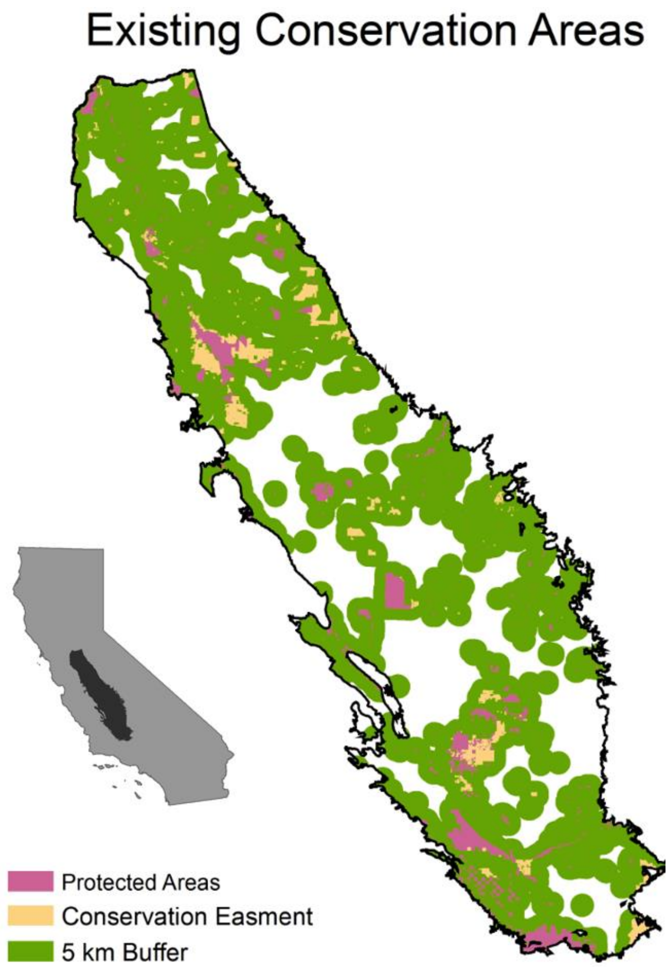


Figure 14: *Existing conservation areas based on conservation easements and protected areas.*

Agricultural fields were scored based on the fraction of the area encompassed in the field relative to the total buffered conservation areas (**Equation 10**).

Equation 10: *Existing conservation area conservation factor score.*

$$Existing\ Conservation\ Area\ Conservation\ Factor\ Score = \frac{Conservation\ Area\ in\ Planning\ Unit}{Conservation\ Area\ in\ San\ Joaquin\ Valley}$$

4.3.5.3. Recommended Conservation Areas

For potential conservation areas or areas recommended for conservation, spatial data was collected from TNC's High Priority Conservation Areas, and San Joaquin Valley essential habitat corridors and connectivity areas for both upland and wetland habitat replenishment projects (**Figure 15**).[125,126] Audubon Important Bird Areas was also included specifically in the wetland habitat model (**Figure 15**).[127] Recommended conservation areas were included in the MBOM in order to leverage existing research performed on the suitability of the areas within the San Joaquin Valley to provide species habitat. This further promotes the holistic and comprehensive approach the MBOM takes in recommending multi-benefit replenishment projects.

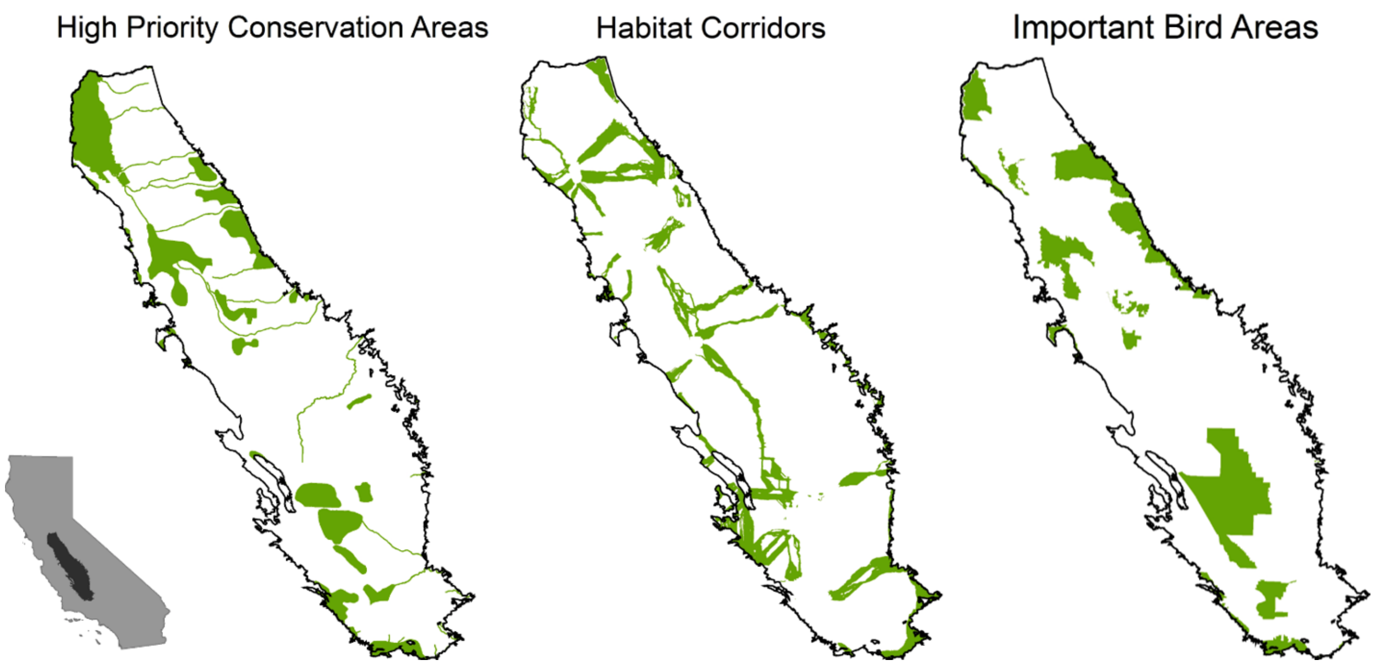


Figure 15: *Conservation areas in San Joaquin Valley.*

For these recommended conservation areas, the same methodology for species habitat range scoring was applied to conservation area scoring (**Equation 11**).[116]

Equation 11: *Recommended conservation area conservation factor score.*

$$\mathit{Recommended\ Conservation\ Area\ Conservation\ Factor\ Score} = \frac{\mathit{Recommended\ Conservation\ Area\ in\ Planning\ Unit}}{\mathit{Recommended\ Conservation\ Area\ in\ San\ Joaquin\ Valley}}$$

4.3.5.4. Proximity to Wetlands

The proximity to existing wetland areas was also considered an important suitability factor for the development of a wetland habitat replenishment project. In the recommended conservation areas above, many areas of existing wetlands were not considered. In mapping out the existing wetlands and the areas proximate to existing wetlands, the areas suitable for replenishment projects were different enough to include another suitability factor for proximity to existing wetlands. This ensures that all existing wetland areas in the San Joaquin Valley and specifically in Kern County, were included in the analysis. Spatial data was collected from California Department of Fish and Wildlife Vegetation Classification and Mapping Program's wetland areas (**Figure 16**).[128]

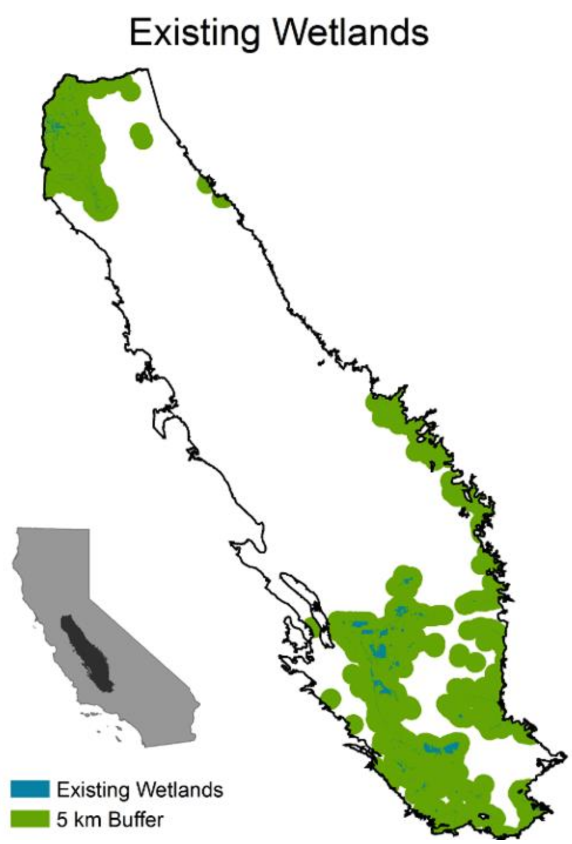


Figure 16: *Proximity to existing wetlands with 5-kilometer buffer.*

A five kilometer buffer was applied around all existing wetland areas equal to the dispersal distance applied to conservation easement and protected areas.[124] A buffer was applied to existing habitat areas due to the existing populations of endangered and wildlife species. Agricultural fields within the buffered distance of existing habitat areas allow for the potential for species to migrate into new habitat restoration areas. Therefore, a buffer was not applied to recommended conservation areas as these are “recommended areas” not yet populated by wildlife species that could migrate to newly restored habitat areas. The conservation factor score for proximity to existing wetlands was calculated based on how much the of the total five kilometer buffer area was encompassed in the given agricultural field (**Equation 12**).[129]

Equation 12: *Proximity to wetlands conservation factor score.*

$$Proximity\ to\ Wetlands\ Conservtaion\ Factor\ Score = \frac{Proximate\ Wetland\ Area\ in\ Planning\ Unit}{Proximate\ Wetland\ Area\ in\ San\ Joaquin\ Valley}$$

4.3.5.5. Groundwater Characteristics

Agricultural fields under consideration for wetland habitat replenishment projects are also determined based the field’s suitability for groundwater replenishment. Specifically, the MBOM considers replenishment capacity, existing groundwater nitrate concentrations, and depth to shallow groundwater as important criteria for replenishment projects. Each conservation factor scoring method is specific to each of these groundwater condition criteria described below.

First, spatial data for replenishment capacity was collected from the UC Davis’ Soil Agricultural Groundwater Banking Index (SAGBI), which identifies the deep percolation rate, the root zone residence time, surface-soil condition (erodibility), chemical limitations (electrical conductivity), and topography factors for areas for California, each based on scores 0 to 100 (most suitable).[110] The average weighted SAGBI score for each agricultural field was calculated and assigned to each field. However, the SAGBI scores are based on a scale of replenishment suitability, not wetland habitat suitability. In order to score an agricultural field based on maintaining a wetland habitat, only agricultural fields with average deep percolations scores and average root zone residence scores less than 35 and greater than 85 were excluded to eliminate sites with poor or excellent percolation (**Figure 17**). Excellent percolation is optimal for traditional recharge ponds, but would not allow for watered wetland habitat at the soil surface.[130]

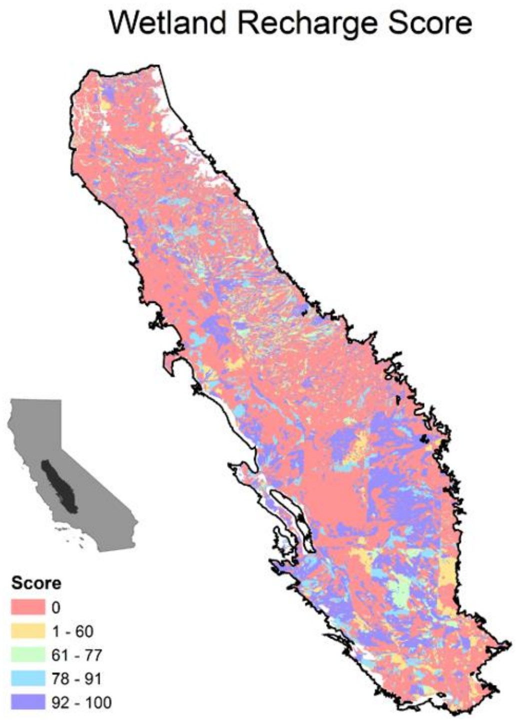


Figure 17: *Suitability scores according to moderate deep percolation rates and moderate root residence zone times.*[110]

Second, interpolated spatial data was collected for groundwater nitrate contamination levels in the San Joaquin Valley from UC Davis' Center for Watershed Science 2017 Nitrate Study.[131] Groundwater nitrate data was collected by the DWR Groundwater Ambient Monitoring and Assessment Program.[131] Nitrate concentrations in the San Joaquin Valley are highly variable both spatially and temporally, and can take one to several decades to reach nearby domestic drinking water wells.[131] Nitrate data interpolated from the complete dataset (111 years) versus the data from the most recent ten years showed little difference in San Joaquin Valley nitrate concentrations (**Figure 18**). Therefore, the MBOM used all nitrate data available from the UC Davis nitrate study. The MBOM excluded agricultural fields with groundwater nitrate levels greater than 45 mg/L, equal to the EPA's Maximum Contaminant Level for drinking water.[132] Nitrate concentration data and further information as to why the MBOM conservatively excluded areas of high nitrate concentrations can be found in Appendix 5 – Groundwater Nitrate Pollution and Replenishment.

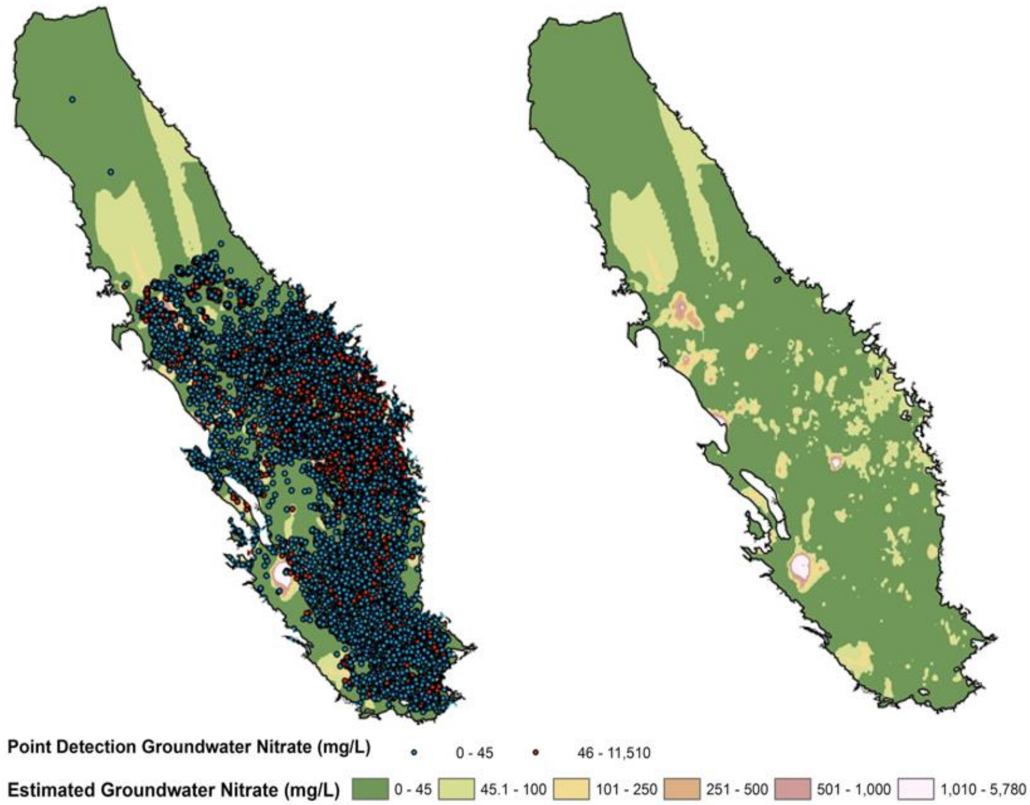


Figure 18: *Interpolated groundwater nitrate contamination concentrations.*

Third, depth to shallow groundwater spatial data was collected from the DWR San Joaquin Valley Agricultural Drainage Program.[133] The San Joaquin Valley Drainage Program interpolated 2010-2012 shallow groundwater elevation data and identified areas between 0-20 feet of groundwater below the ground surface as problem areas for agricultural drainage.[134] The MBOM excludes fields where groundwater levels were less than 20 feet per the San Joaquin Valley Agricultural Drainage Program problem area designation (**Figure 19**). Problem areas, defined by the Agricultural Drainage Program, are located in areas of semi-confined aquifers indicative of shallow aquifer levels and drainage-related problems, like salt accumulation.[133] Because there are significant unmonitored areas with no data, the DWR well completion reports were pulled for areas of Kern County to determine groundwater levels reported when wells were drilled.[135] In the unmonitored areas of eastern Kern County, wells drilled between years 2012-2017 had an average groundwater elevation depth of 279 feet. Ninety-percent of wells reported groundwater levels deeper than 51 feet below the ground surface. Similarly, the average groundwater well level between 2012-2017 in western Kern County was 139 feet with 90% of levels being deeper than 75 feet below the ground surface. Therefore, the MBOM assumes that the San Joaquin Valley Drainage Program data accurately reflects areas of historically shallow depth to groundwater levels.

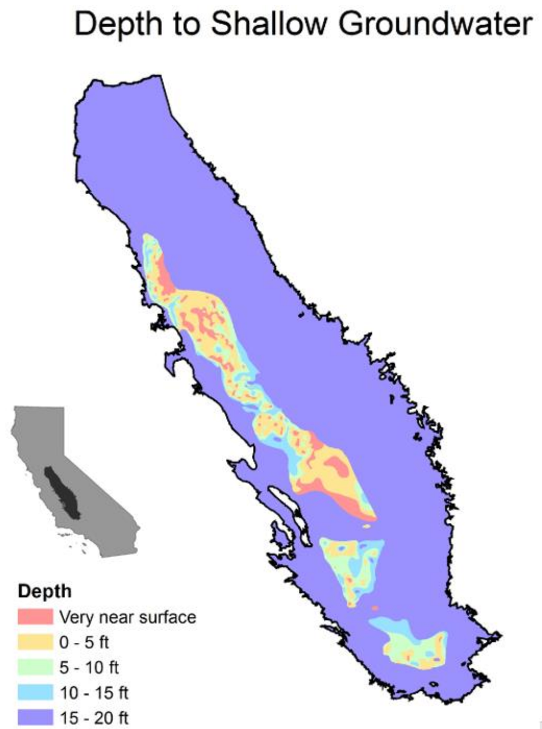


Figure 19: *Interpolated depth to shallow groundwater in the San Joaquin Valley.*

For the area of analysis (Kern County within the San Joaquin Valley), approximately 8,000 agricultural fields were excluded for potential wetland replenishment projects due to unsuitable groundwater conditions described above (**Figure 20**). Excluded fields were being primarily driven by wetland suitability exclusions (3,000 fields) versus nitrate contamination (108 fields).

