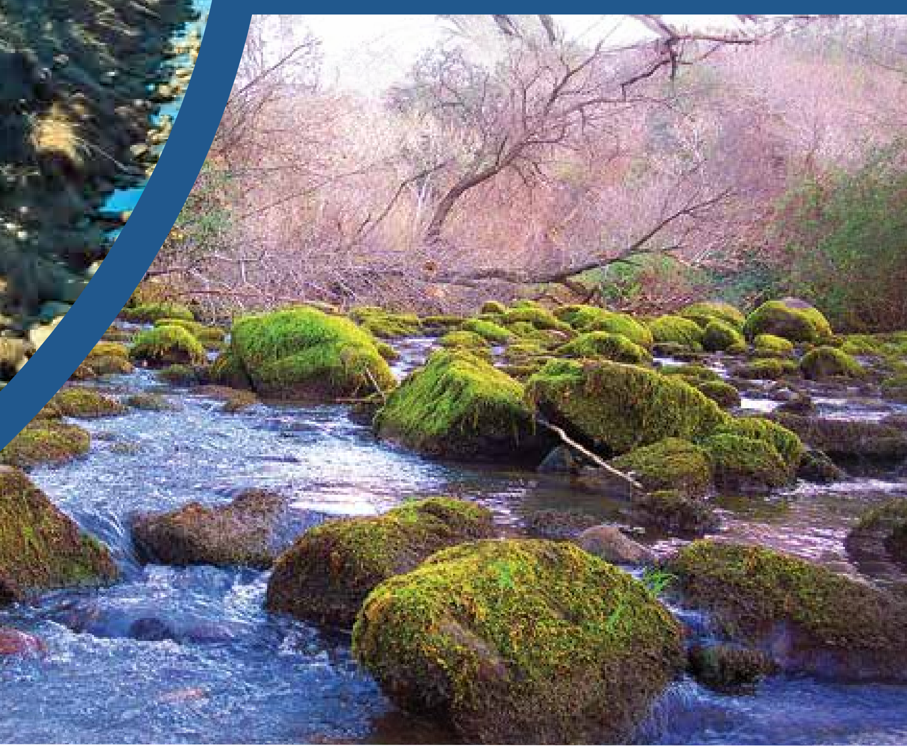
Groundwater Sustainability Plan Solano Subbasin

Draft Section 8 Projects and Management Actions



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8. SUSTAINABLE GROUNDWATER MANAGEMENT: PROJECTS AND MANAGEMENT ACTIONS (§ 354.44)

This Section describes the projects and management actions (PMAs) that have been considered or developed for implementation in the Solano Subbasin (Subbasin). In accordance with 23 CCR §354.44, PMAs were developed to achieve and maintain the Subbasin sustainability goal by 2042 and avoid undesirable results over the GSP implementation horizon and beyond. Projects generally refer to structural features, whereas management actions are typically non-structural programs or policies designed to support sustainable groundwater management.

This Section is organized as follows:

- Section 8.1 provides an introduction and description of the need for PMAs in the Solano Subbasin. This section includes an overview of the PMA development approach, goals, and engagement process with the Solano Collaborative.
- Section 8.2 summarizes all PMAs included in the GSP.
- Sections 8.3 thru 8.5 describe the PMAs in accordance with 23 CCR §354.44.
- Section 8.6 describes tools developed by The Freshwater Trust (TFT) that the Solano Subbasin may use to implement select PMAs.
- Section 8.7 summarizes financing and funding mechanisms to pay for PMAs and GSP implementation.

8.1. Introduction

SGMA requires GSPs to develop PMAs that achieve the sustainability goal for the Subbasin and respond to changing conditions in the Subbasin. Implementation of PMAs must result in quantifiable benefits that meet measurable objectives. This Section describes the development process and provides conceptual-level descriptions of PMAs specific to the Solano Subbasin. It also provides detailed information for those activities identified as likely to be implemented within the Subbasin.

Section 5 demonstrates that the Solano Subbasin is generally likely to continue to avoid undesirable results, and therefore remain sustainable, under current and projected future conditions. However, a range of PMAs has been developed so they are ready to be implemented by the GSAs in the event that conditions change in a way that was not anticipated and action is needed to maintain sustainability.

8.1.1. Project and Management Action Goals

Based on Section 5 findings for the historical, current, and projected water budgets, the Solano Subbasin as a whole can be maintained at sustainable groundwater levels and quality with minimal to no additional intervention by the GSAs. However, the northwestern portion of the Solano Subbasin is vulnerable to declining groundwater levels. Therefore, the PMAs identified in this GSP are generally not required to be implemented to maintain sustainability throughout the Solano Subbasin, but they are available to the GSAs should conditions anywhere in the Subbasin demonstrate a need.

In both the current land use and projected future land use water budget scenarios, groundwater storage in the Solano Subbasin is forecast to increase modestly at an average rate of approximately one (1) thousand acre-feet per year (TAF/yr). In the projected water budget with future land use and adjustment for the 2070 central tendency (2070CT) climate change scenario[1], groundwater storage is still projected to modestly increase at a rate of approximately 0.8 TAF/yr, despite climate-related effects on irrigation demand and an associated increase in groundwater pumping. This change in groundwater storage is less than 0.2 percent of the more than 450,000 acre-feet (AF) of water that flow into and out of the Solano Subbasin groundwater system annually.

The aggregate changes in groundwater storage are considered to be within standard modeling error for this type of analysis. Section 7 Monitoring Data and Reporting, and Section 3 Basin Setting, identify data gaps that will be addressed as part of GSP implementation (Section 9), which will improve the modeled outputs, water budget parameters, and understanding of the Solano Subbasin groundwater conditions.

As described above, localized areas of declining groundwater levels are present in the northwestern region of the Subbasin. In an approximately 38,000-acre area identified as the "Northwest Focus Area," localized groundwater levels have declined by approximately 10 feet or more between 1988 and 2018 (see Section 5.8.1 for a full discussion of the Northwest Focus Area water budget). PMAs were developed to address this specific area as well as potential future changes in groundwater conditions across the Subbasin.

8.1.2. Goals, Policies, and Ordinances

As described in Section 1.3, the Solano Subbasin is managed by GSAs that span portions of Solano County, Sacramento County, the City of Vacaville, Solano Irrigation District, and numerous reclamation districts (RD), as well as a very small section of Yolo County. The five GSAs[2] have authority over their respective portions of the Solano Subbasin. Goals, policies, and ordinances within the jurisdiction of each of these entities have the potential to affect ongoing groundwater sustainability and GSP implementation in the Solano Subbasin.

The Solano Collaborative has held regular, joint meetings throughout GSP development to maintain ongoing collaboration and alignment of SGMA-related goals across all agencies within the Solano Subbasin. Prior to, or upon completion of the GSP, a Memorandum of Understanding (MOU), or some other legal instrument, will be executed to describe the governance and implementation of the GSP among the Solano Collaborative members.

The Solano Collaborative includes representatives from Solano County and Sacramento County, which are responsible for ordinances and policies related to well permitting, groundwater aquifer protection, and groundwater use across the Solano Subbasin. Involvement of these representatives in GSP

[1] See Appendix 5B Solano Integrated Hydrologic Model Documentation Report
[2] GSAs include Solano Subbasin, County of Sacramento, Solano Irrigation District, City of Vacaville, and RD 501 in association with Northern Delta. Three small areas (~3,100 acres) within Yolo County are part of Solano Subbasin GSA.

development and implementation facilitates coordination of County-level policies and ordinances that are directly aligned with the Subbasin sustainability goal established by the GSAs and the PMAs described in this GSP.

Specific policies and ordinances that may be reviewed during GSP implementation include but are not limited to:

- Well permitting ordinances to align with well construction recommendations as needed in response to increased understanding of groundwater conditions, and/or to help protect water quality, allow for better screening, and avoid interference or impacts of pumping on neighboring wells. Well permitting ordinances should be designed or revised to protect domestic wells. Protections include, but are not limited to, monitoring requirements or capacity limitations of new wells.
- Ordinances to regulate groundwater use or limit export and illegal diversion of surface water. This would only be pursued if other PMAs were insufficient to maintain sustainability.