Due to the number of excluded agricultural fields for wetland replenishment projects, a baseline MBOM run was performed to only exclude fields with depth to shallow groundwater (less than 20 feet) and poor replenishment suitability scores (less than 35). The relaxed changes of no longer excluding SAGBI poor and excellent replenishment fields and nitrates allowed for an additional 3,000 agricultural fields suitable for traditional recharge pond installment. Agricultural fields with underlying groundwater nitrate contamination were included in the baseline, adding 108 additional high-nitrate fields. Additionally, the wetland replenishment baseline run did not optimize for habitat creation due to the relaxed standards for suitable wetland habitat. The wetland baseline run, therefore, provides the total reserve cost for agricultural fields to achieve groundwater savings targets.

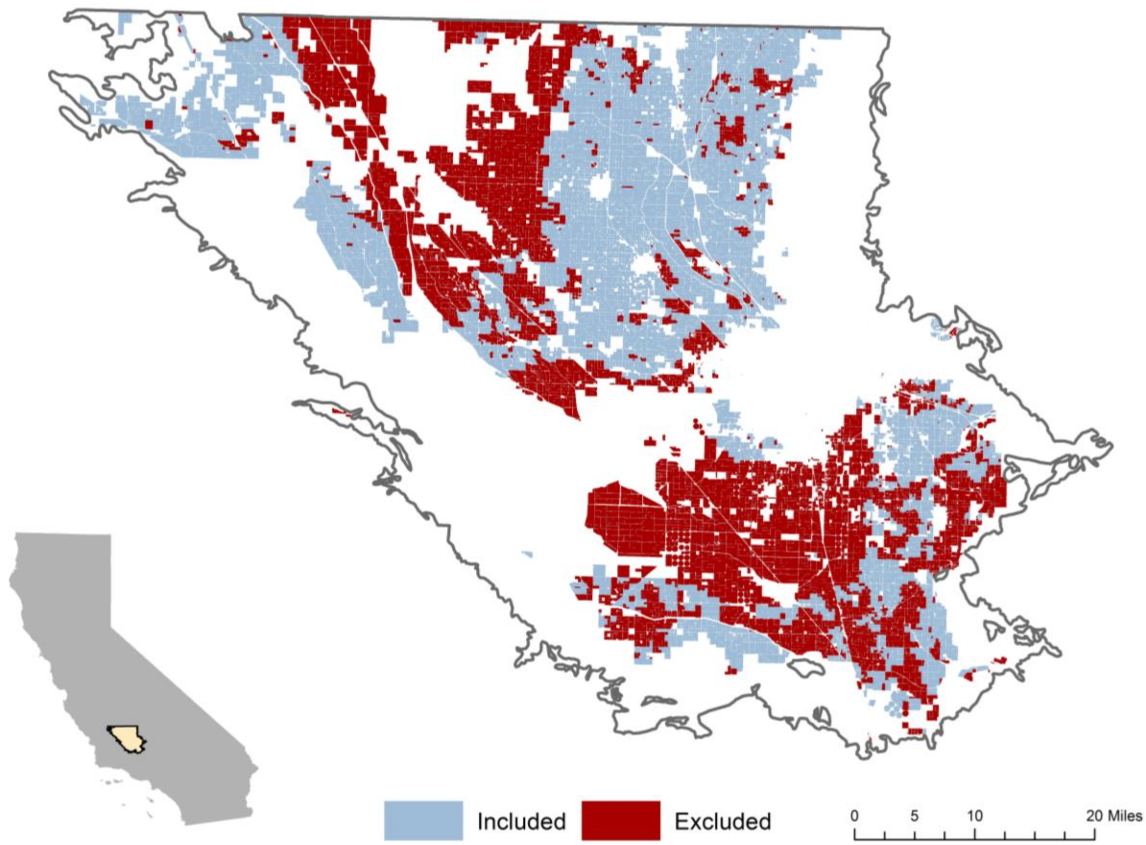


Figure 20: *Agricultural fields excluded based on groundwater characteristics, including depth to shallow groundwater, nitrate contamination, and Soil Agricultural Groundwater Banking Index scores.*

A similar baseline MBOM run was performed for upland habitat replenishment projects that excluded optimization for achieving habitat creation targets. This determined the difference in total reserve cost when not optimizing reserves to meet habitat conservation targets, and rather to only meet groundwater savings goals at the least cost.

4.3.5.6. Water Savings

Conservation factors are also designed according to the suitability of the field to either save water from foregone irrigation or ability to infiltrate water. For upland habitat replenishment projects, water savings is a function of the foregone crop irrigation demand, i.e., the water saved from no longer watering agriculture. DWR collects irrigation consumption data by crop and by county.[136] The total crop water demand per field was calculated for all agricultural fields according to crop type (**Figure 21**).

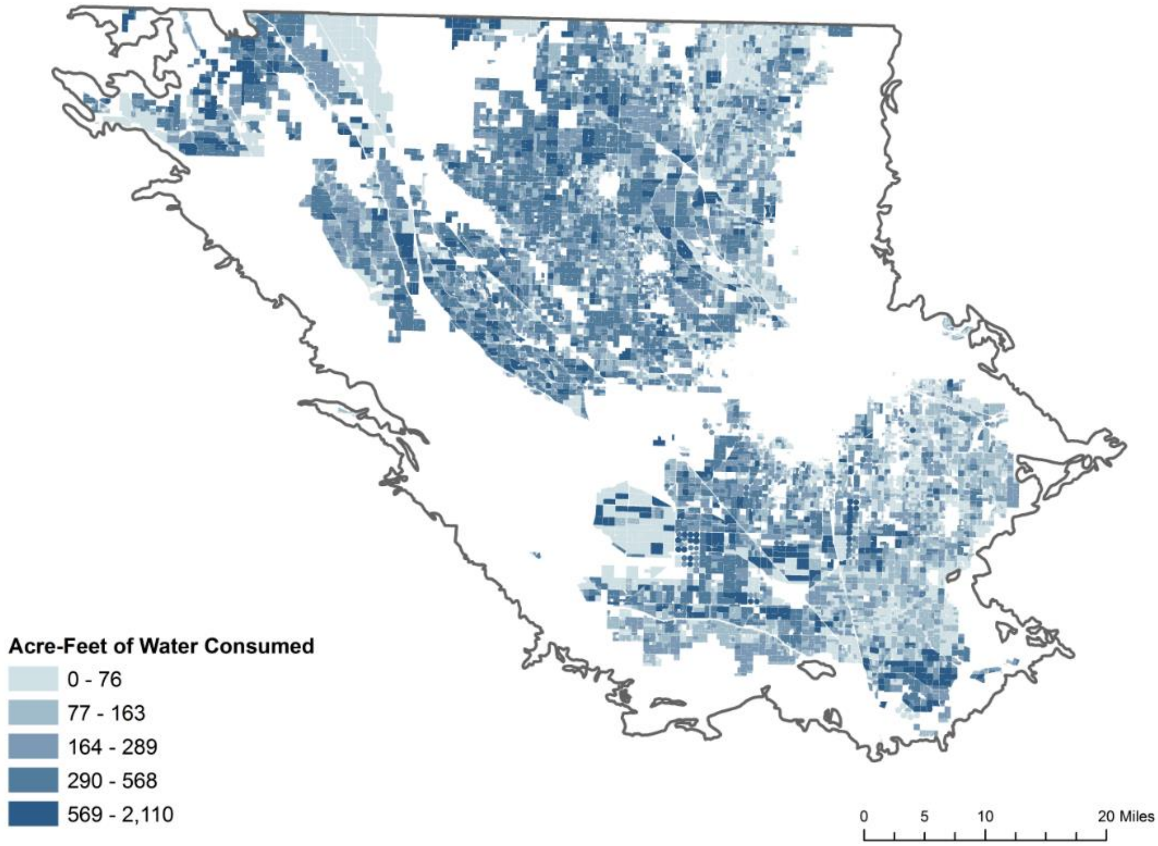


Figure 21: *Average annual water demand by agricultural field.*

Applied water data was collected as the total AF of applied water for a given crop. Upland habitat project water savings is calculated as the field's crop applied irrigation water demand multiplied by the acreage of the field (**Equation 13**).

Equation 13: *Upland habitat replenishment project water savings.*

$$\begin{aligned} &Upland\ Habitat\ Replenishment\ Project\ Water\ Savings \\ &\qquad = Crop\ Applied\ Irrigation\ Water\ \times\ Field\ Acreage \end{aligned}$$

This calculation therefore assumes retirement of the entire field and that each field was being irrigated with groundwater, translating water savings to groundwater use savings. For idle farmland, the water savings is assumed to be zero. Historically idle farmland analysis found that 50% of fields fallowed in the spatial data had been fallowed the year before, supporting the assumption that the field was not being rotated. If in the future the MBOM were to account for watering savings from spatially identified idle fields, it is recommended that the last grown crop on the field be identified and subsequently assigned the crop's applied water demand in case the field was being rotated when identified as "idle."

For a wetland habitat replenishment project, the potential water savings for a given agricultural field is a function of the groundwater replenishment rate. In MBOM, replenishment rates were a function of the SAGBI spatial data on deep percolation rates. For the model, a wet period of two months was calculated with a 95% efficiency of replenishment. A 5% leave behind rate (or inefficiency rate) is the leave-behind rate for the Kern Water Bank, operating in Kern County based on operational experience and observed efficiencies of the recharge ponds.[129] For each field, the volume of water replenished over a two-month time period was calculated according to the deep percolation rate (mm/hour, hydraulic conductivity, **Equation 14**).

Equation 14: *Wetland habitat replenishment project water savings.*

$$Wetland\ Habitat\ Replenishment\ Project\ Water\ Savings = Deep\ Percolation\ Rate\ \times Field\ Area\ \times\ Two\ Months\ \times (1 - Leave\ Behind\ Rate)$$

Upland habitat replenishment project conservation factors and associated scoring criteria are summarized in **Table 16**. Wetland habitat replenishment project conservation factors and scoring criteria are summarized in **Table 17**.

4.3.5.7. Summary Table of Conservation Factors

Table 16: *Upland habitat conservation factors and scoring criteria summary.*

Factor	Description	Score Criteria	Source
SJV Kit Fox Habitat	Land identified as target SJV kit fox habitat	Score 0-100 equal to percentage of total San Joaquin Valley species range encompassed in the field.	US Fish and Wildlife, Joni Mitchel 2007.
Tipton Kangaroo Rat Habitat	Areas determined as potential habitat for the Tipton kangaroo rat	Score 0-100 equal to percentage of total San Joaquin Valley species range encompassed in the field.	UCSB Bren School San Joaquin Valley Landscape-Scale Planning for Solar Energy and Conservation (2015)[112]
High Priority Conservation Areas	Areas of biodiversity significance and priority conservation action	Score 0-100 equal to percentage of total High Priority Conservation Areas encompassed in the field.	The Nature Conservancy (TNC)[125]
Habitat Corridors	Areas for conservation that would enhance ecological networks	Score 0-100 equal to percentage of total Habitat Corridor areas encompassed in the field.	Huber et.al. (2012)[137]
Conservation Easements	Conservation easement records from land trusts and public agencies	Score 0-100 equal to percentage of total buffered conservation easements encompassed in the field.	California Conservation Easement Database (CCED)[122]
Protected Areas	Protected lands including federal, state, local, and private lands	Protected areas were spatially joined with Conservation Easements.	California Protected Areas Database (CPAD)[123]
Water Savings	Applied Irrigation Water demand (AFY) by county by crop per acre	Total AF of applied water per year.	California Department of Water Resources (CADWR)[71]

Table 17: *Wetland habitat conservation factors and scoring criteria summary.*

Factor	Description	Score Criteria	Source
Soil Agricultural Groundwater Banking Index (SAGBI)	Suitability index for groundwater replenishment on agricultural land where each factor is scored 0-100.	Areas with poor and excellent deep percolation and root zone residence scores are excluded from consideration (<35, >85).	UC Davis Soil Resource Lab[110]
Nitrate Groundwater Quality	Estimated nitrate levels based on interpolation	Areas with groundwater nitrate levels greater than 45 mg/L are excluded.	UC Davis Center For Watershed Science Nitrate Study (2017)[131]
Depth to Groundwater	Depth to shallow groundwater interpolated data for 2010, 2011, and 2012	Areas with groundwater depth less than 20 feet below surface are excluded.	California Department of Water Resources (CADWR) San Joaquin Valley Agricultural Drainage Program[133]
Giant Garter Snake Habitat	Potential habitat of snake species	Score 0-100 equal to percentage of total San Joaquin Valley species range encompassed in the field.	US Geological Survey Gap Analysis[138]
Habitat Corridors	Conservation areas that would enhance ecological networks	Score 0-100 equal to percentage of total Habitat Corridor areas encompassed in the field.	Huber et.al. (2012)
Proximity to Wetlands	Vernal pools, riparian areas, saline and palustrine wetland area	Score 0-100 based on the percentage of potential wetland areas encompassed in the field.	California Department of Fish and Wildlife (CDFW)[139]
Important Bird Areas	Critical terrestrial and inland water habitat that supports rare, threatened or endangered birds, and/or exceptionally large concentrations of shorebirds and waterfowl	Score 0-100 based on the percentage of total Important Bird Area encompassed in the field.	Audubon California[127]

High Priority Conservation Areas	Areas of biodiversity significance with to be prioritized for conservation	Score 0-100 equal to percentage of total High Priority Conservation Areas encompassed in the field.	The Nature Conservancy (TNC)[125]
Conservation Easements	Conservation easement records from land trusts and public agencies	Score 0-100 equal to percentage of total buffered conservation easements encompassed in the field.	California Conservation Easement Database (CCED)[122]
Protected Areas	Protected fee lands in the United States, including federal, state, local, and private lands	Protected areas were spatially joined with Conservation Easements.	California Protected Areas Database (CPAD)[123]
Water Savings	Deep percolation rate, SAGBI	Score equal to two months of deep percolation replenishment with a 10% leave-behind rate.	UC Davis, SAGBI Deep Percolation Layer[110]

4.3.6. *Cost Valuation*

To comprehensively select agricultural fields for multi-benefit replenishment projects, the relative value of fields needs to be taken into consideration. The value of each field was calculated as the one-year foregone crop revenue according to crop type. Specifically, planning unit costs were determined through creating a crop name crosswalk between the USDA and Kern County, calculating total annual crop revenue, accounting for crop rotation, and calculating the value of open farmland.

4.3.6.1. Crop Crosswalk Methodology

The spatial crop layer built by LandIQ has 41 unique crop name categories across the San Joaquin Valley counties, 40 of which are also grown within Kern County (rice excluded). To assign dollar values to the spatial data, crop value data was obtained from the USDA NASS. This data, however, records crop statistics against 69 unique crop name categories in Kern County, many of which are not direct matches the LandIQ crop categories. LandIQ, for instance, displays spatial data for “Avocados,” but “Avocados” are not a category in USDA NASS’s dataset. LandIQ also has a category for “Melons, Squash, and Cucumbers,” yet the USDA NASS reports statistics in separate categories for “Cucumbers,” “Melons Cantaloupe,” “Melons Honeydew,” “Melons Watermelon,” “Melons Unspecified,” and “Squash.”

A crosswalk was developed to match the applicable USDA NASS crop categories to the spatial crop categories by LandIQ. If future work will scale this analysis to a San Joaquin Valley scale, the crosswalk should be revisited and potentially revised to ensure that all applicable USDA NASS crop categories are accounted for in the per acre crop values across the Valley.

4.3.6.2. Annual Crop Revenue

Costs were calculated in terms of a total foregone crop revenue for a one-year period according to 2016 revenue data. Revenue data was collected from the USDA NASS Pacific Regional Field Office.[63] NASS publishes an annual dataset that aggregates all of the annual crop reports compiled by the California County Agricultural Commissioners. This analysis uses the “2016 County Ag Commissioner’s Data Listing,” which is the latest published dataset on the NASS website.

NASS’s dataset of aggregated county data includes crop name, total value, harvested acreage, total production, and unit price (for tons, pounds, dozen, cubic weight, etc., depending on the crop type).[63] To obtain an acre value for each commodity by county, “Total Value” was divided by “Harvested Acres” as a way to analyze the cost to replace agriculture with benefit replenishment projects. This cost methodology also assumes that the crop’s yield by acre is constant across fields. The crosswalk was used to match NASS per acre crop values with the LandIQ spatial layer. Weighted averages of crop values were determined where one LandIQ crop category matched to several NASS crop categories (e.g. LandIQ’s “Grapes” category matches to USDA NASS’s “Grapes Raisin,” “Grapes Table,” and “Grapes Wine” categories).

Because a portion of the crop values were also derived from the 2016 Kern County Agricultural Crop Report (in PDF format) due to USDA data gaps, a weighted average approach of revenue data was not readily possible for all crops.[140] The NASS data over the past several years requires cleaning because it lacks certain data on sale value for many years. A comprehensive weighted average approach should be performed but requires an additional literature review on how to appropriately weight recently harvested sales against prior years’ sales.

The annual crop revenue method does not account for the value of open or idle fields, and underestimates fields that typically undergo multiple crop rotations. Methods for accounting for crop rotations and idle fields are further described below.

4.3.6.3. Accounting for Crop Rotation Value

Agricultural field spatial data (collected from LandIQ) shows only a snapshot of the crops being grown in 2014. The spatial data therefore does not account for crop rotation and undervalues the lost revenue for annual crops being rotated with other crops. Annual crops are typically rotated more than once per year.[141–144] Annual crops are defined as the crops produced and cultivated within a year, unlike perennial crops, which are planted but are harvested potentially each year for many years until the perennial crop is aged out. Annual crops are vegetable or row crops, whereas perennial crops are typically orchard, tree and vineyard crops. Crop rotations refer to when annual crops are produced, cultivated and then replaced with a different, complimentary crop. The most common rotated crops in the San Joaquin Valley include: alfalfa, barley, carrots, corn, cotton, garbanzo beans, garlic, lettuce, melons, onions, potatoes, safflower, sugar beets, tomatoes, and wheat.[141–144] In order to account for additional revenue from crop rotations (rather than a year's revenue from a single crop), the revenue of annual crops (temporary and/or row crops) were multiplied by the average number of rotations based on Kern County specific spatial analysis. This method was also validated by the Kern County Agricultural Commissioner's office. Accounting for the value of fields that undergo crop rotations is important in that rotations add value to the field. Only accounting for one crop would undervalue the cost of the field, and therefore would be more frequently selected by MBOM to minimize the total cost of the recommended reserve. Accounting for crop rotational value more accurately depicts the annual revenue and value of fields, which in turn allows the fields to be more competitive with higher revenue fields for MBOM selection.

To calculate the average number of crop rotations, an analysis was performed on the number of crop rotations for all agricultural fields in Kern County according to the 2016 Kern County Agricultural Commissioner spatial dataset.[140] To determine the number of crop rotations per field, spatial data was processed in GIS by assigning centroids to each field ID per the Kern County "multiples" recommendation. The 2016 data indicates the number of plantings per year for each field is two, with some leafy green crops being greater than five. Thus in MBOM, revenues were doubled for all annual crops.

It is important to note that crop rotations were already accounted for in the applied water by crop per acre.[71] Therefore, applied water was not adjusted for annual crops.

4.3.6.4. Value of Open/Idle Farmland

The MBOM also includes open farmland or idle fields as potential replenishment project sites. Open farmland fields were included in the LandIQ spatial data.[115] In Kern County, idle fields ranked third in total acreage, accounting for almost 97,000 total acres or 13% of total agricultural area considered.[140] Because there is no crop revenue for an idle agricultural field, the MBOM accounted for the cost value of open farmland by comparing surrounding agricultural field cost values. The median value of approximate fields (1 km) was assigned to each idle field. Kern County's median open farmland value was $6,818. Idle fields not approximate to fields in production were assigned the calculated median value of all other idle fields in Kern County.

4.3.7. *Marxan Analysis and Setting Determination*

Marxan requires the setting of conservation targets for each conservation factor, as well as each conservation factor's penalty for not achieving conservation targets. Marxan also includes a setting for reserve connectivity or fragmentation, and a number of simulation runs Marxan will perform to find the near optimal reserve outcome.

4.3.7.1. Conservation Target Setting

Marxan requires conservation targets for each conservation factor. Marxan aim to generate a least cost reserve that also achieves all conservation targets. The objective for MBOM is to achieve groundwater savings (replenish groundwater), create habitat, while also minimizing costs. The Conservation Target setting for water savings was set as the estimated proportion of the San Joaquin Valley's water use that relies on groundwater overdraft, which from year 2000 to 2016 was equal to 15%.[1]

For habitat focused conservation targets, three levels were set: baseline, low, and high. The baseline conservation target was set at 20% for the least represented endangered species in Kern County: the San Joaquin Valley kit fox for upland habitat and the giant garter snake for wetland habitat. The rest of the conservation targets were scaled to either a similar acreage or percentage target according to the following equation (**Equation 15**):

Equation 15: *Conservation target scaling.*

$$T_{CF} = \frac{\max\left(T_{End} \cdot S_{CF}, \sqrt{\frac{S_{CF}}{S_{End}}} \cdot (T_{End} \cdot S_{End})\right)}{S_{CF}}$$

Where:

- T_{CF}: is the target of the conservation factor as a percentage,
- T_{End}: target as percentage for the least represented endangered species in the zone under study,
- S_{End} is the total surface of the endangered species in the zone under study and,
- S_{CF}: is the total surface of the conservation factor in the zone under study.

Under the "low level" conservation targets were set to 10% for the least represented endangered species range within the county and high conservation targets were set as 30% of the least represented species rage within the county. However, a "high level" 30% target was not set for wetland habitat due to the constraints on available giant garter snake habitat and the inability of the model to achieve habitat targets greater than 20%. Targets for other conservation targets were then scaled according to **Equation 15**.

Table 18: *Upland habitat conservation targets: baseline, low and high target settings.*

Conservation Factors	Total SJV	Fraction in Kern County	Baseline Conservation Target	Low Conservation Target	High Conservation Target
	(acres)	(% of SJV) (acres)	(% of Kern) (acres)	(% of Kern) (acres)	(% of Kern) (acres)
SJV Kit Fox	4,860,306	4.8%	20%	10%	30%
		231,312	45,142	22,571	67,713
Tipton Kangaroo Rat	11,394,521	2.5%	20%	10%	30%
		280,902	55,025	24,920	82,538
TNC Areas	1,561,003	4.4%	37%	18%	55%
		68,258	24,649	12,324	36,973
Habitat Corridors	1,365,694	4.8%	37%	19%	56%
		65,435	24,121	12,060	36,181
Conservation Areas	7,255,837	8.1%	20%	10%	30%
		586,411	114,739	57,369	172,108
Water Savings (AF)	NA	NA	15%	15%	15%
			426,670	426,670	426,670

Table 19: *Wetland habitat conservation targets: baseline and low target settings.*

Conservation Factors	Total SJV	Fraction in Kern County	Baseline Conservation Target	Low Conservation Target
	(acres)	(%) (acres)	(% of Kern) (acres)	(% of Kern) (acres)
Giant Garter Snake	4,766,706	2%	20%	10%
		86,332	16,909	8,455
TNC Areas	1,561,003	4.4%	22%	11%
		68,258	15,086	7,543
Habitat Corridors	1,365,694	4.8%	23%	11%
		65,435	14,763	7,381
Conservation Areas	7,255,837	8.1%	20%	10%
		586,411	113,739	57,369
Important Bird Areas	1,442,776	8.8%	20%	10%
		126,271	24,810	12,405
Proximity to Wetlands	3,087,263	16.1%	20%	10%
		496,566	93,372	48,686
Water Savings (AF)	NA	NA	0.51%	0.51%
		83,301,390	426,670	426,670

Cost is implicit in Marxan and therefore does not have a conservation target as Marxan operates to minimize the total reserve cost.

Sensitivity analysis was performed on the low, baseline, and high conservation targets for the upland and wetland MBOM to determine the appropriate target setting for Kern County. Under the upland habitat replenishment MBOM, a similar cost per acre was achieved across low, baseline, and high conservation target settings (**Figure 22**). Thus, the baseline target setting was selected for upland habitat replenishment projects due to similar costs between target settings.

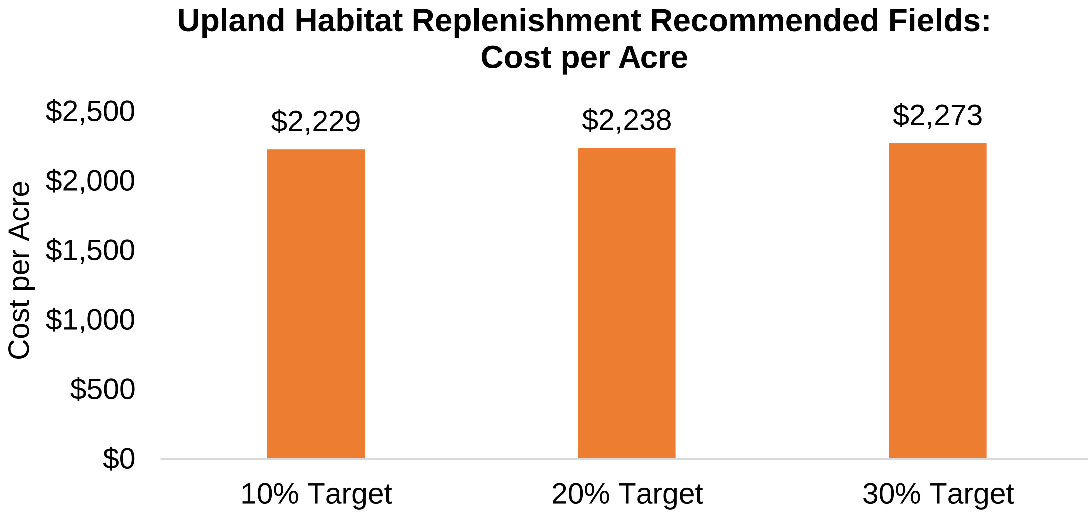


Figure 22: *Sensitivity analysis on conservation target settings for upland habitat replenishment projects by cost per acre.*

For the wetland habitat replenishment project MBOMB, sensitivity analysis performed between the low and baseline conservation target settings revealed a similar cost per acre (**Figure 23**). Therefore, a baseline target setting of 20% was also selected for the wetland habitat replenishment MBOM.

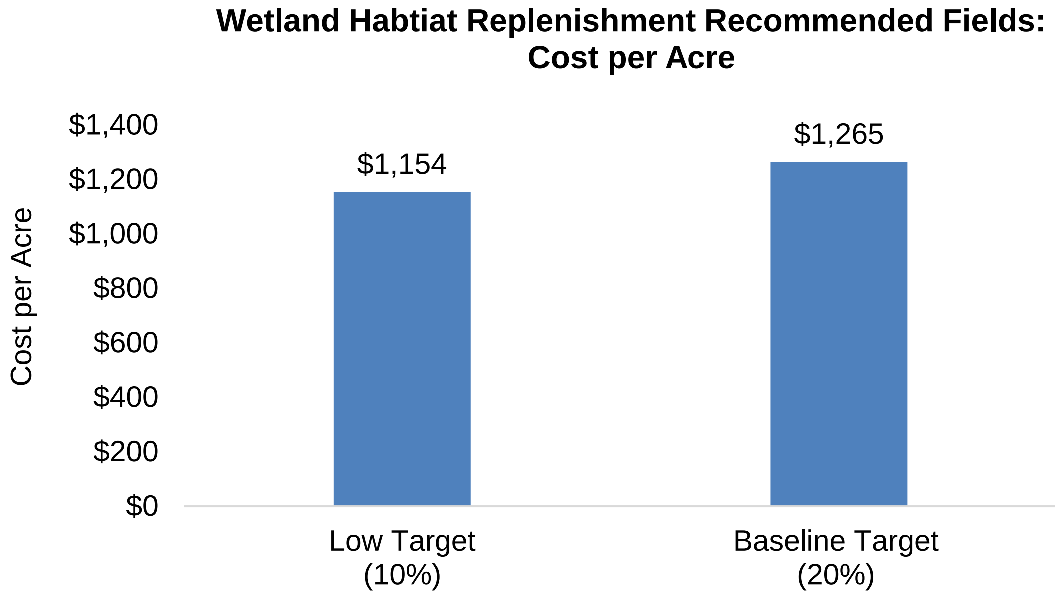


Figure 23: *Sensitivity analysis on conservation target settings for wetland habitat replenishment projects by cost per acre.*

4.3.7.2. Penalty Setting

In addition to setting conservation targets, Marxan also requires the setting of penalty factors by the user. Penalty factors inform Marxan on the relative importance of achieving different conservation targets. The penalty value is multiplied by how much the planning unit misses achieving a conservation target. Per common Marxan methods, penalties in MBOM were greater for endangered species and less for potential conservation areas. The weight for threatened and endangered species conservation factors was three times greater than other conservation factors (**Table 20**).

Table 20: *Penalty importance weighting.*

Conservation Factor	Importance
SJV Kit Fox	3
Tipton Kangaroo Rat	3
Giant Garter Snake	3
Important Bird Areas	2
TNC Conservation Areas	1
Habitat Corridors	1
Conservation Easements and Protected Areas	1

Penalties assigned to conservation targets were also a function of the relative priority of achieving water savings versus habitat creation. This approach was created in order to help future users of the MBOM more easily determine the appropriate penalties to assign when different types of conservation factors are considered, in this case water and habitat ones (**Table 21**).

Table 21: *Marxan run scenarios based on user-defined priorities between water, habitat, and cost.*

	User Defined Priorities		
Scenario	**Water**	**Habitat**	**Cost**
1. Equal Priority	0.50	0.50	1.00
2. Water Priority	0.75	0.25	1.00
3. Habitat Priority	0.25	0.75	1.00

Three scenarios represent how a user may be either indifferent to achieving water versus habitat or may alternatively prioritize water savings rather than habitat creation. These specific priorities were chosen as example analyses to illustrate how the reserve may change when prioritizing between habitat and water savings, with cost held constant. These decisions were also tested out on a Kern County Agricultural Producer who preferred an MBOM analysis that prioritized cost first, water second, and habitat third according to the “Water Priority” scenario above.

Once these priorities are determined, the final penalties are calculated and assigned as follows (**Equation 16**).

Equation 16: *Conservation Factor Penalty.*

$$Penalty_{CF,k} = \frac{P_k}{\sum_k P_k} \times \frac{I_{CF,k}}{\sum_{CF} I_{CF,k}}$$

Where P_k *is the priority of the factor* k; k *is either Water or Habitat; CF is each conservation factor of the* k *category, and* $I_{CF,k}$ *is the importance of each conservation factor of the* k *category. This is further detailed in the tables below for each scenario in both the upland and wetland MBOM according to three different run scenarios (**Table 22** &*

Table 23).

Table 22: *Upland habitat replenishment conservation factor penalties relative to importance to the landowner (Imp.).*

	Scenario: Equal Priority Water = Habitat			**Scenario: Water Priority** Water > Habitat			**Scenario: Habitat Priority** Habitat > Water		
Conservation Factor	**Priority**	**Imp.**	**Penalty**	**Priority**	**Imp.**	**Penalty**	**Priority**	**Imp.**	**Penalty**
SJV Kit Fox	0.5	3	0.17	0.25	3	0.08	0.75	3	0.25
Tipton Kangaroo Rat	0.5	3	0.17	0.25	3	0.08	0.75	3	0.25
TNC Priority Areas	0.5	1	0.06	0.25	1	0.03	0.75	1	0.08
Habitat Corridors	0.5	1	0.06	0.25	1	0.03	0.75	1	0.08
Conservation Areas	0.5	1	0.06	0.25	1	0.03	0.75	1	0.08
Habitat Sum:	**-**	**-**	**0.5**	**-**	**-**	**0.25**	**-**	**-**	**0.75**
Water Savings	0.5	1	0.5	0.75	1	0.75	0.25	1	0.25
Water Sum:	**-**	**-**	**0.5**	**-**	**-**	**0.75**	**-**	**-**	**0.25**

Table 23: *Wetland habitat replenishment conservation factor penalties relative to importance to the landowner (Imp.).*

	Scenario: Equal Priority Water = Habitat			**Scenario: Water Priority** Water > Habitat			**Scenario: Habitat Priority** Habitat > Water		
Conservation Factor	**Priority**	**Imp.**	**Penalty**	**Priority**	**Imp.**	**Penalty**	**Priority**	**Imp.**	**Penalty**
Giant Garter Snake	0.5	3	0.17	0.25	3	0.08	0.75	3	0.25
TNC Priority Areas	0.5	1	0.06	0.25	1	0.03	0.75	1	0.08
Habitat Corridors	0.5	1	0.06	0.25	1	0.03	0.75	1	0.08
Conservation Areas	0.5	1	0.06	0.25	1	0.03	0.75	1	0.08
Important Bird Areas	0.5	2	0.11	0.25	2	0.06	0.75	2	0.17
Proximity to Wetlands	0.5	1	0.06	0.25	1	0.03	0.75	1	0.08
Habitat Sum:	-	-	*0.5*	-	-	*0.25*	-	-	*0.75*
Water Savings	0.5	1	0.5	0.75	1	0.75	0.25	1	0.25
Water Sum:	-	-	*0.5*	-	-	*0.75*	-	-	*0.25*

Final conservation targets and penalties were selected based on robustness testing previously shown and according to four different habitat-water scenarios (**Table 24** & **Table 25**).

Table 24: *Upland habitat Marxan setting summary.*

	Water Savings Habitat = 0		Water Priority Water > Habitat		Equal Priority Water = Habitat		Habitat Priority Water < Habitat	
	Target	Penalty	Target	Penalty	Target	Penalty	Target	Penalty
SJV Kit Fox	-	-	20%	0.08	20%	0.17	20%	0.25
Tipton kangaroo rat	-	-	20%	0.03	20%	0.17	20%	0.08
TNC Priority Areas	-	-	37%	0.03	37%	0.06	37%	0.08
Habitat Corridors	-	-	37%	0.03	37%	0.06	37%	0.08
Conservation Areas	-	-	20%	0.06	20%	0.06	20%	0.17
Water Savings	15%	0.75	15%	0.75	15%	0.5	15%	0.25

Table 25: *Wetland habitat Marxan setting summary.*

	Equal Priority Water = Habitat		Water Priority Water > Habitat		Equal Priority Water = Habitat		Habitat Priority Water < Habitat	
	Target	Penalty	Target	Penalty	Target	Penalty	Target	Penalty
Giant Garter Snake	-	-	20%	0.08	20%	0.38	20%	0.25
TNC Priority Areas	-	-	22%	0.03	22%	0.13	22%	0.08
Habitat Corridors	-	-	23%	0.03	23%	0.13	23%	0.08
Conservation Areas	-	-	20%	0.03	20%	0.13	20%	0.08
Important Bird Areas	-	-	20%	0.06	20%	0.13	20%	0.17
Proximity to Wetlands	-	-	20%	0.03	20%	0.13	20%	0.08
Water Savings	15%	0.75	15%	0.75	15%	1	15%	0.25

4.3.7.3. Reserve Setting (BLM)

Marxan allows for the adjustment of connectivity or fragmentation of possible reserve networks. The boundary length modifier (BLM) is a multiplier applied on the total perimeter (boundary length) of planning units in the recommended reserve, where reserve networks with greater fragmentation will have a greater total boundary length. The BLM is considered in the total score for each possible reserve network.

A range of BLM values was tested for this analysis in order to find the most appropriate BLM for MBOM. The BLM is such where cost remained less than 10% or roughly the point at which the total cost increased but the restored land increased marginally and was fixed at 0.00002 (**Figure 24**).

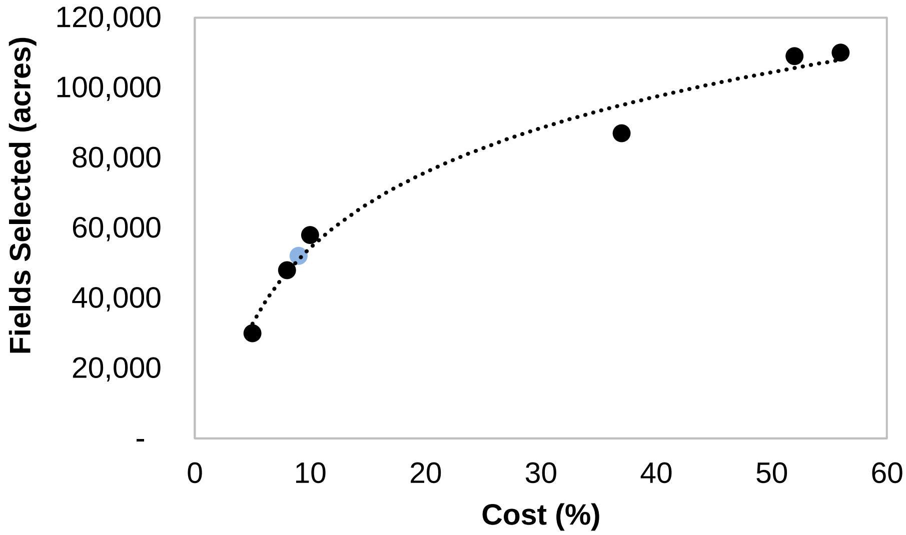


Figure 24: *Boundary Length Modifier (BLM) robustness test where percent cost is the fraction of the total reserve cost relative to the total cost of all agricultural fields. The blue point indicates the selected BLM.*

4.3.7.4. Run Setting

Marxan was operated with 100 runs, where each run through 10,000,000 combinations of possible reserve outcomes. This decision was informed through a sensitivity analysis whereby lesser cost reserves were chosen more frequently by Marxan when performing 10,000,000 combinations across 100 runs, rather than runs greater than 100 with less than 10,000,000 combinations (vice versa).

4.4. Multi-Benefit Optimization Model Results

4.4.1. *Upland Habitat Replenishment Projects*

The MBOM was run under four scenarios for upland habitat restoration: (1) Water Priority, (2) Equal Water and Habitat Priority, (3) Habitat Priority, and (4) Water Replenishment. The following map (**Figure 25**) displays the recommended fields for upland replenishment under a Water Priority scenario, the most preferred scenario indicated by landowners.