As described in Section 2.5 of this GSP, the Solano Subbasin GSP is being developed with outreach to and coordination with stakeholders, beneficial users, user groups, and agencies within the three counties overlying the Solano Subbasin. Therefore, the development, maintenance, and implementation of the Solano Subbasin GSP will also be conducted in alignment with these agencies and their plans to achieve sustainable groundwater management. These agencies include those participating in the Westside Sacramento Regional Water Management Group (Westside RWMG), which implement the Westside Sacramento Integrated Regional Water Management Plan (Westside IRWM Plan) and projects and activities, as described in Section 2.2.8.5 of this GSP.

8.1.3. Development Approach

Development of meaningful PMAs considered the feasibility of implementation and acceptance by stakeholders, in addition to the desired benefits of implementing PMAs. Therefore, development of PMAs was and will continue to be an iterative process with robust stakeholder engagement, adding new PMAs, dropping some, or evolving others due to changing needs of the Subbasin and its stakeholders. Development of PMAs also considered the property owners, private well owners, beneficial users, and other parties that may be impacted or otherwise affected by the implementation of a PMA. Appendix 8a identifies the potential parties that may be impacted/affected by implementation for each PMA described in this Section.

Initial PMA concepts were developed considering the following:

- Will current or projected conditions in the Subbasin lead to unsustainable use of groundwater?
- What PMAs can be implemented to ensure ongoing sustainability?

An initial list of conceptual actions was developed as a “toolbox” of options (Appendix 8b) available to address problems identified by the assessment of historical groundwater conditions and the groundwater modeling results for projected future land uses and climate change. The Westside IRWM

Plan project list was reviewed to identify geographically relevant and beneficial projects to that would advance the Subbasin's sustainability goal. The Solano Collaborative and other members of the individual GSAs provided input on this initial list by refining concepts, submitting new concepts not already on the list, and assessing actions with respect to potential benefits and effectiveness in achieving the sustainability goal for the Subbasin.

8.2. Summary of Projects and Management Actions

Table 8-1 summarizes the resulting PMAs developed through the process described in Section 8.1. As this GSP and its PMAs are implemented, this table, as well as the PMAs described in this Section, will be updated with PMA status changes, new PMAs, or additional details as needed. **Table 8-1** is organized by the following categories:

- Ongoing PMAs are those that are already being implemented within the Solano Subbasin. These PMAs are described in Section 8.3.
- PMAs developed for implementation are those that have been identified as feasible for implementation and align with the GSP goal to maintain sustainability within the Solano Subbasin. These PMAs are described in detail in Section 8.4 and comply with 23 CCR §354.44.
- Potential PMAs are concepts that require additional development to be implemented within the Solano Subbasin. Potential PMAs are not required to maintain sustainability within the Subbasin but may be developed to assist in sustainable groundwater management activities such as data collection or outreach. These PMAs are described in Section 8.5.

As shown in **Table 8-1**, several types of PMAs are included in the Solano Subbasin GSP, such as multi-benefit recharge, a potential demand management program, and other water use projects (e.g., recycled water).

Table 8-1: Summary of Projects and Management Actions

Name	Brief Description
Ongoing PMAs	
Municipal & Industrial Water Use Efficiency Outreach & Implementation	Develop Outreach materials and incentives for municipal and industrial water users to increase water use efficiency.
PMAs Developed for Implementation	
City of Vacaville Recycled Water	Develop City's Recycled Water Program as recommended in the 2020 Recycled Water Master Plan Feasibility Study, including construction and installation of recycled water treatment, storage and conveyance facilities; development of a recycled water use ordinance; updating permits; and identifying customers and executing supply contracts.
Westside Streams Stormwater Capture Project	Develop an implementation schedule for potential projects in the Northwest Focus Area to enhance groundwater recharge and support local groundwater sustainability.

Name	Brief Description
Rainfall Managed Aquifer Recharge Demonstration Project	Evaluate the use of specific managed aquifer recharge activities on local farms to generate multiple benefits for groundwater sustainability and stormwater management.
Potential PMAs	
Other Groundwater Recharge Opportunities	Several conceptual recharge projects have been identified along Ulatis Creek to support ongoing groundwater sustainability in the Solano Subbasin. The Nature Conservancy has provided GSAs with guidelines to implement on-farm, multi-benefit groundwater recharge efforts that would also be applicable in the Solano Subbasin.
Grower Education Related to On-Farm Practices for Sustainable Groundwater Management	Use of Solano Agricultural Scenario Planning System (SASPS), a web-based application that GSAs and other local agencies can use to design voluntary programs to engage agricultural producers in on-farm sustainable groundwater management projects.
Demand Management	Develop a program that would incentivize voluntary participants to reduce water consumption.
Groundwater Trading Institution	Monitor Solano Subbasin conditions and consider a groundwater trading market to increase flexibility (options) to respond to potential demand management programs.
Education and Collaboration	The Solano Resource Conservation District (SRCD), TFT, Local Government Commission (LGC), and RD 2068 all provide groundwater and water conservation education to classrooms and growers within the Solano Subbasin.
Well Owner Outreach and Education	Develop and implement education and outreach about private domestic well monitoring.
Participation in Other Water Resources Management Programs	Implement other groundwater management strategies including further use of recycled water, expanded conjunctive water management, changes to well regulations, and other actions.

8.2.1. Multi-Benefit Recharge

Multi-benefit recharge projects are promising tools to maximize the benefits of recharge for numerous beneficial uses and users of groundwater. For the Solano Subbasin, these projects are focused on capturing and utilizing rainfall runoff on agricultural fields for managed aquifer recharge (MAR). In this GSP, multi-benefit recharge projects that strategically inundate fields with winter stormflows are referred to as “Flood-MAR” projects, whereas recharge projects that strategically capture and recharge rainfall on fields are referred to as “Rain-MAR” projects.

The main goals of these multi-benefit recharge projects are to simultaneously:

- Recharge groundwater supplies using available surface water supplies and runoff, and
- Create temporary habitat for environmental water users, such as migratory shorebirds along the Pacific Flyway.

These multi-benefit recharge projects would be implemented through participating growers that voluntarily flood their fields with available stormflows (Flood-MAR) or construct berms or sumps to capture and recharge rainfall runoff (Rain-MAR). These projects would contribute recharge to the aquifer system and also provide benefits to flood risk reduction, water quality improvement, climate change adaptation, and ecosystem enhancement for wildlife, especially shorebirds during peak migratory periods.

The scale of recharge project implementation will vary depending on grower or landowner interest, which in turn will vary depending on water availability, water reliability, outreach, local interests, incentives (if applicable), and other community needs.

Successful multi-benefit recharge projects will realize the greatest benefit from selecting sites with high groundwater recharge potential, flooding those sites at times when social and environmental benefits are greatest, and implementing recharge methods with the greatest practicality for site conditions. Ideal sites have soil and crop conditions favorable for flooding or rainfall capture (generally between late fall and early spring) during peak migratory periods along the Pacific Flyway (generally July 15-October 1 and/or March 15-April 30), and/or can attenuate excess runoff from developed areas prone to flooding. Practical sites have infrastructure that supports field-flooding and diversion of available stormflows.

Without projects, the Solano Subbasin is generally being managed sustainably now and projections show this condition continuing without undesirable results over the GSP implementation horizon and beyond. Multi-benefit recharge is a concept with great potential to address localized groundwater issues in the Subbasin. Thus, two multi-benefit recharge projects have been developed for implementation in the Solano Subbasin (see Sections 8.4.2 and 8.4.3 for more information).

The Northwest Focus Area was chosen as an area of interest for multi-benefit recharge projects. Groundwater levels in this nominal 38,000-acre area have declined by approximately 10 feet or more between 1988 and 2018 (see Section 5.8.1 for a full discussion of the Northwest Focus Area water budget). Multiple analyses were conducted to identify potential PMAs and suitable locations for their implementation.

Determination and consideration of community challenges and interests were led primarily by the Dixon and Solano Resource Conservation Districts (RCDs) and Local Government Commission (LGC) through previous NRCS Conservation Innovation Grant (CIG) funding and Proposition 1 Severely Disadvantaged Communities (SDAC) engagement projects managed by The Freshwater Trust (TFT). The Dixon RCD also serves as the drainage district and is able to provide important insights into the flooding challenges experienced in northern Solano County. Multiple grower interviews were conducted in 2019 and 2020 by TFT and others to determine community interest, need, and willingness to adopt specific farm management practices.