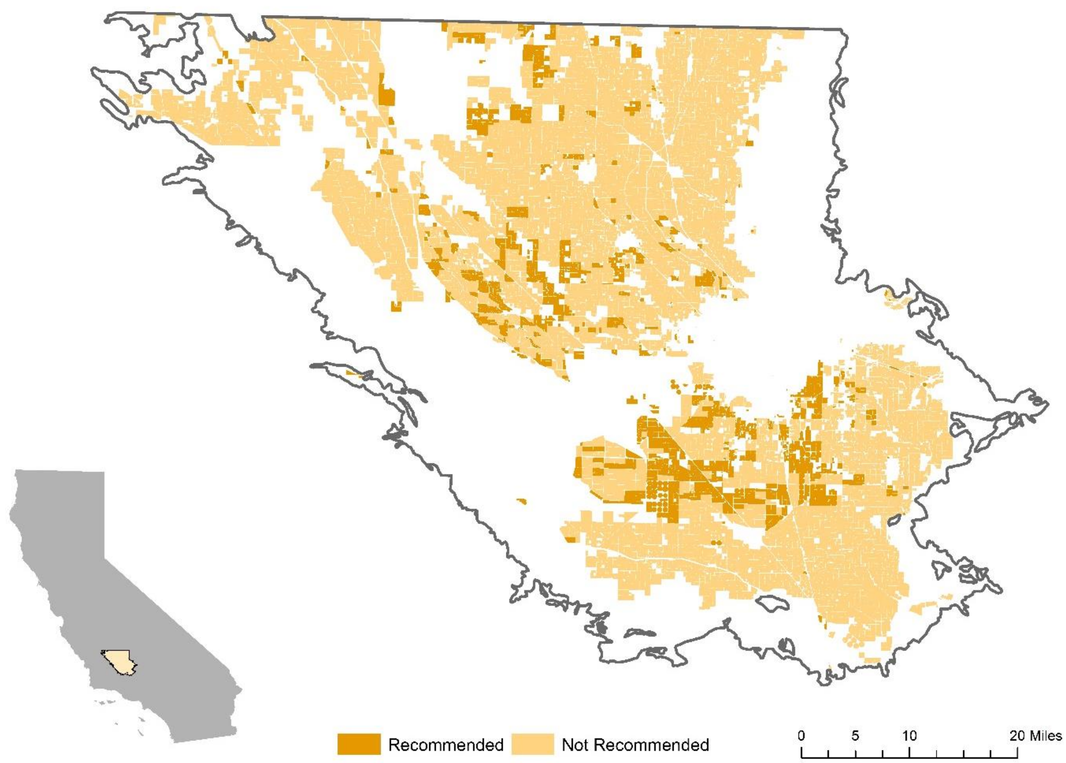


Figure 25: *Recommended agricultural fields for upland habitat replenishment projects under the Water Priority scenario.*

Under each of the four scenarios, the 15% water savings target of 426,676 AFY was successfully achieved or surpassed while the Habitat Priority scenario came the closest to achieving the habitat targets (**Table 26**). As described in the methodology above, Conservation Targets and achievements are expressed as the percent of each conservation factor in the San Joaquin Valley that occurs in Kern County agricultural fields or the available planning units.

***Table 26**: Conservation factors targets and achievements among four priority scenarios for Upland Habitat Replenishment Projects. A fourth scenario, Water Savings Only, is a baseline scenario to determine water savings without habitat considerations.*

Scenario	**Priority Conservation Areas**	**Habitat Corridors**	**Existing Conservation Areas**	**SJV Kit Fox Habitat**	**Tipton Kangaroo Rat Habitat**	**Water Savings**
Target	**37.0%**	**37.0%**	**20.0%**	**20.0%**	**20.0%**	**15.0%**
Water Savings	23.1%	8.2%	13.7%	12.0%	19.2%	15.0%
Water Priority	27.8%	8.2%	14.7%	13.3%	20.0%	15.0%
Equal Priority	30.1%	10.3%	14.7%	16.0%	20.4%	15.0%
Habitat Priority	34.7%	14.4%	15.8%	17.3%	20.0%	14.9%

While the Habitat Priority scenario came the closest to achieving the conservation targets, each of the four scenarios produced significant habitat benefits. The Water Savings scenario recommended the least amount of habitat, however, under this scenario MBOM still generated 117,000 acres of agricultural fields recommended for upland habitat replenishment projects (**Table 27**). In this scenario, of the 117,000 acres recommended for upland projects 27,076 acres overlap with potential SJV kit fox habitat and 52,505 acres overlap with potential Tipton kangaroo rat habitat (**Table 27**, **Figure 26**).

***Table 27:** Conservation Target achievements in MBOM for upland habitat replenishment projects.*

	Unit	**Scenario: Water Savings** Habitat = 0	**Scenario: Water Priority** Water > Habitat	**Scenario: Equal Priority** Water = Habitat	**Scenario: Habitat Priority** Water < Habitat
TNC Priority Areas	acres	16,146	19,042	20,025	22,922
Habitat Corridors	acres	5,773	5,915	6,876	8,988
Conservation Areas	acres	79,939	85,375	86,585	94,976
SJV Kit Fox	acres	27,076	30,443	36,304	38,905
Tipton Kangaroo Rat	acres	52,505	55,069	55,338	55,028
Water Savings	AFY	426,671	426,670	426,670	424,254
Total Acreage	acres	117,368	120,949	122,177	122,128
Total Cost	$	$265,622,275	$269,560,809	$273,451,815	$277,538,166
Average Cost per Acre	$/acre	$2,263	$2,229	$2,238	$2,273

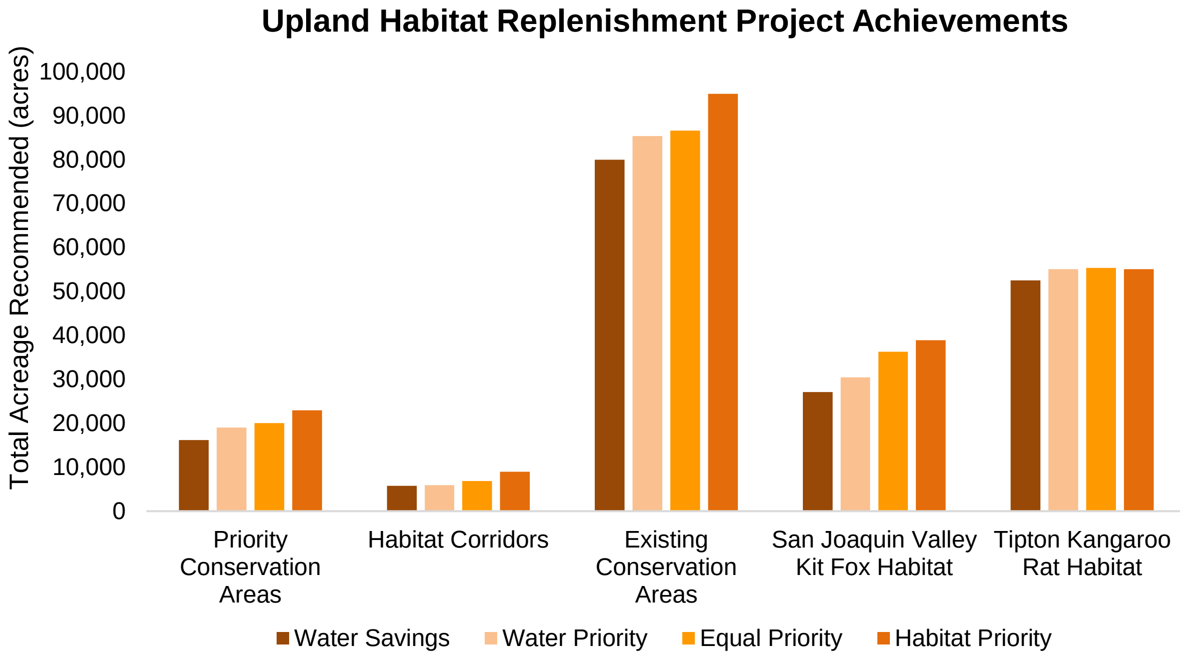


Figure 26: *Acres of upland habitat achievements under priority scenarios.*

The Habitat Priority scenario recommends similar total reserve acres for restoration as the Water Priority scenario. Further, the total acres recommended for upland habitat replenishment projects is like the baseline scenario of not optimizing for achieving habitat creation targets and focusing solely on replenishing groundwater. Therefore, to strategically fallow agricultural fields to achieve groundwater savings through irrigation, an additional 26,900 acres of upland habitat can be created for an additional cost of $11.9 million.

The water savings and habitat achievements of the Habitat Priority scenario come at a similar cost per acre as the Water Savings, Water Priority, and Equal Priority scenarios. Fields recommended in the Habitat Priority scenario average $2,723 in lost revenue per acre of land recommended for restoration, compared to an average cost per acre of $2,229 in the Water Priority scenario (**Figure 27**). In total, the Habitat Priority scenario recommends a reserve network at a cost of $227.5 million in annual crop revenue to fully achieve all conservation targets, while the Water Priority scenario recommends an area that would cost $269.5 million.

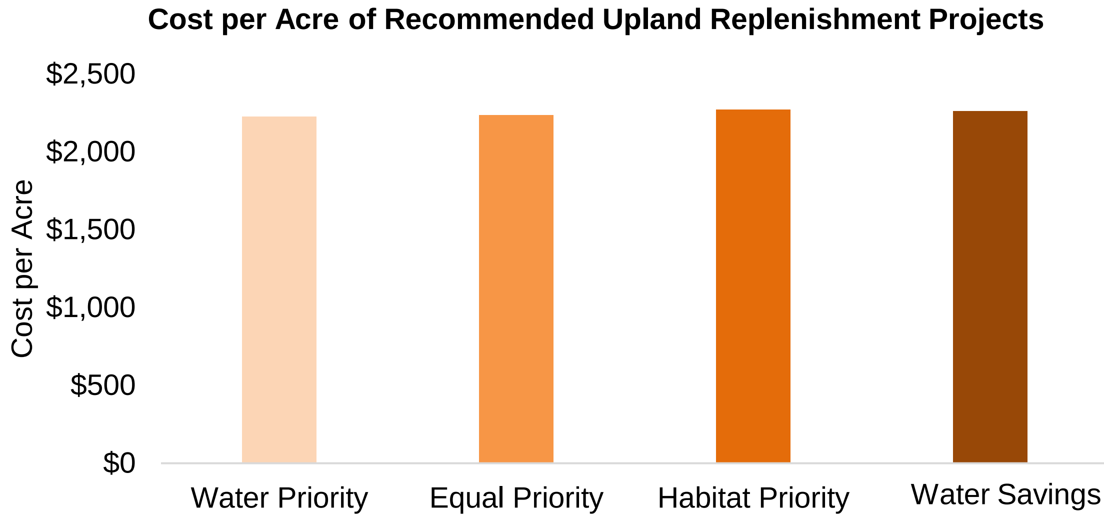


Figure 27: *Cost per acre of recommended fields under three varied priority scenarios and the baseline water savings only scenario without habitat considerations.*

Under a Water Priority scenario, MBOM recommends a reserve network that achieves water targets and significant habitat benefits at relatively low costs. This was achieved by prioritizing the selection of crop fields with a low value and/or high water use such as alfalfa (30% of fields selected), wheat (21%), cotton (12%), and almond (10%) fields (**Figure 28**).

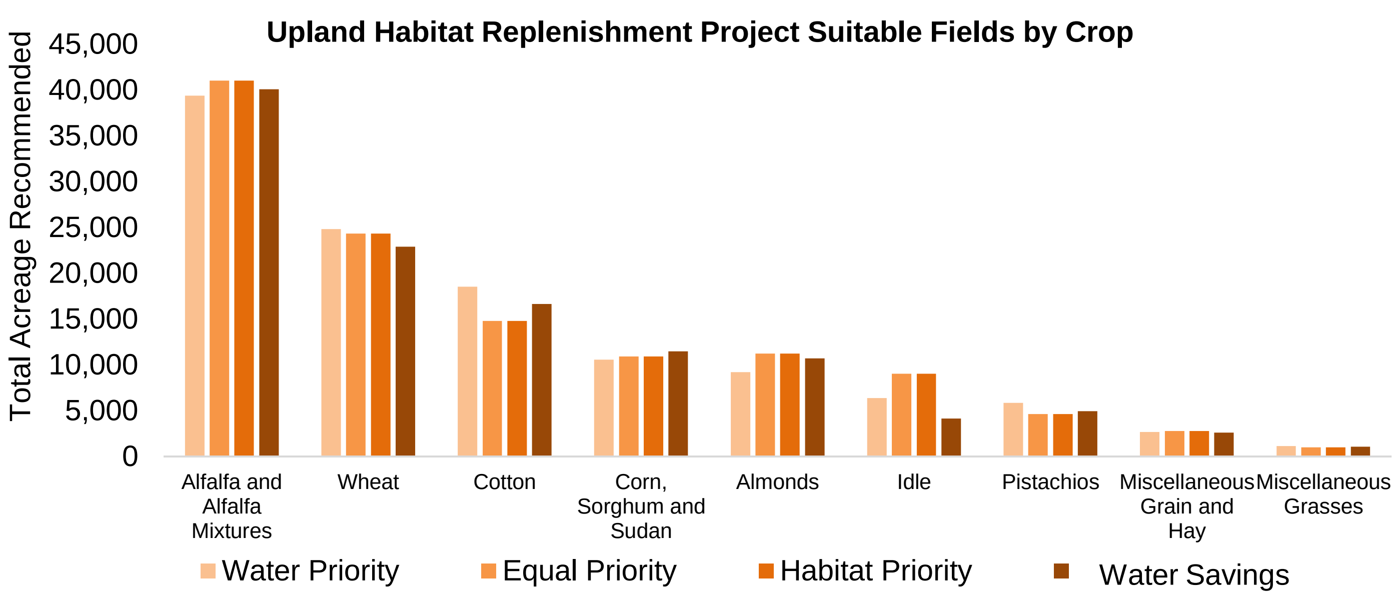


Figure 28: *Fields recommended for Upland Habitat Replenishment Projects by crop under three priority scenarios and the baseline scenario without habitat considerations (Water Savings).*

While high water use-low value crops, such as alfalfa, generate less than $500 per AF of water applied, crops like grapes, pomegranates, and citrus can provide up to $3,000 per AF in revenue for landowners (**Figure 29**). Crops that provide high revenue relative to water use are rarely selected by MBOM, as the crops accrue a high cost while providing limited water savings when removed from production.

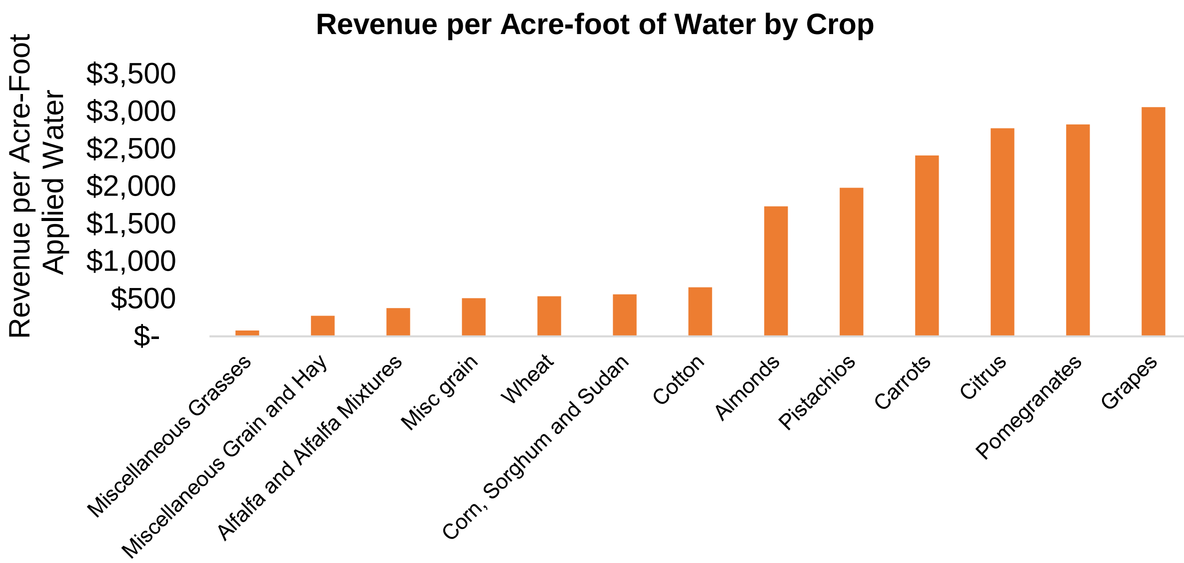


***Figure 29**: Revenue per acre-foot of water applied by crop type.*

In initial conversations with landowners interested in using MBOM, a Water Priority scenario aligned most closely with most landowners' interests in first minimizing costs, second saving groundwater and third creating habitat. The upland habitat MBOM under a Water Priority scenario recommends a reserve network that could save 426,670 acre feet of water per year (19% of Kern County's irrigation demand) and create 120,950 acres of upland habitat (14% of Kern County fields) while sacrificing only 4% of Kern County's annual crop revenue equal to $227.5 million.

4.4.2. *Wetland Habitat Replenishment Projects*

As in the upland habitat analysis, the same four scenarios were analyzed for wetland habitat replenishment projects: (1) Water Priority, (2) Equal Priority, (3) Habitat Priority, and (4) Water Savings. Under each of these scenarios, the water replenishment target was set to 426,670 AFY, equal to the water target for upland habitat replenishment projects and equal to Kern County's reliance on groundwater overdraft – equivalent to 0.51% of the total water that could be recharged in Kern County in 2 months. Habitat conservation targets were set to achieve at least 20% of giant garter snake available in Kern County agricultural fields, equivalent to 0.4% of the total giant garter snake habitat in the San Joaquin Valley. The remaining conservation area factors were scaled up using Equation 15 (**Table 28**).