The GSA Collaborative ultimately selected two multi-benefit recharge PMAs: the first is the "*Westside Streams Stormwater Capture Project*" and the second is the "*Rainfall Managed Aquifer Recharge (Rain-MAR) project,*" both of which are described in detail in Section 8.4.

8.2.2. Demand Management

The GSAs anticipate that the other PMAs included in the GSP (see Section 8.4), will be sufficient to ensure continued, sustainable groundwater conditions in the Subbasin over the GSP implementation period and into the future. However, recognizing the importance of sustainable groundwater management to water users in the Solano Subbasin and the inherent uncertainty in modeling future conditions under climate change, the GSAs considered demand management programs that would be a "backstop" to other PMAs (i.e., considered after implementation of other feasible and cost-effective projects). The Solano Collaborative explored a range of potential demand management actions that would support groundwater management in the Subbasin.

Demand management broadly refers to any water management activity that reduces the consumptive use of water. To be effective for groundwater sustainability, demand management must result in a reduction in combined groundwater pumping. Activities that, for example, reduce canal seepage or reduce deep percolation from irrigation would not be effective; they may decrease quantity of water diverted or applied but they also reduce recharge to usable groundwater, and so do not improve the net pumping from the aquifer.

Demand Management activities included in the GSP (see Section 8.5.3) incentivize, enable, or possibly require water users to reduce their consumptive use, but does not dictate exactly how users do so. Agricultural users can respond to demand management by changing to crops that use less water or can tolerate less water than normally consumed for full yield, reducing evaporation losses, and/or reducing irrigated acreage. Urban users can respond to demand management via in-home conservation programs (e.g., low-flow toilets and shower nozzles), by irrigating less, planting lower water-use landscapes, reducing evaporative losses, and/or reducing landscape area that requires irrigation.

As an example of potential demand management actions, local government entities may consider ordinances to incentivize reductions in groundwater use (e.g., tiered fees for groundwater extractions), or explicitly curtail or restrict groundwater extractions (e.g., ordinances related to landscaping, other water efficiency measures, or a groundwater allocation program). Other examples might include restrictions on land use change that would increase water demand in the Subbasin. At this stage of GSP development, these examples are conceptual only. Demand management is not currently a planned PMA.

8.2.3. Other Water Management

Recognizing the GSP data gaps and uncertainties in the basin setting (per 23 CCR §354.44(d)), other groundwater management strategies may be considered and implemented through an adaptive approach informed by continued monitoring of groundwater conditions. These groundwater management strategies include:

- **Use of Recycled Water:** The GSAs may explore opportunities for using recycled water of suitable quality (e.g., treated wastewater) for direct groundwater recharge and for urban and/or agricultural irrigation to decrease groundwater demand. This can be considered in lieu recharge. The GSAs may also consider providing incentives for using recycled water.
- **Conjunctive Management:** The GSAs may promote and incentivize growers to apply on-farm practices that maximize the use of surface water when it is available, providing in-lieu and direct groundwater recharge to support groundwater pumping in years when surface water is unavailable.
- **Changes to Well Regulations**: The counties may consider creating additional guidelines during the well permitting process to reduce competition between nearby wells (i.e., suggestions regarding well pumping capacity, total well depth, depth of well perforations, and location of a new well in relation to existing wells). These efforts should at minimum be designed to protect domestic drinking water wells, and other domestic wells as needed.
- **Other Actions in Cooperation with Cities and Other Stakeholders**: The GSAs may consider implementing any other actions that reduce groundwater demand and/or increase groundwater recharge.

8.3. Ongoing Projects and Management Actions

As presented in Sections 1 and 2 of this GSP, various agencies within the Solano Subbasin have a history of managing the area's water resources. Ongoing PMAs consist of supporting the continuation and development of these coordinated activities.

8.3.1. Municipal & Industrial Water Use Efficiency Outreach & Implementation

Current efforts within the Solano Subbasin include rebates and programs to help residents save water and money, water-wise tips, events and workshops, and resources for schools:

- Eligible residents served by the Solano County Water Agency (SCWA) and member agencies can apply for rebates[3] for implementing water-conserving products (e.g., swimming pool covers, rain barrels, rain sensors, etc.), installing high-efficiency appliances (such as washing machines), applying smart irrigation techniques for existing landscaping, and replacing lawns with water-efficient landscapes.

[3] https://www.scwa2.com/water-efficiency/rebates-programs/residential-rebates/

- The SCWA website[4] also lists water conservation tips and resources. These tips include saving water indoors (e.g., checking for leaks, how to read your water meter, etc.) and outdoors (e.g., gardening, watering cycles, etc.).
- SRCD's School Water Education Program[5] provides free resources for K-12 educators to teach water conservation. In 2021, they also held a water awareness video contest for the county, which gave monetary prizes to teachers and students for creating videos that spread awareness of water conservation. Funding for this program is provided by the cities of Vacaville, Fairfield, Suisun City, Vallejo, and Benicia, as well as the Solano County Water Agency, Fairfield-Suisun Sewer District, and Solano Irrigation District.
- The Agriculture Water Conservation Committee in Solano County provides resources on irrigation management and water use efficiency to growers within the county. [6] This committee operates weather stations to be used by the growers for irrigation scheduling, soil moisture monitoring, irrigation system evaluation, irrigation scheduling services, and pump efficiency testing. It also provides Irrigation Efficiency Workshops every year in both English and Spanish.

8.4. Projects and Management Actions Developed for Implementation

This section describes the PMAs that were identified through the screening process and were ultimately selected to be developed for quick implementation if needed to maintain sustainability. These PMAs are described in detail in compliance with 23 CCR §354.44.

8.4.1. City of Vacaville Recycled Water

The City of Vacaville 2020 Recycled Water Master Plan Feasibility Study (Carollo, 2020) evaluates the feasibility of providing recycled water to its existing and potential customers. The City owns and operates the Easterly Wastewater Treatment Plant (Easterly WWTP), which treats wastewater collected from the City of Vacaville and the unincorporated community of Elmira. The Easterly WWTP treats wastewater to Title 22 reclamation requirements, including filtration and advanced disinfection, producing water that is allowed for uses by the State Water Resources Control Board such as: park irrigation, animal feed irrigation, industrial uses, and landscaping. This treated water is currently discharged to Old Alamo Creek, a tributary to New Alamo Creek and Ulatis Creek, which flow to Cache Slough and the Sacramento-San Joaquin River Delta (Carollo, 2020).

Although the City currently does not deliver recycled water, the City has been installing recycled water pipelines since 2014 and has required new developments to install recycled water pipeline. As of 2020 there is approximately 20 miles of recycled water pipeline within the City (Carollo, 2020). The City's 2020 Recycled Water Master Plan Feasibility Study (Carollo, 2020) evaluated five concepts for developing its Recycled Water Program:

[4] https://www.scwa2.com/water-efficiency/tips-resources/
[5] https://www.solanorcd.org/projects-and-programs/education/swep.html
[6] https://www.scwa2.com/water-efficiency/agricultural-water-conservation/

Concept 1: Downstream diversions within Solano County and just outside Solano County using existing recycled water pipelines

Concept 2: Irrigation use for local athletic fields

Concept 3: Agricultural irrigation by local farmers

Concept 4: Irrigation for Cypress Lakes Golf Course and Travis Air Force Base

Concept 5: Irrigation for housing developments

8.4.1.1. Water Source

The City of Vacaville obtains its municipal water supply from several natural and man-made streams in the City; Lake Berryessa, a man-made water supply reservoir; and eleven groundwater wells (Carollo, 2020). According to the City's 2020 Urban Water Management Plan (UWMP), the City delivered about 18,000 AFY of potable water to numerous residential, commercial, and industrial customers within the City's service area (Vacaville, 2021). This water is thereafter discharged to the sewer system to the Easterly WWTP. The Easterly WWTP has a permitted dry weather flow capacity of 15 million gallons per day and discharged 8,154 AF of tertiary treated disinfected water in 2020, according to the City's 2020 UWMP (Vacaville, 2021).

8.4.1.2. Construction Activities and Requirements

Implementation of the City's Recycled Water Program is scheduled over three phases: immediate (2018-2022), near-term (2023-2029), and long-term (2030-2037) (Carollo, 2020). Construction infrastructure, activities, and requirements for the Recycled Water Program are shown in **Table 8-2**. Overall, this project includes 10.6 miles of new pipeline over the three phases and a pump station with 675-horsepower (hp) capacity in total (70 hp required for immediate phase, 100 hp required for near-term phase, and 500 hp required for long-term phase). This project also includes a new recycled water truck filling station to be constructed at Easterly WWTP that can be constructed during any phase. A 175-hp booster pump station and 1.45 MG of storage are to be constructed in the long-term phase (Carollo, 2020).

Table 8-2: City of Vacaville Recycled Water Program Construction Infrastructure and Requirements (Carollo, 2020)

		Phase		
		Immediate-Term	**Near-Term**	**Long-Term**
Concepts	**1**	Additional infrastructure is not required. Formal agreements with downstream entities required.		
	2	1,300 LF of new pipeline and 6 HP pump capacity. Agreements are not required as it is for City irrigation.		
	3		4,835 LF of new pipeline and 50 HP of pump capacity for parcel 17C.	9,667 LF of new pipeline and 100 HP of pump capacity for parcels 17G and 17H.
	4		9,800 LF of new pipeline and 19 HP of pump capacity for Cypress Lakes Golf Course.	31,300 LF of new pipeline and 136 HP of pump capacity for Travis AFB.
	5	10,300 LF of new pipeline and 64 HP of pump capacity for Leisure Town Road.	12,400 LF of new pipeline and 55 HP of pump capacity for Leisure Town Road.	32,500 LF of new pipeline, 85 HP of pump capacity, 221 HP Easterly WWTP Pump Station capacity, and 2.3 MG of storage for Vaca Valley Business Park, North Village Development, and the planned development at Gibson Canyon Creek WWTP.

8.4.1.3. Relationship to Sustainability Criteria

This project may offset groundwater pumping by providing an alternative water source for urban, agricultural, and industrial irrigation. Recycled water use as a replacement for groundwater pumping is expected to primarily benefit groundwater levels and groundwater storage. If recycled water is used to offset surface water demand, an indirect benefit of this project would also be expected to benefit groundwater levels and groundwater storage by making surface water available for other groundwater uses.

8.4.1.4. Metrics for Evaluation

Evaluation of the benefits of this project to groundwater levels and groundwater storage may include comparison of pre-project groundwater pumping for irrigation and post-project recycled water delivered for applicable recycled water customers. This approach would require metering of irrigation sources pre- and post-project.

8.4.1.5. Expected Benefits

According to the City of Vacaville Water Master Plan, the proposed potable water offset is approximately 2,830 AF. The City plans to use 1,825 AF within the existing service area; the remainder is to be used outside the City's service area. The two beneficial uses are landscape irrigation and industrial use (Carollo, 2020).

8.4.1.6. Timetable for Implementation

The City of Vacaville Water Master Plan estimates that operations for the immediate-term construction will start in 2023, near-term in 2030, and long-term in 2037. These approximate start dates are likely to change based on design and construction (Carollo, 2020).

8.4.1.7. Notice to Public and Other Agencies

The general public, stakeholders, impacted users and other agencies will be engaged in project implementation activities through the outreach and communication channels and procedures, as identified in Section 9 of the GSP.

8.4.1.8. Legal Authority, Permitting Processes, and Regulatory Control

This project will need recycled water permits, customer agreements, and diversion agreements. The City will need to obtain all permits from the Regional Water Quality Control Board and Division of Drinking Water (DDW). They will also need to conduct an environmental analysis (CEQA) at the start of each implementation phase.

The City will need to receive firm agreements from the recycled water customers and the downstream diversion customers at the start of each implementation phase. The customers' agreements will be made for non-regulatory or financial terms. Diversion agreements will be made to allocate a fixed flow of recycled water to each customer over a period of time for a certain cost.

8.4.1.9. Cost Factors

Planning-level costs were developed and presented in the City of Vacaville Recycled Water Master Plan Feasibility Study and are based on 2017 conditions. As shown in **Table 8-3**, the estimated total project cost is $40M and annual operation and maintenance (O&M) costs are $396,000. Further breakdown of the costs for implementation was provided over the three phases, immediate-term (2018-2022), near-term (2023-2029), and long-term (2030-2037). Actual costs will depend on variables including, but not limited to, labor and materials costs, market conditions, and final project details at the time of implementation (Carollo, 2020).

Table 8-3:City of Vacaville Recycled Water Project Estimated Total Project Costs (Carollo, 2020)

Phase	Estimated Project Cost[1]	Estimated Annual O&M	Annualized Total Cost[2]	Assumed Recycled Water Yield (AFY)	Estimated Unit Cost ($/AF)
Immediate Term	$6,652,000	$31,500	$464,100	2,425	$290
Near-Term	$11,828,000	$103,600	$1,305,800	4,155	$430
Long-Term	$21,565,000	$396,000	$3,001,000	6,685	$540
Overall	$40,045,000	$396,000	$3,001,000		$540

[1] August 2017 (ENRCCI = 12037) costs with an accuracy range of -50% to +100%. Estimated Project Cost includes all legal, engineering, and design. Costs are not cumulative.
[2] Include energy costs, and these costs are cumulative.

8.4.1.10. Project Uncertainty

Availability of recycled water for this project varies based on potable water usage in the City. Any cutbacks to water usage, such as periods of drought and/or improvements in water use efficiency, would reduce the amount of recycled water available.

The City has 17,000 LF of existing pipeline infrastructure that will be used in Concept 1 and Concept 2 with little additional infrastructure (Carollo, 2020). Concept 2 could be implemented immediately, as the recycled water will be used at City athletic fields. Concept 1 will require contracts with entities within and outside of Solano County. Both concepts have a higher certainty of being implemented than the other concepts, which require new infrastructure.

Funding has not yet been secured for this project. According to the City of Vacaville Recycled Water Master Plan Feasibility Study, three scenarios have been considered to fund this project: Pay-as-you-go, State Revolving Fund (SRF) Loan, and conventional debt. Additionally, sales contracts have not been put into place, nor have customer agreements and diversion agreements (Carollo, 2020).

8.4.2. Westside Streams Stormwater Capture Project

8.4.2.1. Project Description

A stormwater capture and recharge project has been developed for implementation in the Northwest Focus Area to supply groundwater recharge and support local groundwater sustainability. During periods of stormflow in the winter and spring, participating growers would divert a portion of stormflows from westside streams and flood their fields, supplying surplus water for direct groundwater recharge to the aquifer through flood managed aquifer recharge (FloodMAR). Project implementation would be distributed across the Northwest Focus Area, operating through voluntary participants with access to existing or newly constructed diversion, conveyance, and on-farm infrastructure suitable for field flooding. The project would be implemented each year that stormflows are available.

The project objectives are primarily to benefit:

- All beneficial uses and users of groundwater, by replenishing groundwater through direct recharge of available stormflows, and
- Environmental water users, including wildlife and migratory shorebirds, by creating temporary shallow wetland habitat on fields.

Numerous ephemeral streams originate in watersheds west of the Solano Subbasin and flow eastward into the Solano Subbasin. In the vicinity of the Northwest Focus Area, the largest of these streams are Pleasants Creek, McCune Creek, Pleasant Creek, Dry Arroyo, English Creek, and Sweeny Creek. **Figure 8-1** illustrates the location of these streams in the context of the Northwest Focus Area. Some of these westside streams flow eastward to Putah Creek while others eventually drain into the Delta.