Table 28: *Conservation factors targets and achievements among three priority scenarios for Wetland Habitat Replenishment Projects. A fourth scenario, Water Savings Only, is a baseline scenario to determine water savings without habitat considerations.*

Scenario	Giant Garter Snake	Priority Conservation Areas	Habitat Corridors	Existing Conservation Areas	Important Bird Areas	Proximity to Wetlands	Water Replenish-ment
Target	**20.0%**	**22.0%**	**23.0%**	**20.0%**	**20.0%**	**20.0%**	**0.51%**
Water Priority	0.6%	1.4%	1.3%	0.8%	1.2%	0.6%	0.51%
Equal Priority	1.7%	3.2%	2.1%	1.4%	2.4%	1.7%	0.55%
Habitat Priority	4.0%	6.1%	4.0%	2.7%	4.8%	4.0%	1.21%
Water Savings	0.6%	1.1%	1.5%	0.8%	0.9%	0.6%	0.80%

Table 29: *Conservation factors achievements among three priority scenarios for wetland habitat replenishment projects and a scenario optimizing without habitat consideration.*

	Unit	**Scenario: Water Savings** Habitat = 0	**Scenario: Water Priority** Water > Habitat	**Scenario: Equal Priority** Water = Habitat	**Scenario: Habitat Priority** Water < Habitat
Giant Garter Snake	acres	843	936	2,233	4,184
TNC Priority Areas	acres	912	851	1,362	2,560
Habitat Corridors	acres	4,124	4,241	8,292	15,378
Conservation Areas	acres	1,085	1,387	2,970	5,867
Important Bird Areas	acres	3,393	3,553	6,946	11,856
Proximity to Wetlands	acres	502	557	1,375	3,467
Water Replenishment	AFY	**663,318**	**426,581**	**457,438**	**1,004,968**
Total Acreage	acres	5,696	3,663	6,384	13,015
Total Cost	$	$7,144,176	$4,228,936	$13,727,682	$41,492,519
Average Cost per Acre	$/acre	$1,254	$1,154	$2,150	$3,188
Surface Water Costs ($667 per AF)	$	$442,433,106	$284,529,527	$305,111,146	$670,313,656
Total Cost with Surface Water Costs*	$	$449,577,282	$288,758,463	$318,838,828	$711,806,175
Average Cost per Acre	$/acre	$78,928	$78,831	$49,943	$54,691

**surface water costs equal to $667 per AF based on results of the CBA.*

Water replenishment targets were met and exceeded in every case, at only a fraction of the acreage needed for the upland habitat replenishment project MBOM (**Table 29** and **Figure 30**). Therefore, water replenishment targets were met at only a fraction of forgone annual crop revenues. None of the scenarios achieved the targeted acreage for giant garter snake or any other conservation target. However, significantly more habitat is created when optimizing for habitat generation rather than water replenishment, but notably at a severe increase in cost.

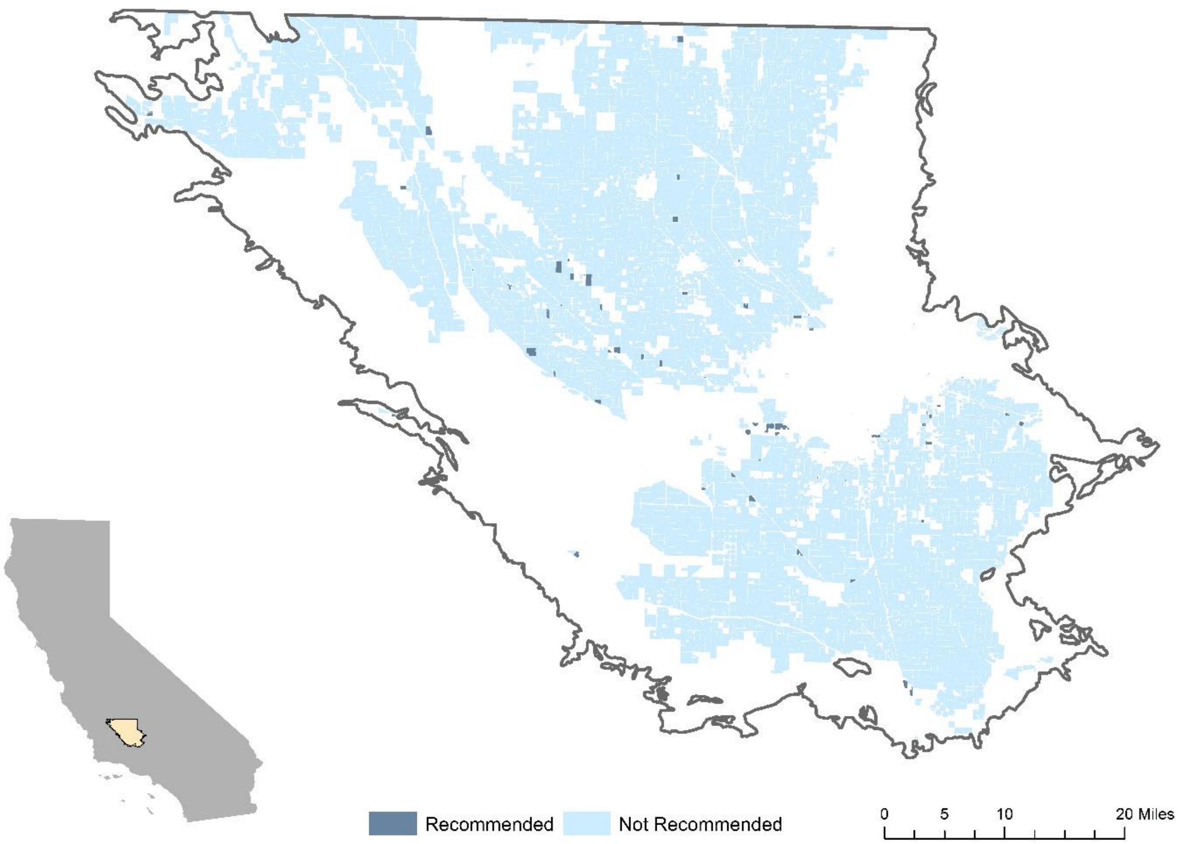


Figure 30: *Recommended fields for wetland habitat replenishment projects under the Water Priority scenario.*

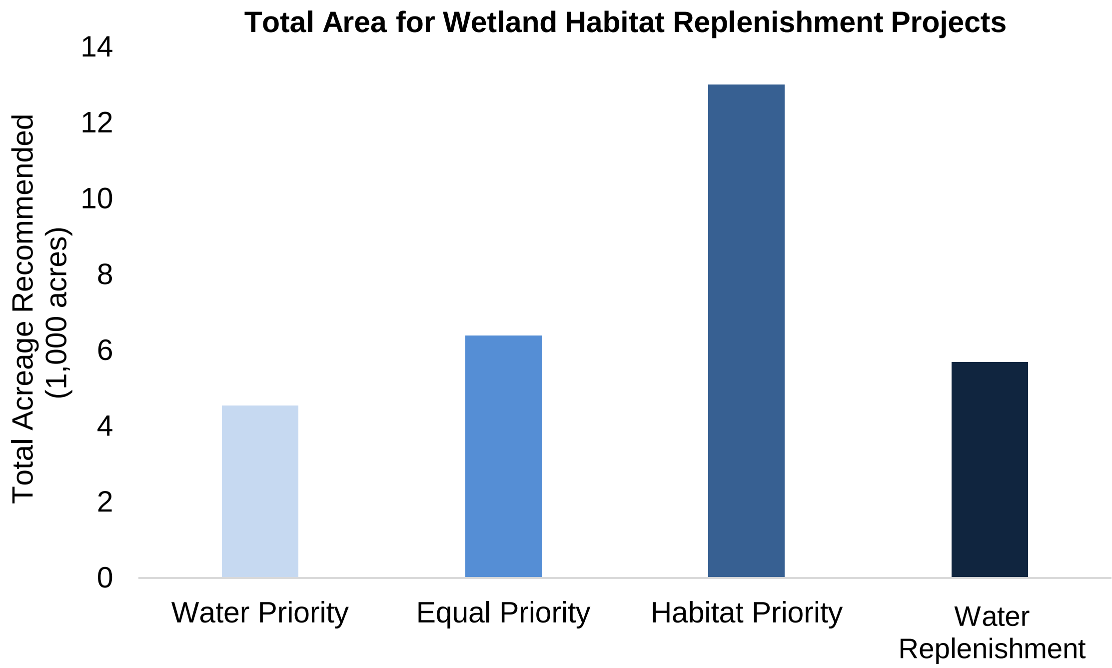


Figure 31: *Total acreage recommended for wetland habitat replenishment projects under three priority scenarios and a baseline scenario only optimizing for groundwater replenishment.*

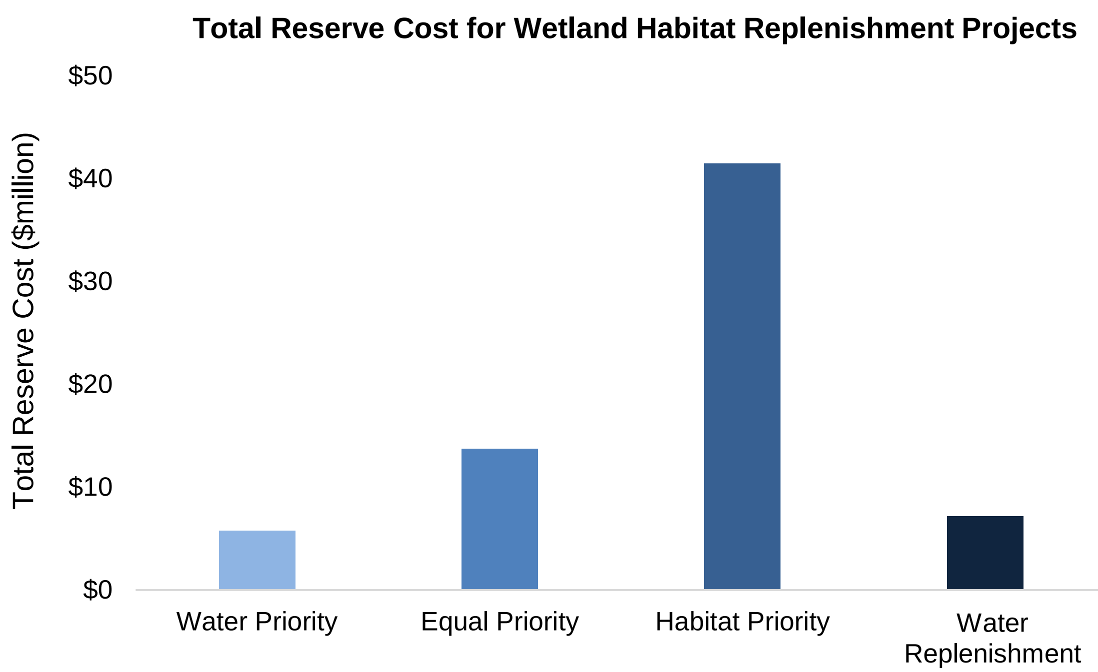


Figure 32: *Total cost in million dollars for wetland habitat replenishment projects under three priority scenarios and a groundwater replenishment only baseline scenario.*

The cost and size of the recommended reserve network for wetland habitat replenishment projects increases as the priority for habitat increases (**Figure 31 & Figure 32**). The average cost per acre increases as a result, as more expensive, high value crop fields are added to the reserve, which already included suitable low value crop fields (**Figure 33**).

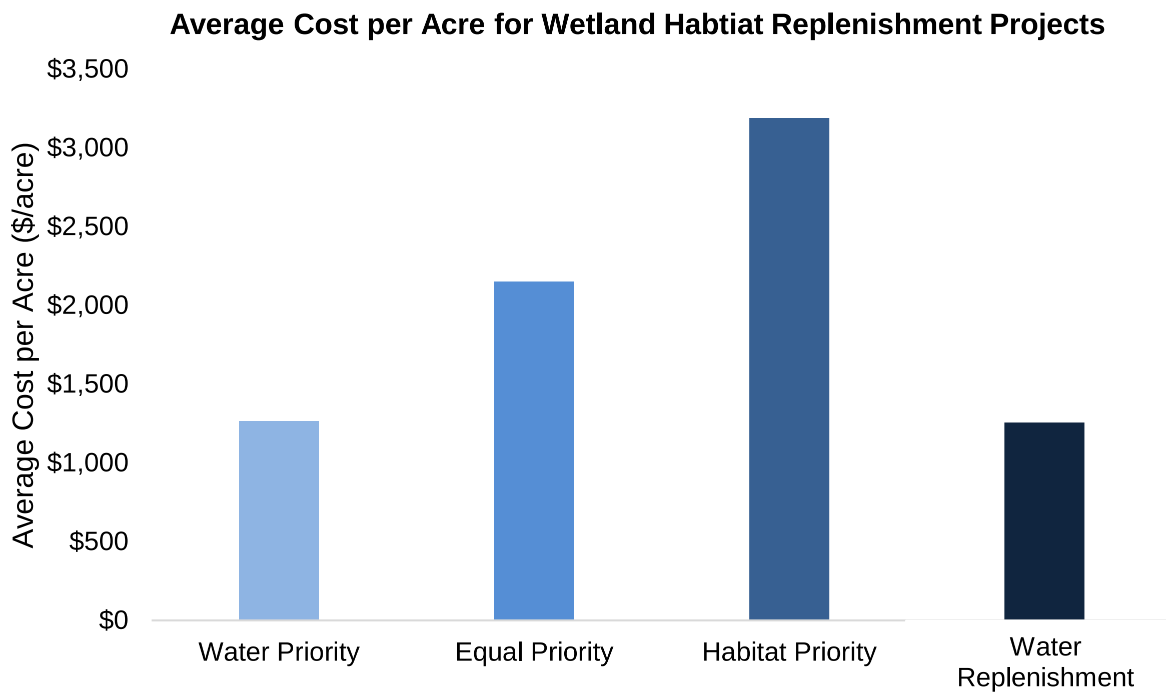


Figure 33*: Average cost per acre equal to total reserve cost divided by total reserve acreage under three priority scenarios and the baseline groundwater replenishment only scenario (excluding surface water costs).*

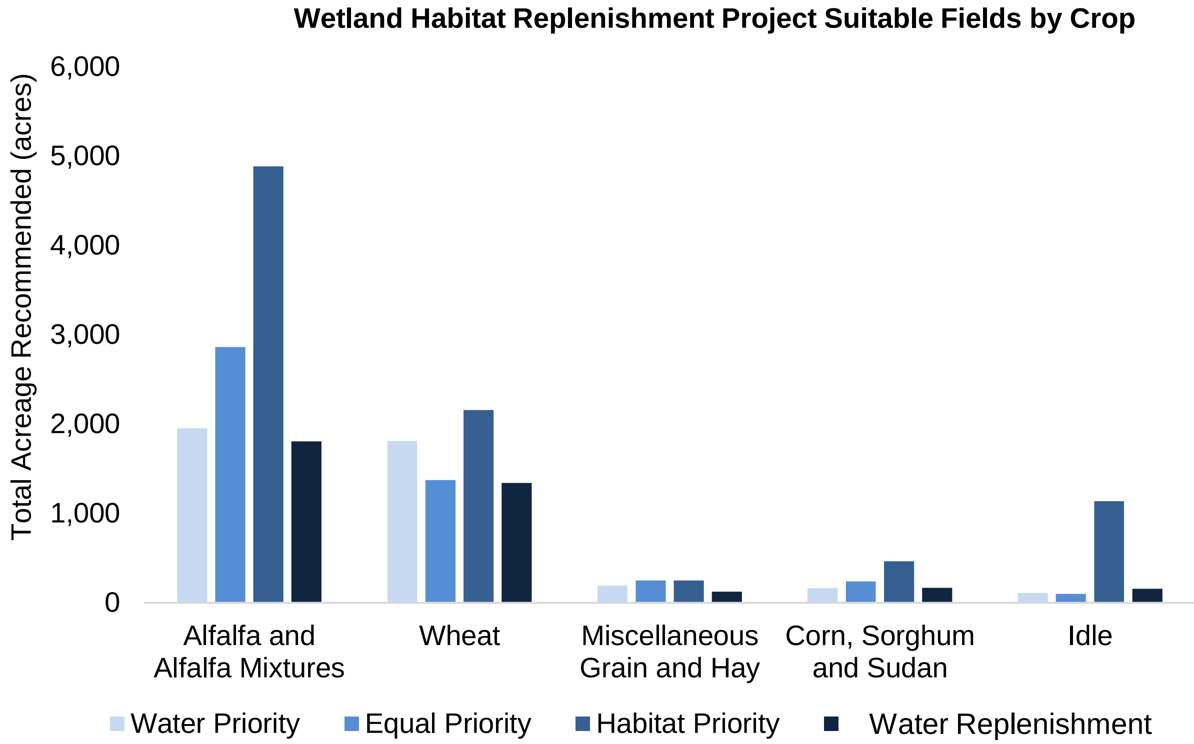


Figure 34*: Top five fallowed crops recommended for wetland habitat replenishment projects.*

The most selected crop for wetland replenishment projects is alfalfa, which accounts for at least 55% of the total area recommended (**Figure 34**). This is consistent with the results from the CBA, where the preferred crops for habitat projects are those with higher water consumption and lower profit margins.

The Habitat Priority scenario achieves a recommended reserve area three times bigger than the Water Priority scenario but creates seven times more habitat for giant garter snake. A similar case happens with all other habitat conservation targets, in that are not met but increase when habitat is more prioritized. This may be explained by two reasons: (1) replenishment suitability and (2) overlap with high value agriculture. First, approximately 50% of agricultural fields are excluded from the MBOM wetland habitat replenishment project analysis, as the fields are not suitable based on shallow groundwater, too high or too low infiltration rates, or 45+ mg/L groundwater nitrate levels (**Figure 35**). Second, remaining suitable fields produce high value crops, such as almonds, walnuts, or pistachios. As a result, it is difficult to find low cost agricultural fields that meet replenishment suitability, and therefore the MBOM cannot completely fulfill all conservation targets.