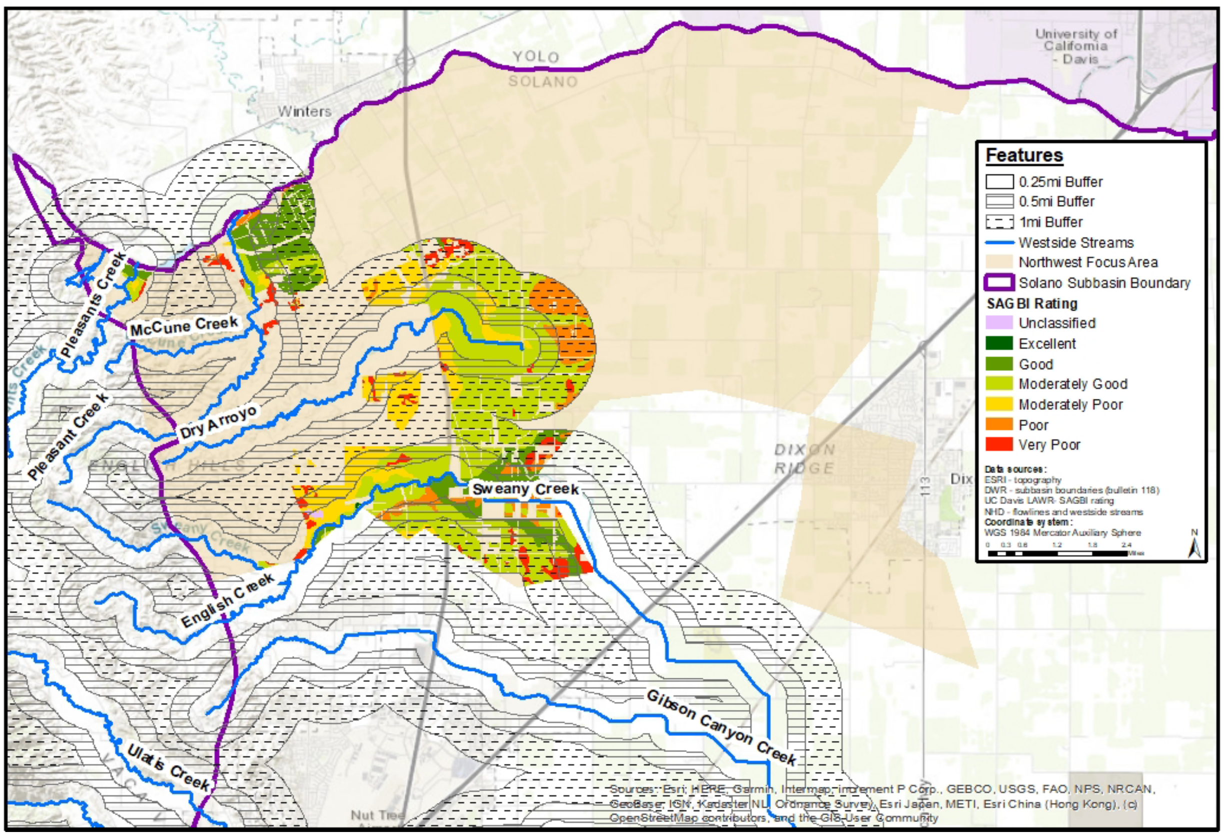

Figure 8-1: Location of Potential Recharge Areas Along Westside Streams in the Northwest Focus Area.

For the stormwater capture project, the GSAs would identify potential recharge areas and coordinate with growers willing to participate. Following site selection and identification of voluntary participants, operation of the project would begin with site preparation. Field preparation would be completed prior to flooding to enhance recharge potential and wetland habitat. Existing vegetation may be removed or incorporated, depending on recommendations or requirements associated with initial site conditions.

After site preparation, participants would implement Flood-MAR on their fields, diverting and spreading water whenever available.

While actual project participation will vary from year to year depending on water availability and grower interest, preliminary mapping has been conducted to identify potential recharge areas that may be suitable for participation. Potential recharge areas were identified according to the following criteria:

- **Groundwater recharge suitability:** Groundwater recharge suitability was evaluated using the Soil Agricultural Groundwater Banking Index (SAGBI) which was developed by the California Soil Resource Lab at UC Davis and UC-ANR. SAGBI indicates the potential for groundwater recharge on agricultural land, according to five main factors: deep percolation, root zone residence time, topography, chemical limitations, and soil surface condition. SAGBI ratings for lands in California are available online (https://casoilresource.lawr.ucdavis.edu/sagbi/). Areas with "Excellent," "Good," and "Moderately Good" SAGBI ratings were identified as potentially suitable for project participation.
- **Cropping suitability:** Cropping was evaluated using the 2018 statewide crop mapping dataset by Land IQ. The dataset represents a statewide, comprehensive, field-scale assessment of agricultural land use and was made available through the DWR SGMA Data Viewer (https://sgma.water.ca.gov/webgis/?appid=SGMADataViewer) to provide consistent, current land use information for SGMA planning. Crop classifications identified as potentially suitable for project participation include various annual and field crops[7], alfalfa, pasture, grain, and fallowed land. Permanent crops and other non-agricultural land uses were excluded from participation.
- **Proximity to westside streams**: Potential areas were evaluated within a buffer region extending from 0.25 to 1.0 mile from the westside streams within the Northwest Focus Area. This buffer region excluded fields directly adjacent to waterways because stormflows may flow back to the waterway instead of percolating into the underlying aquifer. This distance range was considered affordable for construction of new infrastructure.

Areas identified as potentially suitable for recharge according to these criteria (bright-color areas) are shown in **Figure 8-1**. In total, approximately 2,400 acres in the Northwest Focus Area are suitable for project participation, though only a fraction of this total is expected to participate from year to year. Other factors that will need to be considered during project implementation are the availability of existing diversion, conveyance, on-farm infrastructure for field flooding, the need for new infrastructure and field preparation, and the potential for additional community benefits such as stormflow attenuation in flood-prone areas. In practice, the location and scale of the project will also depend on grower interest and willingness to participate. Locations could be anywhere within the Northwest Focus Area where surface water supplies are available and recharge conditions are favorable.

To encourage project participation, the project may offer financial incentives to growers. Steps for developing financial incentives may include:

[7] Crops include beans, corn, cucumbers, melons, sorghum, squash, sudan, sunflowers, tomatoes, and all other miscellaneous field and truck crops.

- Evaluation of grower interest, and the types and extent of economic incentives that may be required to support project participation, with specific attention to protecting the needs and interests of small farmers.
- Evaluation of options for funding sources to support project participation, which may include the $50 million State funding earmarked for the Department of Conversation to support multi-benefit agricultural land repurposing.
- Program monitoring and revision to ensure satisfactory participation and to respond to grower feedback and changing conditions in the Solano Subbasin.

8.4.2.2. Water Source

The surface water source for the project will be stormflows along the westside streams within or near the Northwest Focus Area, including Pleasants Creek, McCune Creek, Pleasant Creek, Dry Arroyo, English Creek, Sweany Creek, and Gibson Canyon Creek. Stormflows will likely be available in wet and above normal years, and that up to 10 percent of the total stormflows will be available for diversion and FloodMAR. Water is expected to be available starting in 2025. Over the entire project implementation period, an average of approximately 2,800 AF/yr of surface water is expected to be available for this project.

8.4.2.3. Construction Activities and Requirements

This project may be configured and operated to utilize existing infrastructure within the Northwest Focus Area, such as conveyance infrastructure within the SID distribution system. Availability and agreements for these uses would need to be refined during the early stages of project implementation.

If new diversion and conveyance infrastructure must be constructed for this project, it is anticipated that up to five diversion points would be required to divert stormflows from the largest westside streams, and that approximately 3,600 feet of conveyance pipeline and approximately 10 turnouts would be required for each diversion (50 total turnouts). Each diversion structure would be constructed with a 20-CFS pump (precise sizing may be refined during future project development), a magnetic flow meter (may be added if desired), and a fish screen, and grower turnouts would also be constructed with magnetic flow meters (may be added if desired) to facilitate project monitoring and reporting.

The project may also require some on-farm activities for participating landowners to enhance field flooding and recharge on existing fields. The program is designed to work within existing field infrastructure and irrigation systems. Any on-farm water management modifications are expected to be modest to increase standing water on fields outside of the growing season to support both recharge and habitat. Prior to field flooding, the GSAs may facilitate a survey of the fields and install pressure transducers or flow meters at inlets and outlets and in adjacent wells to facilitate measurement of applied water depths and changes in groundwater depth.

8.4.2.4. Relationship to Sustainability Criteria

This project would directly recharge groundwater. These mechanisms are expected to primarily benefit groundwater levels and groundwater storage in the Northwest Focus Area. The project may also help to prevent potential depletions of interconnected surface water and land subsidence, to the extent that these sustainability indicators are connected to changes in groundwater levels and groundwater storage.

8.4.2.5. Metrics for Evaluation

Benefits to groundwater conditions in the Northwest Focus Area would be evaluated by comparison of without- and with-project monitoring data, especially of applied water depths and changes in groundwater depths in the vicinity of participating fields. During site preparation, flow rate and groundwater level monitoring equipment may be installed in the fields, as needed, to facilitate monitoring. Soil and water samples could also be collected to ascertain water quality prior to wetting, as desired, to evaluate any potential project effects on groundwater quality. Throughout GSP implementation, evaluation of benefits to groundwater conditions (especially groundwater levels and groundwater storage) will also be supported by modeling using the Solano Integrated Hydrologic Model (IHM) which was used for GSP development.

Benefits to migratory shorebirds would be evaluated by monitoring bird presence. During site preparation, a stage gauging ruler should also be installed to support monitoring of water depths.

During Flood-MAR, participants would record any changes in applied water in an irrigation log. Meanwhile, the GSAs would coordinate monitoring of changes in groundwater depth and bird presence.

8.4.2.6. Expected Benefits

The expected benefits of this project are summarized in **Table 8-4**. Benefits to the groundwater system were modeled in the Solano IHM by simulating potential diversions from the westside streams (see Section 8.4.2.2) to potential recharge areas over the projected future water budget period. Habitat benefits are estimated to be equal for each participating area.

As described previously, the total potential area suitable for this project was evaluated based on recharge potential, cropping, and proximity to the westside streams. In total, approximately 2,400 acres are potentially suitable for recharge according to these criteria. Of this total, approximately 50 percent or 1,200 acres might be expected to participate in the program in an average year. Actual participation in the project will vary from year to year, depending on grower interest, water availability, changes in cropping, and other factors.

Based on these assumptions, estimated benefits to the groundwater system are approximately 2,100 AF/yr (1.8 AF/acre) and estimated annual habitat benefits are approximately 1,200 acres/yr. While changes in water availability may impact the extent of program participation from year to year, the program is anticipated to continue every year, providing both groundwater recharge and migratory bird habitat along the Pacific Flyway. Besides groundwater recharge, the westside streams stormwater capture project can also provide benefits to flood risk reduction and climate change adaptation. Those potential benefits are not quantified at this time.

Table 8-4: Estimated Average Recharge Volume and Temporary Wetland Habitat Formation for the Westside Streams Stormwater Capture Project.

Project	Estimated Potential Recharge Area (Acres)	Estimated Participating Area (Acres/ water year)	Estimated Average Annual Recharge[1] (AF/water year)	Estimated Average Annual Recharge Depth (AF/ac-water year)	Estimated Annual Habitat Benefit (Acres/ water year)
Westside Streams Stormwater Capture	2,400	1,200	2,100	1.8	1,200

[1] Average annual increase in deep percolation in the Northwest Focus Area attributed to the westside streams stormwater capture project, calculated as the difference between the Solano IHM projected future water budget results with projects and the projected future water budget results without projects.

8.4.2.7. Timetable for Implementation

A general annual timeline of project implementation is provided in **Table 8-5**. At this time, the project has been developed and evaluated at an investigative, planning level. Should the GSAs obtain funds for implementation of the project, the GSAs would develop and implement the program annually following the general implementation schedule presented in **Table 8-5**.

Table 8-5: Potential Annual Implementation Timeline for the Westside Streams Stormwater Capture Project.

Timeline Activity	Start[1]	End[1]
Participant Applications	April-May	August-September
Site Selection	June-July	July-September
Site Preparation (If Needed)	June-July	July-September
Operation (Field Flooding)	October-November	March-April
Financial Incentive Payment (If Applicable)	October	June

[1] Start and end dates assume that participants may implement Flood-MAR beginning in the fall migratory period along the Pacific Flyway (generally July 15-October 1) and ending in the spring migratory period (generally March 15-April 30), or whenever stormflows are available. Timeline is also dependent on water availability and grower participation and planting schedule.

8.4.2.8. Notice to Public and Other Agencies

The general public, stakeholders, impacted users and other agencies will be engaged in project implementation activities through outreach and communication channels, as identified in Section 9 of the GSP.

8.4.2.9. Legal Authority, Permitting Processes, and Regulatory Control

The project would be organized by the GSAs as a collaborative effort with private landowners or growers that have the legal authority to implement this project and facilitate Flood-MAR on their lands. Implementation will be done in accordance with the required County permitting processes and regulatory controls.

The following agencies have potential permitting roles for the project: Solano County and the State Water Resources Control Board (SWRCB), which may require permits for diversion of surface water to the extent that diversions are not already permitted under existing water rights and contracts. Recharge projects may also require an environmental process under CEQA. If required, this project would likely qualify for a Mitigated Negative Declaration.

8.4.2.10. Cost Factors

Typical project costs for field preparation, flooding, and project administration are summarized in **Table 8-6**, on a per site basis. Slightly higher costs are typically incurred in the first year of participation in the project, as more coordination and site preparation are typically required. As a site continues to participate in the project, lower costs are anticipated from year to year. Costs per site may vary depending on future changes in project requirements and incentives (if applicable). The total costs of the program will vary over time, depending on the number of sites enrolled and the extent to which new sites are enrolled or returning sites continue to participate in the project.

Table 8-6: Estimated Capital Costs and Average Annual Operations and Maintenance Costs Per Site for the Westside Streams Stormwater Capture Project.

Cost Component Per Site	Estimated Average Annual Cost at New Sites ($)[1]	Estimated Average Annual Cost at Established Sites ($)[1]
Capital Costs		
Equipment and Direct Cost	$2,000	$1,000
Operations and Maintenance Costs		
Labor, Coordination, Administration, and Analysis	$2,000	$2,000
Total Costs	**$4,000**	**$3,000**

[1] *Costs estimated based on implementation costs for a multi-benefit recharge pilot project to conduct Flood-MAR and create wetland habitat for migratory shorebirds in Colusa Subbasin. Typical costs will vary between individual programs, depending on how the GSAs plan to implement and monitor the program.*

If existing infrastructure and facilities are available and used for this project, the infrastructure construction costs would be less. This project may be configured and operated to utilize existing infrastructure available within the Northwest Focus Area, such as conveyance infrastructure within the SID distribution system. SID's typical irrigation season is from the beginning of March to the end of October, therefore additional canal capacity would be needed during the irrigation season.

If new diversion and conveyance infrastructure must be constructed for this project, it is anticipated that this project would require up to five pumped diversions, each with approximately 3,600 feet of conveyance pipeline and approximately 10 turnouts to supply water to fields for recharge. Estimated costs for constructing all five diversions and the associated conveyance and delivery infrastructure are summarized in **Table 8-7**. These costs are considered to be preliminary, and would be refined during future project development, according to the selected project configuration and requirements. **Table 8-7** also displays the annualized per AF cost of the project. Lifecycle present value costs include the capital cost of the project amortized over its economic life (assumed at 80 years), plus annual operations, maintenance, and repairs costs. The expected annual benefits from recharge are approximately 1,785 per year, adjusted for frequency of water availability and an assumed leave-behind percentage. The annualized (lifecycle present value) cost of the project is approximately $264 per AF.

Table 8-7: Estimated Costs for Construction of New Diversion and Conveyance Infrastructure for the Westside Streams Stormwater Capture Project.

Cost Component	Notes	Estimated Cost Per Site ($)	Estimated Total Cost ($)
Capital Costs			
Diversion and Conveyance Infrastructure	Includes: five diversion structures, each equipped with one 20-CFS pump, a magnetic flow meter, and fish screen; 18,000 feet of PVC conveyance pipe (3,600 feet per site); 50 grower turnouts and magnetic flow meters (10 per site)	$880,000	$4,400,000
Indirect Costs			
Planning, Administration, and Construction Contingencies	Includes: Mobilization/demobilization, bonds, and insurance, permits; planning, design, and environmental costs; construction management and administration; monitoring and assessment; stakeholder outreach; easement acquisition and access agreements; and other contingencies	-	$2,300,000
Total Costs		**-**	**$6,700,000**
Lifecycle Present Value Cost ($/AF)			**$264**

8.4.2.11. Project Uncertainty

The primary sources of uncertainty and potential constraints on the operation of this project are: (1) the availability of sufficient surface water supply, and (2) the participation of growers with fields conducive to groundwater recharge.

Surface water supply conditions needed for this project include stormflows that are sufficient to flood participating fields.