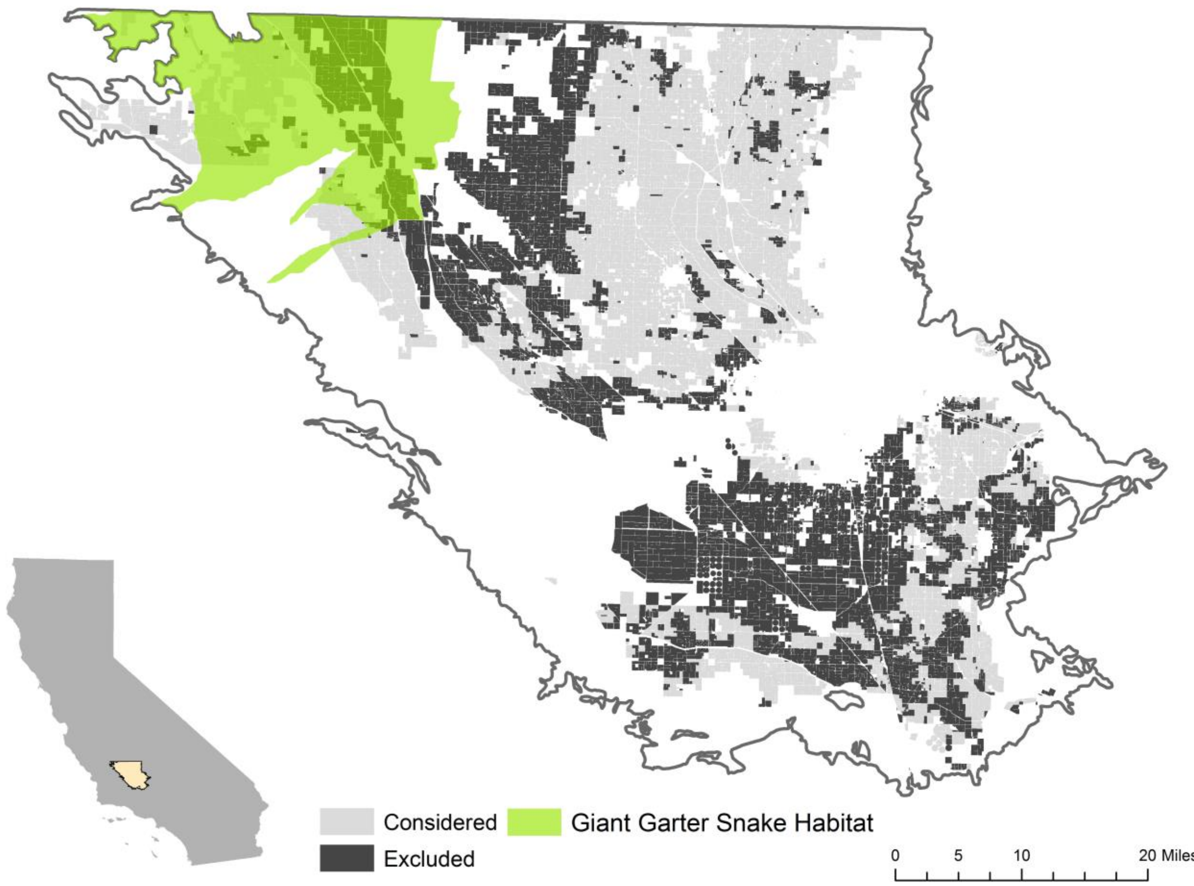


Figure 35: *Considered (grey) and excluded (black) fields for wetland habitat replenishment projects. Green area represents giant garter snake habitat.*

Although the loss of agricultural revenue for the recommended wetland habitat replenishment project network is one order of magnitude lower than for upland habitat replenishment projects, this comes at the expense of potential high surface water cost. Using an average surface water cost of $667 per AF, as informed by the CBA, the cost for purchasing surface water for wetland habitat replenishment projects is $284 million for the water priority scenario. Therefore, the total annual cost of the MBOM wetland habitat replenishment project reserve $290 million under the Water Priority scenario. This is more expensive than the most inexpensive upland habitat replenishment project Water Priority scenario totaling $269 million.

4.5. Model Conclusions

The MBOM successfully determined that upland and wetland habitat replenishment projects can be strategically located to generate additional co-benefits at marginal additional costs under the Water Priority, Equal Priority, and Habitat Priority scenarios compared to traditional management strategies.

For both replenishment projects, groundwater savings were achieved in all scenarios, regardless of whether habitat was weighted equal to, or greater than groundwater savings targets. Notably, under the Water Priority scenarios, annual forgone revenues represented less than 5% of the total Kern County agricultural revenue ($6.2 billion). Alfalfa was the most frequently recommended agricultural crop to either be fallowed for upland habitat or retired and converted to wetland habitat. This is most likely due to a combination of alfalfa's high water demand and relatively low annual revenue.

For upland habitat replenishment projects, achieving groundwater savings targets of 426,670 AFY led to a recommended reserve network of 14% of the total agricultural acreage in Kern County (120,949 acres) when optimizing for groundwater savings. As a result, habitat conservation targets were easily achieved while achieving water conservation targets at minimal costs.

In contrast, achieving 426,670 AFY of groundwater replenishment through wetland habitat replenishment projects required a fraction of the agricultural land needed than that for upland habitat replenishment projects. This is because wetland habitat replenishment projects require little land area to replenish an equivalent amount of water as fallowed agriculture in upland replenishment projects. Due to the lesser areas required to meet groundwater targets through wetland habitat replenishment projects, less area of habitat was created in the wetland recharge model runs. Further, less habitat could be created due to limits on the number of agricultural fields suitable for replenishment projects. Remaining suitable fields within conservation and habitat areas also coincided with high value agriculture. Therefore, habitat conservation targets were difficult to achieve due to the field's prohibitive costs and groundwater condition suitability.

The total cost for wetland habitat replenishment projects (calculated as the annual forgone revenue) exceeded costs for upland habitat replenishment projects by $442.3 million when accounting for the cost of surface water at $667 per acre-foot. This is because the land required to support a wetland habitat replenishment project is significantly less than the land needed for achieving groundwater savings targets for upland habitat replenishment projects. Because MBOM does not account for the cost of acquiring surface water, an additional cost of $667/AF (based on the results of the CBA) was multiplied by the water savings, for a total cost of $711.8 million for the recommended wetland habitat replenishment project reserve. This was at a cost significantly more than the upland habitat replenishment project reserve, which achieved needed water savings targets but created 107,934 acres more habitat.

Finally, MBOM results coincide with CBA results in that alfalfa is the most selected crop to fallow in both wetland and upland habitat replenishment projects, because of having high water demands and low revenue or low profit margins. Other most selected crops included grains, such as wheat, sorghum and corn, and cotton, due to similar high-water demand and low profit margins. High value crops, such as almonds and pistachios, were only selected as targets were increased and were increasingly selected when habitat was prioritized over water, as endangered species habitat overlaps high value agricultural particularly in the northwestern areas of Kern County.

Overall, the MBOM can be used by landowners, GSAs and stakeholders to spatially locate and optimize agricultural fields for multi-benefit replenishment projects. The MBOM can be used at different spatial scales and to allow for optimization across several combinations of geographic regions. Through an analysis of Kern County, the MBOM successfully selected agricultural fields for multi-benefit replenishment project and can serve as an example analysis for future regions of interest.

5. Groundwater Sustainability Plan Chapter

Basin Framework for a Multi-Benefit Groundwater Replenishment and Trading Program

CHAPTER [XX]: Multi-Benefit Groundwater Replenishment

I. Introduction
   a. Achieving groundwater sustainability in many critically overdrafted basins is contingent upon collaboration between landowners/pumpers/operators (“operators”) and GSAs to replenish groundwater.
   b. This chapter sets forth mechanisms to encourage and incentivize operator engagement in groundwater replenishment projects, with opportunities to pair these efforts with community and natural resource values, such as habitat creation and improved drinking water quality.

II. Groundwater Replenishment Actions
   a. Importance and contribution to GSP measurable objectives
      i. The GSA has documented a need for groundwater replenishment projects in order to ensure the basin is operated within its sustainable yield and has determined to leverage operators’ capacity to meet that objective.
   b. The GSA will encourage and cooperate with operators to implement direct replenishment methods, including the following:
      i. Recharge basins
      ii. Flooding agricultural lands
      iii. Instream and canal replenishment
      iv. Aquifer injection
   b. The GSA will encourage and cooperate with operators to implement indirect replenishment methods, which result in a reduction in groundwater pumping in the basin, including the following:
      i. In-lieu recharge
      ii. Temporary fallowing, such as removing permanent plantings or landscaping and delaying replanting for a defined time or rotational fallowing of annual crops
      iii. Reducing consumptive use by conversion to less water intensive plantings
      iv. Permanent land retirement
   c. The GSA will encourage and cooperate with operators to obtain and deliver water supplies for direct replenishment and in-lieu recharge, including the following:
      i. Imported surface water
      ii. Flood flows, reservoir flood control releases, stormwater capture
      iii. Recycled water
      iv. Desalination
      v. Groundwater allocation transfers

d. The GSA will cooperate with the operator to avoid or mitigate third party impacts associated with replenishment projects.
e. The GSA will cooperate with operators to adhere to applicable regulatory processes (federal, state, and local) and state water rights laws.
f. The GSA will coordinate with DWR, SWRCB, and operators to access any available financial assistance for water replenishment projects and management actions.

III. Crediting and Accounting for Operator Replenishment

a. To incentivize operator participation in groundwater replenishment, the GSA will develop appropriate crediting and compensation mechanisms that:
    i. Allow operators to document through a written agreement with the GSA the terms and conditions of the replenishment program, including the amount of water to be credited or other form of compensation to the operator.
    ii. Provide a documented right for the operator to utilize or market a defined portion of the developed water; and
    iii. Establish a basin-wide accounting framework for each operator’s developed groundwater supply. If the GSA has established extraction limits, the framework shall account for the operator's groundwater allocation as well as credits to the operator’s accounts for developed water.
b. The GSA will credit replenishment subject to the following conditions and limitations:
    i. Replenishment projects returning more than X AF per year must be permitted by the GSA. The operator’s permit application will include the following:
        1. Method of replenishment
        2. Estimated volume of water
        3. Beneficial use of the replenished water and conditions for extraction
        4. Measurement and reporting requirements for replenishment
    ii. Replenishment will be credited less a “leave-behind” for the benefit of the basin and/or related community and natural resource values.
    iii. Extraction rates may need to be limited to avoid third party impacts, with consideration for hydrologic and other conditions.
    iv. The GSA may credit replenishment projects that occurred prior to the initiation of the GSP.
c. The operator may draw upon the credits as follows:
    i. For application to land overlying the basin, subject to any applicable limitation of state law or local ordinance.
    ii. For sale, transfer or exchange for use within the basin boundaries and subject to the market established pursuant to Chapter [YY] below.

IV. Community and Natural Resource Values

a. The GSA will assist operators in implementing groundwater replenishment projects in a manner that promotes local community and natural resource benefits.

b. Management of direct replenishment projects

    i. The GSA will work with operators to develop appropriate baseline management conditions for direct replenishment methods, such as recharge ponds and on-farm recharge, to control sediment buildup, rodents, mosquitos, and other undesirable outcomes.

    ii. The GSA will provide an additional menu of options of natural resource management strategies that may be implemented in conjunction with replenishment projects that provide multiple benefits, available in Appendix A, in order to achieve defined and measurable conservation and/or community resource values. These may include improved water quality or supply reliability for local community water systems, providing wetland habitat for migratory birds, and diverting stormwater to aid in flood management.

c. Management of fallowed or retired lands

    i. The GSA will work with participating operators to develop appropriate baseline management conditions for fallowed land to avoid undesirable outcomes for the community, such as invasive plant infestations or dust emissions, or to provide public benefits on these fallowed lands, such as improved habitat.

    ii. The GSA will provide an additional menu of options of natural resource management strategies that may be implemented in conjunction with replenishment projects that provide multiple benefits, available in Appendix A, such as the creation of saltbush scrubland habitat for listed species and pollinator habitat.

d. Voluntary agreements and assurances for management of fallowed or retired lands

    i. Voluntary commitments to provide natural resource and/or community values may be reflected in appropriate agreements or easements depending upon the nature and duration of the commitment.

        1. The GSA commits to working with appropriate resource management agencies to provide operators assurances that future activities will not be inhibited by providing for such conservation and/or community resource values.

    ii. Where possible, the GSA will aid in the development of programmatic voluntary conservation agreements (e.g., Safe Harbor Agreements). Operators will be able to choose to enter into such land management agreements in exchange for assurances that further land management requirements and associated costs will not be imposed on the operator.

e. Other Land Use Issues
    i. As groundwater replenishment efforts often require changes in land use management, these actions may require local, state, and federal natural resource management agency approvals. The GSA will assist operators interested in replenishment projects with co-benefits in coordinating with the appropriate agencies. Appendix B outlines agencies that may be relevant to implementation of such replenishment projects.
f. Incentives
    i. Where possible, state, federal, and private financial incentives can be used to support the creation of habitat and community benefits.

CHAPTER [YY]: Water Trading

I. Introduction: This chapter provides a framework for implementation of groundwater trading programs as a groundwater management mechanism.

II. Groundwater Trading Program

   a. Importance and contribution to GSP measurable objectives
      i. The GSA has determined that a trading program for groundwater shares and/or allocations will serve as an appropriate mechanism for efficiently distributing scarce groundwater among operators and minimizing economic dislocation.
   b. The GSA will develop and administer a robust groundwater trading system covering the following:
      i. Water available pursuant to credits acquired by participating in activities authorized by Chapter [XX] above, including those accrued pre-GSP adoption.
      ii. Groundwater that may be available when the GSA places a cap upon pumping equal to the sustainable yield and apportions pumping shares and/or allocations among existing operators.
   c. When developing and administering the groundwater trading system, the GSA will take into consideration the following elements to accommodate local basin conditions:
      i. The status of local groundwater rights
      ii. How to evaluate trading impacts in order to minimize adverse impacts on third parties
   d. The GSA will establish and enforce trading rules, including the following:
      i. No transfer of credits or pumping allocations (either on a temporary or permanent basis) shall occur without the approval of the GSA.
      ii. The GSA will facilitate the trading of water shares and allocations, on short-term and permanent bases.
      iii. The GSA will determine carryover rates for unused credits and allocations (i.e., a landowner trading current use for future use) that cause no impact to third parties.
      iv. If management zones are established, trading will occur subject to ratios that correspond to each zone. The GSA will revise these as necessary as basin conditions vary. Trading ratios may depend upon whether trading occurs within zones of confined or unconfined aquifers or between zones, or upon protections in place for community and natural resource values.
      v. Approval of transfers will be conditioned on the trading parties publicly reporting the following information:
         1. Share, or volumetric allocation among, being transferred
         2. The price pursuant to which the share or allocation is being transferred

3. The location of the property that is the source of the share or allocation being transferred
4. The name of the operator and location of the property that shall receive the share or allocation being transferred
5. The depth to groundwater in the location of the property that is the source and destination of the share or allocation
6. Groundwater quality in the location of the property that is the source and destination of the share or allocation
7. The duration of the transfer
8. Identification of any community water systems proximate to the property that is the origin and destination of the share or allocation
9. Identification of any natural resources proximate to the property that is the source and destination of the share or allocation

e. The GSA will ensure the trading parties are in compliance with the California water rights system, environmental reviews, and other regulations as applicable.

f. The GSA will establish monitoring protocols to evaluate how groundwater trading has impacted the basin's sustainability indicators.

g. Oversight and enforcement
   - i. The GSA will ensure operators are not over-extracting beyond their allocations, and will ensure that trading rules are followed.
   - ii. Penalties for non-compliance will be imposed by the GSA.
   - iii. The GSA will provide corrective measures for non-compliant operators.

h. Adaptive management
   - i. The GSA will periodically assess the effectiveness of the trading program in meeting sustainability goals.
   - ii. The GSA will consider updating the trading program structure, process, and/or rules on an annual basis, or as significant information regarding basin sustainability indicators is made newly available.

i. The GSA will ensure that all information regarding trading applications and completed trades is made public, and that operators are engaged in decision-making processes of the groundwater trading program.

j. The GSA may provide an online trading platform that connects willing buyers and sellers of groundwater shares and allocations.

<u>**GSP Chapter Appendices**</u>

Appendix A – Menu of Options

Selection and Recommendations for Replenishment Projects with Co-benefits

Purpose: This document is intended to provide decision making support for landowners interested in replenishment projects that maximize replenishment, and the co-benefits of species habitat and community benefits.

Support Table for Selection of Replenishment Projects with Co-benefits

Replenishment Method	Habitat Potential	Site Characteristics	Community Benefits
Recharge Ponds with Intermittent Wetland Habitat	- Intermittent wetland and upland habitat - Migratory bird and other wetland species habitat	- High soil infiltration rates (0.1-1 foot/day) usually associated with coarse textured soils without clay pans - Low soil salinity, selenium, and nitrate levels - Ideally located nearby existing wetland areas - Access to seasonal water available for replenishment, preferably direct from rivers or streams	- Education, recreation, and aesthetic benefits associated with waterfowl and wetland species - Improved groundwater quality - Improved municipal well reliability - Reduced downstream flood risk
On-farm Recharge	- Predatory bird species foraging habitat - Waterfowl foraging habitat - Pollinator habitat	- Flooding tolerant crops, such as alfalfa, vineyards, almonds, and pistachios - Low levels of residual nitrogen in soil after growing season is completed	- Improved groundwater quality - Improved municipal well reliability - Reduced downstream flood risk
Fallowing with Upland Habitat Restoration	- San Joaquin Valley saltbush scrub land habitat - Supports bird, small mammal, and reptile species - Pollinator habitat	- Ideally located nearby or between existing wildlife areas	- Reduced soil erosion and associated surface water quality benefits - Reduced dust emissions, improved air quality

Management Strategies to Enhance Replenishment Project Co-benefits

1. Recharge Ponds with Intermittent Wetland Habitat
    a. Pond Construction
        i. Natural topography should be utilized where possible, with low earth berms used as levees. Including microtopography will provide a range of water depths to help support a broader spectrum of species and life stages.
        ii. Berms should be planted with grasses and shrubs from local seed to prevent bank erosion and provide peripheral species habitat. Seeding should occur in the winter or fall, prior to this first rain event of the season.
        iii. Inter-basin structures are needed to control movement, flow rate, and water levels in and between basins. Controlling the movement of water will allow for strategic management of the basins.
    b. Pond Management
        i. Vegetation
            1. A balance between aquatic vegetation and open water is essential to providing habitat and mitigating potential issues, such as excessive mosquito and algal growth. Approximately 30% of the shallow area of the pond should host rooted, floating, and submersed aquatic vegetation with the remaining 70% of the pond left as open water.[1]
            2. Native vegetation growth should be encouraged on the basin floor to provide habitat for upland species during dry periods between pond fillings. However, invasive plants, such as Russian thistle, may create blockages in flood gates and canals and should be actively removed.
                a. Disking and heavy equipment use is not recommended for vegetation removal as this can result in soil compaction and reduced infiltration.
                b. Grazing is the recommended method for vegetation removal due to its low cost and effectiveness when managed correctly. There is a risk of soil compaction if herds are too dense or grazing is used for an extended duration. Grazing should be used when soil conditions are dry to avoid compaction.
        ii. Filling ponds
            1. Pond depth should be managed to ensure basin turnover rates high enough to avoid negative effects associated with stagnant water including algae build up, mosquito breeding, and avian disease. Deeper ponds should be avoided as they tend to compress clogging layers into the recharge

pond floor, reducing recharge basin infiltration rates over time.[2]

2. Basin series should be filled in a hierarchical pattern so that some basins are used more frequently while others are only filled occasionally. Designating basins for high, medium, and low frequencies of inundation will help support a broader diversity of vegetation and wildlife that prefer a range of soil moisture levels.
3. When possible, use natural water sources to supply recharge basins as these will help expedite the introduction of wetland vegetation, fish, and invertebrate species.

iii. Sediment management
    1. Over time, fine sediment can build up in recharge basins clogging soil pores and decreasing infiltration rates. Excess sediment can be removed using a grater and a scraper can be used to build islands within the recharge basins, providing additional habitat for nesting waterfowl.
    2. Establishing marsh vegetation at the pond's inflow can help filter water and reduce sediment transport through the system.

iv. Rodent management
    1. Rodents such as ground squirrels and pocket gophers can cause structural damage to earthen levees. As traditional methods of pest control can be harmful to target species, alternative methods for rodent population and damage control are suggested.
        a. The installation of owl boxes and maintenance of perching structures for hawks and falcons can help encourage predation to control rodent populations.

v. Mosquito management
    1. Mosquito abatement techniques that do not adversely impact groundwater quality or wildlife are encouraged where possible. These techniques include:
        a. Locating constructed wetlands in open areas where wind can produce waves in the wetland.
        b. Introducing Mosquito fish (*Gambusia affinis*) that prey on mosquito larvae.
            i. Some regional vector control or mosquito districts may be able to supply mosquitofish at little or no cost to the pond operator.
        c. Conserving predators such as dragonflies and backswimmers by avoiding broad-spectrum insecticides to support larvae predation.

d. Providing cover and foraging habitat for bird species that consume mosquito larvae.
e. Installing aeration systems that introduce water movement to help decrease mosquito coverage.
f. Employing targeted chemical controls by a certified pesticide applicator as a last resort if physical and biological controls are ineffective.