Grower participation needed for this project includes:

- Willingness of growers to participate in this program, informed by program applications;
- Availability of participating fields suitable for groundwater recharge, based on soil texture, crop type, and availability of suitable surface water flood irrigation infrastructure; and
- Proximity of participating fields to streams with sufficient stormflows.

8.4.3. Rainfall Managed Aquifer Recharge (Rain-MAR) Demonstration Project

8.4.3.1. Project Description

The Rainfall Managed Aquifer Recharge (Rain-MAR) Demonstration Project is a voluntary demonstration to evaluate the use of specific MAR activities on local farms to generate multiple benefits for groundwater sustainability and stormwater management. Working with willing landowners, the project will develop and test methods for maximizing retention of precipitation on and reducing sheet runoff from agricultural fields in the Northwest Focus Area during winter storm events. In addition to recent groundwater level declines, the Northwest Focus Area drains to areas with floodwater and stormwater management issues according to the Dixon Watershed Management Plan.

TFT has worked closely with NRCS and the Dixon RCD to develop preliminary protocols for Rain-MAR practices. TFT also developed prioritization criteria to identify agricultural fields most conducive to Rain-MAR and methods to estimate volumetric benefits and implementation costs at a field scale.

Applying these methods, TFT has identified 108 agricultural fields suitable for Rain-MAR within the Northwest Focus Area, including five fields where both the sump and berm methods are feasible and an additional 103 fields where only the sump method would be feasible. For this demonstration project, suitable sites will require the participation of willing landowners and fields with the following optimal characteristics: soil types, SAGBI rating[8], subsurface soil texture from nearby well construction logs, groundwater levels as documented by groundwater monitoring efforts, crop types, field size, and topography.

This work has been supported by California NRCS through a Conservation Innovation Grant (CIG Grant # NR209104XXXXG007) and through a Sustainable Groundwater Planning Grant from DWR (Proposition 68 funding, project titled *Solano Subbasin GSP Development and Well Installation Project*). Documentation of the methods and feasibility analysis for recharge in the northern Solano Subbasin is included in Appendix 8c.

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[8] California Soil Resource Lab. 2021. Soil Agricultural Groundwater Banking Index. https://casoilresource.lawr.ucdavis.edu/sagbi/ The SAGBI scores for the area are the primary factor limiting eligibility for the berm form of Rain-MAR. Conversely, sumps are dug deeper than the surficial depth evaluated by SAGBI; therefore, low SAGBI values are not a factor in determining site eligibility for the sump method.

The objectives of the Rain-MAR Demonstration Project are to:

A. Implement two methods of Rain-MAR (each on at least one field): (1) using a pre-existing end of field sump or (2) grading temporary 18-inch berms along the field edge, to reduce runoff and increase infiltration of rainwater between December and February for up to three years. Water will be obtained by capturing winter precipitation that falls directly onto the field.

B. Design Rain-MAR practices so they avoid or minimize impacts to the normal use of the demonstration fields for growing healthy and abundant agricultural crops, and to avoid the potential for adverse impacts to neighboring fields.

C. Evaluate the (1) volume and rate of groundwater infiltration (percolation), and (2) the volume of captured runoff resulting from the practice on each demonstration field as compared with similar control fields where the practice is not applied.

D. Monitor and evaluate mounding, crop health, and nitrate risk on both demonstration and control fields.

E. Field-test a groundwater accounting system using a network of monitoring sensors, data transmission technology, and secure web-tools that could be used for tracking and crediting of groundwater recharge actions in the future.

F. Develop recommendations for a future management program that provides incentives to growers for voluntary practices to recharge groundwater and prevent runoff in conjunction with ongoing agricultural production in the Northwest Focus Area.

Demonstration Project Implementation. Once GSAs secure a funding source, the demonstration project would be implemented on two or more annual crop fields in the Northwest Focus Area of the Solano Subbasin, generally located to the east of Highway 505, north of Highway 80, and south of Putah Creek (**Figure 8-2**.). Additional fields will be monitored (with no Rain-MAR activities) as control sites. Depending on local needs, the Solano GSA Collaborative and/or local partners may opt to seek funding to implement the proposed demonstration. Project outcomes will be analyzed, reported, and, if appropriate, applied to the development and implementation of a Rain-MAR program for the Northwest Focus Area.

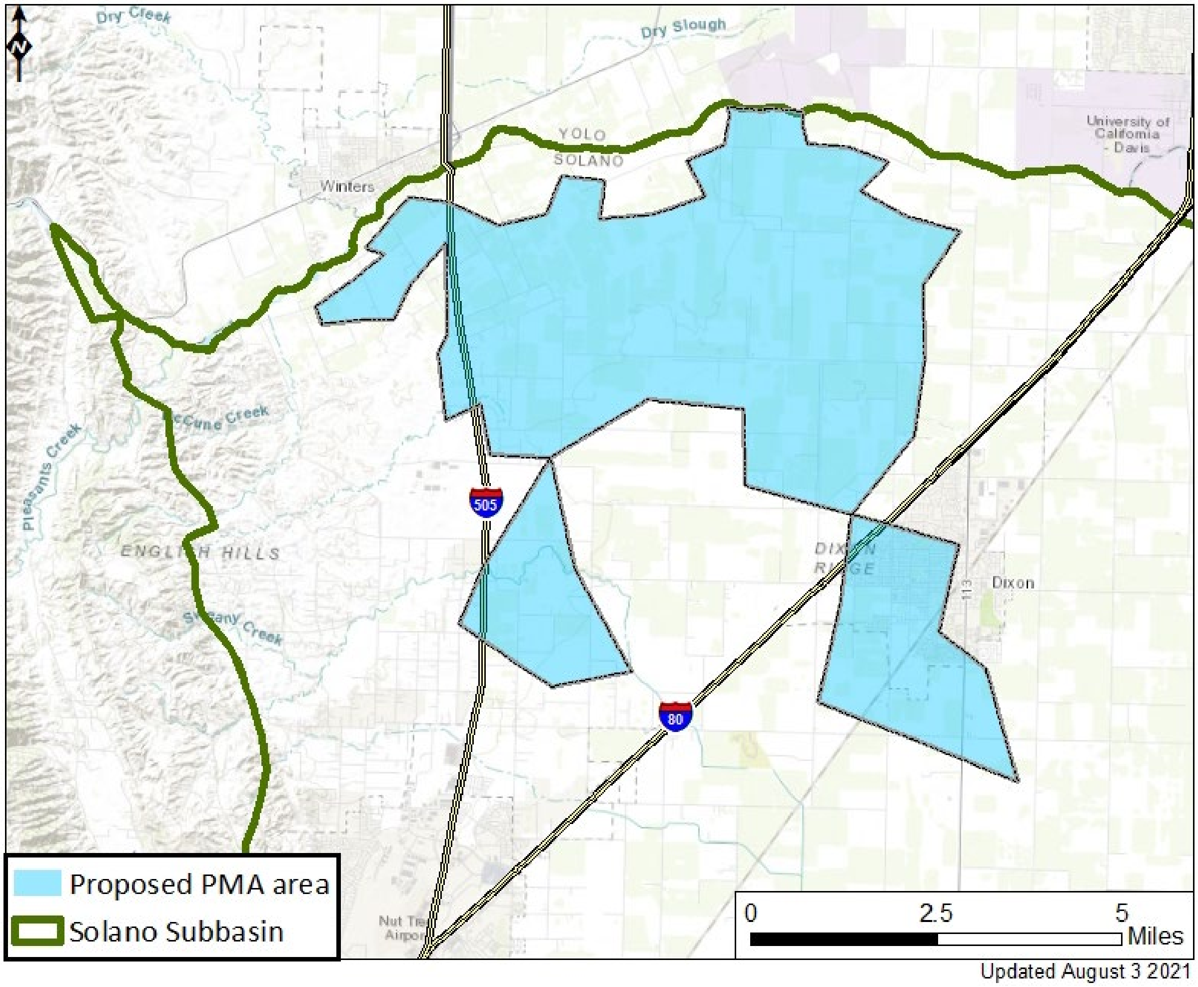


Figure 8-2: Proposed Rain-MAR Demonstration Project Area

The demonstration projects would occur within the portion of the Northwest Focus Area that is east of Highway 505, north of Highway 80, and south of Putah Creek.