2. On-farm Recharge
    a. Timing
        i. Field inundation for on-farm recharge should occur in the winter or during the crop's dormant period prior to bud break. During this time, the risk of root damage is greatly reduced.[3] The most current research from the UC Davis Groundwater Recharge Research Project should be consulted in determining the most appropriate duration of on-farm flooding for various crop types.
        ii. On-farm recharge can help mitigate downstream flood risk by diverting storm water from streams and rivers. Ideally, on-farm recharge projects should be designed to capture storm water from surface flows. This can be accomplished by selecting fields adjacent to rivers or streams or fields with conveyance systems that can intercept surface flows.
        iii. Timed reservoir releases can provide another opportunity for landowners to access water available for replenishment to be used in on-farm recharge.
    b. Species Support
        i. Pond filling events can often expose prey species such as moles, gophers, and ground squirrels. Owl boxes and perching structures should be maintained adjacent to fields selected for on-farm recharge in order to support predatory bird species such as owl, hawks, and falcons.
    c. Pollinator Habitat
        i. Landowners are encouraged to plant vegetation that may attract and support pollinators, such as birds and butterflies. Consult Xerces's California Planting Guide to select pollinator plants best suited to your area.

3. Upland Habitat on Fallowed Land
    a. Defining Restoration Objectives
        i. Existing local reference sites should be identified to define success criteria for restoration. In the San Joaquin Valley, much of the pre-development landscape was dominated by desert shrubland habitat with minimal herbaceous cover. Managing fallowed land to achieve

targeted ecosystem functionality will largely depend on balancing vegetation cover and structure to meet the needs of focal species that are representative of the broader ecosystem community. In the San Joaquin Valley, kangaroo rats are often targeted as the focal species for desert shrubland restoration projects.

b. Selecting Vegetative Cover
    i. Selecting vegetation for planting will depend upon the site's soil texture, structure, and chemistry. In areas with degraded soil, plants used for restoration may need to be selenium and/or saline tolerant.
    ii. Some plant species fare better in restoration projects and require fewer inputs to establish and maintain. Preferred qualities of restoration plant species include:
        1. Seeds readily available for collection with a low cost associated with harvest, cleaning, conditioning, and storage.
        2. Strong establishment capabilities, with high germination rates and seedling vigor.
        3. Ability to suppress and resist weed competition
        4. Native, with seeds available for collection at a similar elevation and within a fifty-mile radius of the project. However, native plant species are not always superior to non-natives in their usefulness in achieving restoration goals. In some instances, non-native species may be a preferable substitute to a native analog due to its relative resiliency or target species utility.

c. Preparation and Maintenance
    i. Minor topographic variation should be preserved or introduced to the landscape in order to provide upland refuge for small animals during flood events and low lying areas that will form sandy, alkaline playas that provide habitat for desert shrubland species.
    ii. Where invasive grasses and sedges have become dominate, livestock grazing can be used to clear excess herbaceous vegetation in preparation of restoration planting.
    iii. Whenever possible, plantings should be done just prior to rain events to enhance seedling establishment.
    iv. Maintaining open space and light herbaceous cover is critical in maintaining habitat for scrubland species. Where herbaceous cover is too thick, small mammals and other species are unable to move freely and predatory birds may have difficulty targeting prey. Grazing can be used in these situations to optimize vegetative cover and help mitigate wildfire risk.
    v. Dense shrubs should also be avoided as this can provide a predatory advantage to coyotes that prey on kit foxes and other

target species. Shrub cover between 5% and 10% is optimal for desert shrubland target species.[4]

d. Irrigation
    i. Limited irrigation may be used in the first season following native seed planting to encourage growth and establishment.
    ii. After the first year, restoration plantings should only be irrigated if the rainfall totals for the year are more than 20% below average.[5] Irrigation may help the native plantings, but it will also encourage weed species invasion.

e. Pollinator Habitat
    i. Landowners are encouraged to plant vegetation that may attract and support pollinators, such as birds and butterflies. Consult Xerces's California Planting Guide to select pollinator plants best suited to your area.

References

1. Ladd, B. & Frankenberger, J. *Management of Ponds, Wetlands, and Other Water Reservoirs to Minimize Mosquitos*. (2003).
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Appendix B – Relevant Agencies

Relevant agencies that may have jurisdiction and regulating authority over actions relating to replenishment actions with associated changes in land use.

Resource	Local	State	Federal
Drinking Water	Cities, Counties, Community water systems, GSAs	CDFW, DWR, PUC, SWRCB	Federal Energy regulatory Commission, NMFS, US Bureau of Reclamation, EPA, USFWS
Irrigation Water	Cities, Counties, Irrigation water suppliers, GSAs	CDFW, DWR, SWRCB	Federal Energy regulatory Commission, NMFS, US Bureau of Reclamation, US Army Corps of Engineers, USFWS
Water Pollution	Cities, Counties, Community water systems, Wastewater agencies, Drainage districts, CV-SALTs, GSAs	California Department of Conservation, CDFW, DWR, SWRCB, Central Valley Regional Water Quality Control Board	Federal Energy regulatory Commission, NMFS, US Bureau of Reclamation, EPA, USFWS
Land Use	Cities, Counties, Community water systems, land reclamation, levee districts, flood control districts, etc.	California Department of Conservation, CDFW	NMFS, US Army Corps of Engineers, BLM, USDA Farm Services Agency, USDA NRCS, USFWS
Air Quality	Wastewater agencies	CARB, SJV Unified Air Pollution District	US EPA

6. Recommendations for Future Research

Landowners in the San Joaquin Valley are currently facing significant land use change decisions on how to best and most efficiently comply with rapidly approaching SGMA deadlines. These economic and spatial analyses provide groundwater managers and landowners with information and support to make decisions that reduce groundwater pumping. These analyses further give landowners guidance on how to offset the costs of SGMA through engaging in alternative market mechanisms that benefit natural resources and local communities. However, there are still many aspects of multi-benefit replenishment as a means for groundwater management that can be further researched.

The CBA can be improved by further analyzing the amount of habitat credits and payment options available, and whether such payment sources will remain accessible over time. The CBA can also be expanded to consider societal costs and benefits and provide insight into the net benefit results of collective action among landowners. The CBA can be expanded to include other counties within the San Joaquin Valley. This data is obtainable from the USDA National Agricultural Statistics Service and county crop reports. Finally, a more robust CBA would include flexible land acreage and groundwater replenishment targets. The current inputs in the model are for a 5000 acre farm with an annual replenishment target of 1000 AF.

To improve the MBOM, additional metrics can be utilized to make the model more comprehensive. For example, adding a metric of labor loss by crop type would allow the model to address the societal impacts of replenishment projects. To robust the economic analysis of the MBOM, crop profit margins can replace current crop revenues to better select crops based on net cost rather than revenues which do not account for changes in operational costs.

In all, the CBA and MBOM are designed to be used as complimentary tools in guiding stakeholders in Kern County achieve groundwater sustainability. The CBA has been designed to be interactive and can be used by landowners in Kern County to determine which groundwater replenishment method is right for them. GSAs and other public agencies can also utilize the CBA tool to determine if additional payments are needed to make multi-benefit methods economically viable. Once a landowner decides to fallow and create habitat (wetland or upland), the MBOM can provide guidance as to where she can site her projects. To facilitate multi-benefit replenishment solutions further, a programmatic safe harbor agreement can be devised by an NGO or other third party.

Both the spatial and economic analyses have been designed as functional tools for landowners, GSAs, and additional stakeholders to deliver specific recommendations at different spatial scales. This will encourage multi-benefit replenishment strategies throughout Kern County, the San Joaquin Valley, and other agricultural areas of California to meet groundwater sustainability goals. Information gathered through these analyses has been synthesized to generate a sample Groundwater Sustainability Plan chapter that can enable newly created GSAs to pursue multi-benefit groundwater management.

Appendices

Appendix 1 – Cost Benefit Analysis Model Description and User Guide

The purpose of the BasinBenefits Cost-Benefit Analysis (CBA) model is to assess the economic feasibility of groundwater replenishment project methods for all the different crops grown in Kern County. This CBA model is dynamic in that a user of the model can change certain parameters to view a cost-benefit outcome scenario. This section discusses the functionality of each tab in the excel workbook, serving as a user guide for the CBA model. The following sub-sections correspond, in order, to each of the tabs in the CBA excel model.

GR&A

- The Ground Rules & Assumptions (GR&A) tab discusses the motivation and background of this project, general model assumptions, and all assumptions made for each of the groundwater replenishment methods.

INPUTS

- The Inputs tab houses the general model inputs (discount rate, acreage, crop type, crop revenue, crop operational costs, crop applied water, quantity of acres fallowed, water purchase type, groundwater depth, and groundwater pumping electricity cost. This tab also houses the derivation of the inputs for the individual groundwater replenishment method tabs.
- Only the following cells (for the general model inputs) are able to be changed by the user:
    - Discount Rate – dropdown menu available
    - Crop Type – dropdown menu available
        - Selecting the crop type automatically changes the crop acre revenue, crop acre operational costs, crop applied water, and quantity of acres fallowed. Manually overriding one of these values will then cause the model to not work when selecting a different crop type. The “Qty Acres Fallowed” cell is determined by the crop applied water and the 1000 AF target amount.
    - Water Purchase Type – dropdown menu available
    - Groundwater Depth (ft) – manual entry
    - Groundwater Pumping Electricity Cost ($/kWh) – manual entry
- Full production acreage (5000 acres), and groundwater recharge target amount (1000 AF) are constants in the model. The functionality to vary these inputs is not built into the model. This would have required significant research to estimate economies of scale relationships between size of a landowner operation, and all input costs and benefits. These relationships will play out and will be better determined over the course of SGMA implementation.
- Data on the unique inputs for each of the replenishment methods were collected from various sources. Users of this model can make changes to the existing

values in these cells, but should not add or delete items in order to preserve the functionality of the model. A drop down menu also exists for (4) Fallow + Upland, in which a user may select between Temporary or Permanent habitat.

Summary

- Results tab comparing all methods and displaying a sensitivity analysis. This tab pulls the total cost and benefits from the subsequent individual replenishment method tabs. To preserve model functionality, the user should make no cell adjustments on this tab.

0 – Full Production & Baseline Fallow

- Method 0 results tab based on the inputs selected in the “INPUTS” tab. To preserve model functionality, the user should make no cell adjustments on this tab.

1 – In-Lieu (SW)

- Method 1 results tab based on the inputs selected in the “INPUTS” tab. To preserve model functionality, the user should make no cell adjustments on this tab.

2 – On-Farm Recharge

- Method 2 results tab based on the inputs selected in the “INPUTS” tab. To preserve model functionality, the user should make no cell adjustments on this tab.

3 – Fallow + Wetland

- Method 3 results tab based on the inputs selected in the “INPUTS” tab. To preserve model functionality, the user should make no cell adjustments on this tab.

4 – Fallow + Upland

- Method 4 results tab based on the inputs selected in the “INPUTS” tab. To preserve model functionality, the user should make no cell adjustments on this tab.

5 – Data Sources

- Links or lists the data sources for all data in the model. For more information on data sources, refer to the CBA content section of this report.

Data >>

- Workbook section break. All following tabs house the normalized cost and benefit data used within the model.

Data Validation & Calculations

- This tab links to data validation drop downs on the INPUTS tab, and has back-end metric/standard conversions. To preserve model functionality, the user should make no cell adjustments on this tab.

Climate Forecast

- This tab uses historical data from the National Oceanic Atmospheric Administration (NOAA) and the US Bureau of Reclamation to determine future climate scenarios. These climate scenarios are correlated with “normal,” “high” and “very high” surface water pricings. The forecasted future climate for 2018-2045 is relevant for the “1 – In-Lieu (SW)”, “2 – On-farm Recharge”, and “3 – Fallow + Wetland” tabs.

Crop Revenues

- This tab feeds the “Crop Acre Revenue (2018 $)” cell on the INPUTS tab. Data was collected from the USDA National Agricultural Statistics Service (NASS) and Kern County Agricultural Reports. This CBA model can, in the future, be expanded to include other counties if crop revenues are compiled from NASS and other county crop reports. Additional columns may be added on this tab for a given county, and a county drop-down can be added on the INPUTS tab. If a user chooses to override an acre crop revenue value currently listed in this tab, it is suggested that the user make a note of the original value and add the new source in the “Data Source” column. Changing an acre crop revenue value on this tab will run the updated value through the CBA model.

Crop Operational Costs

- This tab feeds the “Crop Acre Operational Costs (2018 $)” cell on the INPUTS tab. Data was collected from the UC Davis Cooperative Extension cost studies. If a user chooses to override an acre operational cost value currently listed in this tab, it is suggested that the user make a note of the original value and add the new source in the “Data Source” column. Changing an acre operational cost value on this tab will run the updated value through the CBA model.

Fallowing & Economic Impacts

- This tab feeds the “Crop Applied Water (AF/acre)” cell on the INPUTS tab, which determines how much acreage needs to be fallowed to meet a 1000 AF groundwater reduction target for each crop (the “Qty Acres Fallowed OR Avoided Fallowed” cell on the INPUTS tab). Applied water amounts per crop were obtained from the California Department of Water Resources (DWR). This tab also shows “lost labor” from fallowing to reach a 1000AF target, in both a wetland and upland scenario for each crop type. If a user chooses to override an “Applied Water (Acre-foot per Acre) value currently listed in this tab, it is suggested that the user make a note of the original value and the new source. Changing an applied water value on this tab will run the updated value through the CBA model.

Inflation Table

- This tab contains the US Bureau of Labor Statistics (BLS) Consumer Price Index (CPI) for January 2018. The inflation index was necessary to use in the model in order to convert the collected historical data into a base year dollar. The model converts all collected data to a base year 2018 (using the January 2018 index). This CBA model may be updated user newer versions of the CPI (as they are made available on the BLS website), by copying and pasting over the current values in the “To Jan. 2018” column.

Appendix 2 – USDA National Agricultural Statistics Service (NASS) to California Department of Water Resources (DWR) Crop Name Crosswalk

The following excel file was created in order to crosswalk crop names of the revenue data (USDA NASS) with the crop names of the spatial data (LandIQ).

BasinBenefits_Crop Name Crosswalk_Fir

Appendix 3 – Cost Benefit Analysis Model

The following excel file houses the CBA model comparing the five groundwater replenishment method scenarios. This file also houses all relevant data to perform economic outcome comparisons between different crop types in Kern County, with the ability to alter select model parameters (refer to Appendix 1 for user guide instructions).

BasinBenefits_CBA_Final.xlsx

Appendix 4 – Summary of MBOM Spatial Data Sources

Field Outlines

Field outlines are supplied by the user to designate potential project boundaries. Fields must have crop data that defines the crop being grown on each agricultural field. The MBOM can only operate on fields located within the Kern County. Fields designated as a "non-crop" are excluded from the analysis (i.e., runway, equipment, mechanical, processing, etc.). Fields considered open farmland, however, are included in the analysis (i.e., idle or currently fallowed farmland). Fields identified as "nurseries" were intersected with data from the DWR Land Use Viewer LandIQ Crop Data (2014) to determine the specific crop being grown. For Kern County analysis, crops outlined in LandIQ Crop Data were used as the field boundaries.

San Joaquin Kit Fox Habitat

The San Joaquin Valley Kit Fox (*Vulpes macrotis mutica*) is listed as a Federally Endangered and California Threatened species. SJV kit fox data was created and modeled by US Fish and Wildlife. US Fish and Wildlife generated a species boundary map to determine which areas of the San Joaquin Valley were most suitable for SJV kit fox habitat. The average home-range size for kit foxes is 5 kilometers. The MBOM conservatively selected a buffer distance of 5 kilometers for kit fox range.

Tipton Kangaroo Rat Habitat

The Tipton kangaroo rat (*Dipodo*mys *nitratoides*) is listed as a Federally Endangered and California Endangered species. Areas determined as potential habitat for the Tipton kangaroo rat were modeled by the University of California, Santa Barbara Bren School of Environmental Science and Management's Wildlight Master's Project in 2015. A Maxent generated species distribution model that utilized 12 predictor variables was used to determine which areas may provide the most suitable habitat for Tipton kangaroo rats.

High Priority Conservation Areas

The Nature Conservancy (TNC) aggregated data from the Ecoregional Assessments used across TNC to identify areas of biodiversity significance and prioritize conservation action. More information about ecoregional assessments and other conservation planning methodologies is available at TNC's Conservation Gateway, the Ecoregional Assessment Status Tool (EAST).

Habitat Corridors

Dr. Patrick Huber of UC Davis published a peer-reviewed dissertation on habitat connectivity areas in the Central Valley in 2012. Dr. Huber's spatial model identified and prioritized areas for conservation that would enhance ecological networks.

Conservation Easements and Protected Areas

The California Conservation Easement Database compiled easement records (both spatial and tabular) from land trusts and public agencies throughout California in a single, up-to-date, sustainable, GIS compatible, online source. Conservation easement data was collected as of 2017 for the San Joaquin Valley. Data for existing protected areas was collected from the California Protected Areas Database. The Database includes spatial data on the protected federal, state, local and private lands in California. California's conservation easements and protected areas were spatially joined to create a single spatial layer.

Crop Revenue

Data on the annual revenue from Kern County crops was collected from the USDA's NASS Pacific Regional Field Office. NASS publishes an annual dataset that aggregates all of the annual crop reports compiled by the California County Agricultural Commissioners. This analysis uses the "2016 County Ag Commissioner's Data Listing," which is the latest published dataset on the NASS website. NASS's dataset of aggregated county data includes crop name, total value, harvested acreage, total production, and unit price (for tons, lbs, dozen, cubic weight, etc., depending on the crop type). To obtain an acre value for each crop name by county, "Total Value" was divided by "Harvested Acres" as a way to analyze the cost to replace agriculture with benefit replenishment projects.[10] Because upland benefit replenishment projects vary by fixed costs and variable costs, the annual foregone revenue by crop and by acre was used as the field cost. This calculation assumes that the crop's yield by acre is constant from field to field.

Soil Agricultural Groundwater Banking Index

The Soil Agricultural Groundwater Banking Index (SAGBI) was developed by UC Davis' California Soil Resource Lab in 2017 as a suitability index for groundwater replenishment on agricultural land. The SAGBI considers five factors for replenishment: deep percolation, root zone residence time, topography, chemical limitations, and erodibility. Suitability is classified on a scale of Very Poor to Excellent for replenishment. For optimizing wetland benefit replenishment projects, different factors within SAGBI were weighted differently in order to promote seasonal wetlands with moderate percolation. Therefore, areas with SAGBI deep percolation and root zone residence time scores less than 35 (low percolation) and greater than 85 (high percolation) were excluded from the model. Remaining areas were then scored according to the remaining factors of topography, toxicity, and erodibility. This re-scoring will allow for groundwater replenishment areas that are more suitable for wetland benefit replenishment projects.

Nitrate Groundwater Quality

Although not studied within this project, the movement of groundwater in the San Joaquin Valley is complex due to the valley's topography, alluvial fans, and modification of the natural hydrologic system.[3] Groundwater nitrate pollution depends on land use practices, soil characteristics, climate, hydrogeology, aquifer replenishment rate, depth to the water table and other geophysical characteristics to know the effects and movement of nitrate pollution. Due to the site-specificity of groundwater movement at potential replenishment sites, the model conservatively excludes areas of high nitrate groundwater pollution from its analysis. Nitrate data was collected from UC Davis' 2017 Nitrate Study and interpolated using an inverse distance weighted GIS model.[5] The California SWRCB's Maximum Contaminant Level for nitrate is 45 mg/L, which will be the cutoff for potential wetland benefit replenishment projects.

Depth to Groundwater

Spring 2017 depth to groundwater spatial data was collected from DWR Groundwater Information Center Interactive Map Application Spring 2017 data was aggregated from the California Statewide Groundwater Elevation Monitoring (CASGEM) Program, where monitoring entities upload groundwater level data semiannually. Groundwater levels less than 20 feet below ground level were excluded from the model optimization.

Because the CASGEM Program relies on self-reporting, many areas of Kern County are not monitored. Groundwater levels were therefore collected from recent well completion reports. When a well is drilled, the groundwater level is marked on a well completion report that is subsequently is submitted to DWR. In the unmonitored areas of eastern Kern County, wells drilled between 2012- 2017 had an average groundwater level of 279 feet. Ninety-percent of wells reported groundwater levels deeper than 51 feet below grounds surface. Similarly, the average groundwater well level between 2012-2017 in western Kern County was 139 feet with 90% of levels being deeper than 75 feet below the ground surface. Thus, the MBOM assumes that shallow groundwater areas reported by CASGEM (largely between the most western and eastern areas of Kern County) are representative of the shallowest areas of the county.

Giant Garter Snake Habitat

The Giant Garter Snake is a Federally Threatened species, which relies heavily on wetland areas in California's Central Valley. Giant Garter Snake spatial habitat data was collected from the United States Geological Survey's National Gap Analysis Project Species Data Portal.

Appendix 5 – Groundwater Nitrate Pollution and Replenishment

Although not studied within this project, the movement of groundwater in the San Joaquin Valley is complex due to the valley's topography, alluvial fans, and modification of the natural hydrologic system.[145] Before major agricultural cultivation and water diversions, replenishment occurred in the mountain fronts and groundwater moved laterally until it discharged in streams and wetlands.[146] Development of the groundwater basin for agriculture increased demand on both groundwater and surface water. Thus, irrigation water became the primary form of groundwater replenishment, causing water and solutes (e.g., pesticides and fertilizer compounds) to move vertically downward through the aquifer.[145]

The agricultural use of inorganic, nitrogen fertilizers is a significant contributor to nitrate-nitrogen groundwater contamination due to historical fertilizer application between years 1960 and 1980.[147] San Joaquin Valley's rural population, namely farm workers and surrounding towns, rely almost exclusively on shallow domestic wells (<150 m deep) for sources of drinking water, of which many have been negatively affected by nitrate contamination.[148] Of 200 domestic drinking water wells across the Stanislaus, Merced, Tulare, and Kings Counties, 46% measured nitrate (NO_3) levels above the EPA's maximum contaminant level (MCL, 45 mg/L).[148] The consumption of nitrate-contaminated drinking water can cause low blood oxygen in infants, known as "blue baby syndrome"[149] and has also been linked to cancer[150] and non-Hodgkin's lymphoma.[151]

However, groundwater nitrate pollution depends not only on land use practices, but rather soil characteristics, climate, hydrogeology, aquifer replenishment rate, depth to the water table and more before knowing the effects and movement of nitrate pollution.[147] Although many studies have researched how landscapes, land use and well depth are related to groundwater nitrate pollution, less research has been performed on how active groundwater replenishment projects may affect groundwater nitrate. Two arguments on how replenishment will affect nitrate behavior have developed in light of SGMA: (1) active groundwater replenishment projects will blend and dilute groundwater nitrate plumes with good quality surface water, and (2) active groundwater replenishment projects will displace and mobilize groundwater nitrate plumes down gradient to potential domestic drinking water wells. Due to the lack of scientific understanding and site-conditional behavior, the following summarizes both arguments, as well as provides a recommendation for how to best proceed with active groundwater replenishment projects.

First, the dilution argument lies in the principle that the infiltration of high quality surface water into aquifers will blend and dilute concentrations of poor groundwater quality to less than MCLs, thereby improving groundwater quality. Because the dominant movement of groundwater is downward, the decline in groundwater nitrate concentrations may be a result of diluted nitrate pollution and nitrate attenuation processes.[152] Attenuation processes include the biological process of denitrification where nitrate is biologically reduced (converted) to nitrogen gas (N_2).[145] This would lead to nitrate pollution declining due to active blending, biological processes, and dispersion as water moves deeper into the aquifer.[145] Public-supply wells typically have screens (windows) that span different aquifers to collect different ages of water that would further blend different qualities of groundwater.[145] However, nitrate contamination in the San Joaquin Valley is shallow, leaving smaller domestic drinking water wells vulnerable due to quicker groundwater movement, less dispersion, and less potential for groundwater blending.[145]

Groundwater flow directions and subsequent direction of groundwater nitrate plumes are highly variable due to local agricultural pumping, local domestic well pumping, and active replenishment sites.[148] The opposing argument where active replenishment may negatively impact groundwater quality asserts that little blending and dispersion exists within the groundwater table and nitrate plumes will be pushed and mobilized to downstream wells rather than being blended. For either argument, tracing groundwater pollutants is hard to determine without advanced tracer modeling and installing observation monitoring wells around replenishment sites.[148] Research performed in Livermore, California, using nitrate isotope data determined nitrate contamination was amplified by artificial replenishment near nitrate source areas.[153] This research further recommended that unconfined aquifers (where replenishment projects will most likely take place) are especially vulnerable to nitrate mobilization due to high rates of vertical replenishment.[153] Research performed in the San Joaquin Valley determined that the dominant land use type within 1.5 miles of each domestic well is significantly associated with the level of nitrate use.[148] For example, wells surrounded by citrus production have median nitrate values above the drinking water limit due to high fertilizer rates and permeable soils.[148] The same research also found that mean ages of groundwater produced from domestic wells ranges from one to six decades and therefore, found well nitrate levels reflect cumulative land use impacts.[148] Thus, when active water is replenishment near these sites, replenishment can potentially mobilize ten to sixty years of cumulative nitrate pollution to nearby domestic wells.

Specific research on the behavior of how depleted aquifers in the San Joaquin Valley will respond to active replenishment is numerous but is lacking with respect to water quality effects. Kamyar Guivetchi, manager of the Statewide Integrated Water Management at the DWR, noted that managed aquifer recharge is a ground-breaking project that may be undertaken without full investigation of the potential risks and benefits.[154] Research currently being performed by Groundwater Resources Association and Sustainable Conservation will specifically investigate the potential water quality impacts from managed aquifer recharge and on-farm flooding.[154] Until water quality impacts are concrete, the liability of potentially exacerbating groundwater nitrate pollution to vulnerable domestic drinking water wells is high.

Treatment processes to remove nitrates from drinking water are costly and have high fixed costs that affect smaller drinking water systems disproportionately.[155] The cost of treating and provide nitrate-compliant drinking water to an estimated 10,000 rural homes in California's San Joaquin Valley is at least $2.5 million or $80-$142 per person per year.[155]

Until the effects of groundwater replenishment projects on groundwater nitrate pollution are further studied, sites suitable for wetland replenishment projects should be conservatively placed where groundwater nitrate concentrations are less than the MCL and where nitrate plumes do not exist down-gradient where there may be the potential to affect domestic drinking water wells. Additionally, it is recommended that landowners map domestic drinking water wells surrounding all agricultural properties and potential replenishment sites to monitor any movement of groundwater pollutants.

Appendix 6 – Oil and Gas Production Research

The oil and gas industries are critical to the economy of the San Joaquin Valley. Oil and gas have a particular importance for Kern County, which contains 78% of all active wells in California, which amounts to over 70% of the state's oil production and over 60% of the state's natural gas production.[156,157] Oil and gas production amounts to 14% of Kern County's private-sector economic output.[158] A collaboration between FracTracker Alliance, Earthworks, and Clean Air Task Force produced the "Oil & Gas Threat Map 2.0" to display areas in the US with health impacts from oil and gas air pollution. One of the indicators used to determine such health impacts is number the number of people living within ½ a mile distance from an active oil and gas well. The threat map uses data from the Census, Department of Education, and oil and gas facilities. With Kern County being the largest oil producer of any county in the lower 48 states, over 75,000 of its residents live within a half mile of the nearly 54,000 oil and gas production facilities.[159]

As landowners move towards adopting groundwater replenishment projects as a SGMA compliance strategy, GSAs and other water management stakeholders should consider the location of oil and gas extraction wells and pipelines for groundwater replenishment project placement. An average oil and gas well-depth is between 6,000 and 8,000 feet, while the average aquifer/groundwater well depth in the Central Valley is a few hundred feet.[160] Assuming a properly constructed oil/gas well including the associated facilities, there is a low probability of co-mingling between oil/gas reserves and groundwater. One concern is that some oil/gas well casings may corrode and leak overtime. California's Division of Oil, Gas, and Geothermal Resources (DOGGR), within the Department of Conservation, oversees the drilling, operation, and decommissioning of wells across the state.[160] DOGGR also serves as the clearinghouse for California's oil, gas, and geothermal industries by maintaining well records and logs, and production and injection statistics. As a product of this data, DOGGR is currently building the Gas Pipeline Mapping System (GPMS), which contains the location and attributes of active gas pipelines and whether a pipeline is in a sensitive area.[161] Operators submit updates of this pipeline data to DOGGR annually. Other pipeline mapping programs available are National Pipeline Mapping System (NPMS) of the US Department of Transportation (DOT), and the California State Pipeline Mapping System (SPMS), of the Pipeline Safety Division of the California State Fire Marshal. The positional accuracy of NPMS and SPMS is ~500 feet and ~100 feet respectively, while DOGGR's GPMS offers a more accurate analysis with a positional accuracy of ~10 feet. To ensure there is no threat of groundwater contamination, replenishment project planners should consider the current and historical leak status of nearby wells and pipelines using the aforementioned publicly available datasets and map viewers.

Appendix 7 – Groundwater Replenishment Crediting Case Examples Research Notes

Semitropic Water Storage District

Summary: Semitropic proposed new set of charges in March 2017, where revenue from the new charges will be utilized to acquire additional surface water supplies for the District on behalf of all landowners to assist with: SGMA compliance; long-term water supply development; and mitigation of water supply impacts on land development. Charges are based upon average consumptive use for all lands within the storage district. Semitropic is currently paying service charges to calculate the average evapotranspiration measured by remote sensing technology, satellite imagery, evapotranspiration monitors, and surface renewal stations. Lands with consumptive use greater than the baseline are charged per AF for water consumed over the baseline. Lands with consumptive use lower than the baseline receive credit that (1) can be paid directly, (2) be utilized to offset other charges of the District, or (3) be converted to a stored water credit. Also proposed is a New Lands Surcharge, which covers cost of Semitropic to acquire additional water supplies for lands developed for irrigation or other water uses during or after 2017.

Questions: Clarity on the differences in land that is eligible for basin sustainability charge/credit vs. the recreation sustainability charge/credit – when is one applied versus the other? What is the status of these proposed charges/credits? How is the District accounting for the risk of a majority of landowners earning credits, and then seeking to use their full credits to extract during dry years (will there be a shortage of supplies)? Or vice versa, if the charge is set too low and majority of landowners choose to over-extract initially?

Fox Canyon Groundwater Management Agency

Summary: Fox Canyon initiated pumping allocations and credits in 1990, which required 5% reductions every 5 years for a total of a 25% reduction. Users pumping less than their allocation were rewarded with a conservation credit to be banked and redeemed in future years. Those who over-extracted incurred large penalties. Withdrawals reduced to the safe yield in just 2 years (resulted in over-compliance with a large number of credits generated). Baseline allocations of 1AF per acre were granted to new agriculture and municipal and industrial uses. Crop Irrigation Allowances establish a benchmark water usage for different crops, evapotranspiration zone, and precipitation. Transfers of extraction allocations were permitted in limited scenarios and most commonly when agriculture was converted to municipal and industrial. Less common transfers included leases and one-off transfers on a case-by-case basis. Conservation and storage credits could have been transferred with approval of the Agency when there is a net benefit to the aquifer. In response to the 2014 drought, Ordinance E reduced the historical allocation cap and crop irrigation benchmarks, suspended the generation or redemption of conservation credits, and required agricultural users to switch to crop irrigation allowances.

Questions: What is the current status of the new allocation regime? How has FCGMA addressed these issues in their current water market program? Do they issue replenishment credits (other than in-lieu pumping or improved efficiency measures)?

Shafter-Wasco Irrigation District (SWID)

Summary: Shafter-Wasco Irrigation District (SWID) engaged in an agreement with Pacific Resources LLC. Pacific Resources was planning for unfarmed lands in 2017 and had access to water supply from Friant-Kern Canal. Per the agreement, landowners can use unfarmed lands at Pacific Resources to replenish the aquifer in exchange for SWID agreeing to acknowledge a "SGMA credit" for replenished water. Replenished water is measured by SWID turnouts, "less losses of 6%" provided that the SGMA credit is consistent and applicable to the GSP, and that the SGMA credit is to offset pumping of groundwater for use within SWID. SWID makes no warranties that SGMA credit will be allowed under the future GSP. The landowner is responsible for all replenishment costs. The landowner will reimburse SWID $1.34 per AF for operation and maintenance costs associated with the replenishment water delivery through the Friant Kern Canal and SWID distribution pipelines. Replenishment water deliveries are at the discretion of SWID and SWID is not liable for damages to landowner per the agreement.

Questions: Has SWID pursued similar agreements with other landowners? Are there any other extraction rules associated with the replenished water? How do the landowner assess the risk of this agreement if SWID makes no warranties?

Eastern Tule Groundwater Sustainability Agency

Summary: Porterville Irrigation District within the Easter Tule GSA is issuing invoices to landowners performing replenishment. These invoices and receipts are not yet institutionalized as part of the GSP, and there is uncertainty over whether these credits will enter the landowner accounts when created. The Porterville Irrigation District's 5-Year Update Agricultural Water Management Plan (July 2012) mentions a conjunctive use program, where the District leases rights to replenishment water in privately-owned borrow pits and retention basins owned by the city of Porterville. Additionally in dry years, the Porterville Irrigation District has groundwater banking arrangements with Terra Bella Irrigation District, Tea Pot Dome Water District, Stone Corral Irrigation District, Vandalia Irrigation District, and Pioneer Water Company.

Questions: Potentially reach out to Porterville Irrigation District Project Manager to ask about the scale of the replenishment efforts. And, how they performed outreach prior to issuing invoices? How do they plan to account for replenishment (amount applied vs. increased groundwater levels), and are there are assurances for future extraction amounts?

SWRCB Temporary Replenishment Permit Application Examples

Summary: Applications to-date are from 5 areas (City of Huron, Scott Valley Irrigation District, Yolo County Flood Control & Water Conservation District, City of Corona, and Eastside Water District). Temporary replenishment permits range from storing water for future irrigation and municipal uses, flood reduction, capturing stormflows, temperature TMDLs, benefitting instream flows for fish, reducing environmental damage downstream. Permit replenishment volumes range from 5,000AF – 72,000AF over six month durations. A portion of the water for Scott Valley Irrigation District was used for the UC Davis study to research on-farm flooding effects. A co-benefit of the Yolo Project is the winter flooding of crops for waterfowl and shorebirds during migration and preserving habitat along the Pacific Flyway (collaborating with Audubon California).

Questions: How long is the SWRCB temporary permit program expected to continue? Which of these programs have employed landowner crediting schemes? How are the UC Davis landowner partners being crediting for their on-farm recharge efforts?

Appendix 8 – Barriers to "Early Action" Groundwater Replenishment Crediting

The original proposal for this research project, "Developing an Early Action Framework for Groundwater Sustainability with Groundwater Sustainability Agencies and Stakeholders," aimed develop a framework of actions and incentives for willing agricultural producers to start achieving sustainability goals prior to Sustainable Groundwater Management Act (SGMA) deadlines. Although the underlying purpose of this research remained the same, the framework pivoted from an "Early Action" focus to a longer planning horizon within Groundwater Sustainability Plans (GSPs). The need to pivot from an Early Action Framework resulted from research and interviews with relevant stakeholders and regulators. Significant barriers for implemented early groundwater sustainability actions namely included: determining sustainable yields, assurance, resource capacity, equity and timing.

Sustainable Yield – Groundwater Sustainability Agencies (GSAs) are responsible for the difficult task of determining an effective sustainable yield to reach SGMA compliance by 2020 (to be submitted with GSPs). Because land use and climate conditions change over time, a hydrogeology model will have larger degree of uncertainty around sustainable yield estimates. Because of this uncertainty, consultants and GSAs will need to choose the most appropriate sustainable yield to be applied within the basin or rather the "most desirable" sustainable yield, so long as the calculation is approved by the DWR. For early action, the sustainable yield would need be tailored in a way to account for a more favorable carryover rate for replenishment efforts that occurred prior to the sustainable yield calculation and GSP. Thus, a layer of complexity is added to the sustainable yield calculation when recommended early action replenishment or fallowing due to the need to account for replenished water extracted at a later date.

Assurances – DWR is responsible for approving sustainable yields and GSPs. Therefore, GSAs are hesitant to employ pre-GSP actions that may not be ultimately approved in GSPs in 2020. For example, if a GSA authorizes an early action credit program for groundwater banking, these credits may be obsolete or no longer valid if DWR does not approve the GSP and therefore, does not approve the early action credit program. Additionally, early action groundwater banking may be deemed by DWR as a "benefit to the basin" and as a result, would not allow the private groundwater user to call upon credits for individual use.

Resource Capacity – Newly formed GSAs are already resource-limited in developing expensive hydrogeology models to inform a resource-heavy GSP by 2020. Therefore, GSAs do not have the capacity to employ an early action program. GSAs will most likely consider any early action sustainability efforts before GSP implantation as a benefit to the basin.

Equity – For an early action program to be successful, important consideration would need to be given to how the program is designed to ensure equity amongst all users in the basin. Conversations with relevant researchers cited the risk of lawsuits from landowners who disagree with program actors being favored and unfairly compensated.

Timing – An early action groundwater sustainability program would require groundwater replenishment efforts to take place from 2018 - 2020. However, recharge basins may take up to three years from design to final construction. Thus, landowners who already have recharge basins may be the only actors to benefit from an early action program.

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