Implementation of this project will commence with the selection of suitable sites for multi-benefit recharge. GSAs would conduct outreach to local growers in the Northwest Focus Area through existing communication pathways described in Section 9, potentially with support from TFT and/or local RCDs. Once demonstration sites are selected, site-level project objectives will be defined, an implementation and monitoring plan developed, fields will be prepared, and monitoring equipment deployed on treatment and control sites. At the conclusion of each season, results from treatment and control fields will be analyzed to quantify site level benefits, assess potential unintended impacts, and determine whether objectives are met. Actual project costs will be itemized and evaluated for comparison with pre-project estimates to refine methods for estimating project costs. Monitoring methods are described further below.

Future Program Development. Lessons learned from the demonstration project will be used to develop a future management program to recharge the aquifer, increase baseflows to local streams, or benefit

GDEs in the Northwest Focus Area while providing flood-reduction benefits downstream in an area with chronic flooding and drainage issues.

Results from the demonstration sites may also be used to update and refine project optimization criteria in the Solano Agricultural Scenario Planning System (discussed in Section 8.6.2).

8.4.3.2. Operation and Monitoring

Operations. Rain-MAR will be applied on a minimum of two fields to demonstrate the sump and berm form of the practice. The treatment practices are as follows:

1. "Berm" method: Initial construction of berms is designed to be consistent with NRCS Interim Practice Standards 817 (On Farm Recharge), using the additional Practice Standard 644 (Wetland Wildlife Habitat Management), and 356 (Dike). This practice will construct 18-inch berms around the perimeter of the treatment field, using three passes with a plow, to capture winter stormwater that would otherwise runoff the field via sheet flow. Maintenance is based on the NRCS Practice Standard 378 (Pond) maintenance of embankments, and annually maintains existing berm field perimeters (that may have been impacted by autumn harvest, pruning, etc.) to ensure they will capture winter stormwater. Berm maintenance occurs annually and includes an inspection, cleaning, repairing eroded areas, compaction, and removal of debris.
2. "Sump" method: Based on the maintenance portions of the draft NRCS Practice Standard 815 (Groundwater Recharge Basin or Trench) and NRCS practice 447 (Tailwater Recovery), this practice involves excavating a sump on the lowest elevation edge of a field. Sump maintenance for this practice involves maintaining access to the sump by repairing undercut and eroded areas, periodic cleaning and removal of debris and sediment from traps, trash racks, and structures, periodic re-grading to maintain proper flow lines and functionality, and periodic removal of surface crusts (light tilling) when infiltration rate is reduced significantly. Sump dimensions are assumed to be 40 feet wide, 10 feet deep, and a quarter of the perimeter of the field in length.

Monitoring. One field will be used as a control each year and will be used for comparing expected benefits of MAR on the other demonstration fields. Monitoring will vary depending upon the type of Rain-MAR employed on the demonstration fields.

Prior to berm construction or use of sumps, monitoring instrumentation will be deployed at treatment fields and control sites. For instance, depending on the site-specific monitoring design, pressure transducers or flow meters may be installed at inlets and outlets and in adjacent wells to facilitate measurement of applied water depths and changes in groundwater depth.

For the sump method, water depth in the sump will be measured using a stage gauging ruler and converted to volume of water by a predefined relationship between sump height and volume. A flow measuring device will be required at the outlet of the sump to measure any spillage. A shallow monitoring well, near the sump, will be used to monitor the groundwater elevation.

For the berm method, multiple stage gauging rulers will be set up in the field to get an average depth of ponded water due to captured runoff from the field. A flow measuring device will be required at the outlet of the field to measure any water that may leave the field as surface flow. A shallow monitoring well, on or near the recharge field, will be used to monitor the groundwater elevation.

8.4.3.3. Water Source

Precipitation will be the sole source of water for the project. Other sources of surface water will not be used.

8.4.3.4. Construction Activities and Requirements

The demonstration project will focus on two forms of Rain-MAR: one that uses a sump to capture sheet flow runoff direct to a corner of the field and one that uses berms around much of the perimeter of the field to retain sheet flow on the field. The program is designed to work within existing field infrastructure and irrigation systems, with modest on-farm water management modifications. If suitable sites are available, the sump treatment will be implemented on a field with a pre-existing basin, such as a tailwater return system that can be re-purposed for the project to reduce implementation costs. The berm treatment will be a temporary feature requiring grading of an 18-inch earthen berm on the downslope end of the field margin.

8.4.3.5. Relationship to Sustainability Criteria

In a typical agricultural site, the captured rainwater may serve a variety of functions for groundwater management, each with associated benefits to either aquifer storage, GDEs, or baseflows in streams. Rain-MAR practices can be prioritized on farms where it will provide one of these specific benefits, if monitoring of the Subbasin indicates that support of storage, ecosystems, or baseflows is needed. Individual sites where Rain-MAR is considered should be evaluated for the potential benefit, using the data generated under the development of this GSP to determine the likely fate of infiltrated water.

Infiltrated water can benefit aquifer storage, particularly in the unconfined portion of the aquifer system. In some winters, precipitation will not be sufficient for infiltrated water to reach aquifer; however, Rain-MAR may have the effect of retaining soil moisture longer into the spring than without the practice, allowing delayed early season irrigation.

Infiltrated water can benefit GDEs by raising the elevation of the groundwater table.

Infiltrated water can benefit baseflows by reducing seepage in a losing stream, increasing baseflows in a gaining stream, or increasing stage at a period of critical flow for various species.

Infiltrated water can benefit local small water systems and private domestic water supply wells in areas where these wells are threatened by dewatering from excess nearby groundwater pumping. Potential benefits to private domestic water supply wells and small community water systems will be factored into project selection.

Project selection analyses also include criteria to avoid contributing to undesirable results. Fields would be removed from consideration where recharge may contribute to groundwater quality concerns in the vicinity of community water systems or private domestic water supply wells.

8.4.3.6. Expected Benefits

Demonstration Project: Expected Volumetric Benefits. Two representative fields were chosen to estimate the volumetric benefits of the proposed Rain-MAR demonstration project, including one field for the sump method and for the berm method. The selection of the fields were based on the amount of additional precipitation retained per acre. **Table 8-8** summarizes the estimated volumetric benefits and implementation costs for each method on the demonstration fields.

The estimated benefits include a range of values in representative DWR Water Years, “critical” and “wet”, as classified for the Sacramento Valley. CIMIS data from Water Years 2015 and 2017 were used to represent a Critical and Wet year, respectively, representing both ends of the precipitation spectrum. The estimated costs include implementation and maintenance of the sump and berm on the representative treatment fields. The sump method assumes use of any pre-existing basin.

Table 8-8: Demonstration project: estimated volumetric benefits of Rain-MAR (AF)

	Sump method		Berm method	
Project Acreage (representative field)	141		117	
	Total volume	*Per acre*	*Total volume*	*Per acre*
Annual additional infiltration, wet year (AF)	95.9	0.68	65.6	0.56
Annual additional infiltration, critical year (AF)	53.0	0.38	40.7	0.35
Prevented annual runoff, wet year (AF)	112.8	0.80	77.1	0.66
Prevented annual runoff, critical year (AF)	62.3	0.44	47.9	0.41
Average annual cost*	$13,270	$94	$1,975	$17
10-year cost*	$132,699	$941	$19,747	$168

**Methods and details of cost estimates are described below in Section 8.4.3.10 (“Cost Factors”)*

The cost estimate reflects expenses for implementation of the practice and does not include agency costs for outreach, recruitment, and the design and deployment of project monitoring. In general, an additional 20% should be added for these tasks.

As shown in **Table 8-8**, the volumetric benefit of both forms of Rain-MAR, even when optimal fields are chosen, result in less than one AF of additional infiltration per year. To have an impact on groundwater level, baseflows, or GDEs, MAR practices would need to be implemented on a substantial number of fields distributed across the Northwest Focus Area.

<u>Volumetric Benefits of Hypothetical Multi-Benefit Incentive Program in Northwest Focus Area</u>

If groundwater levels decline near or below minimum thresholds, a program may be needed to support recharge in those areas where undesirable results may occur.

To illustrate the efficacy of distributed MAR practices over a broader area, a hypothetical scenario was developed for the Northwest Focus Area. to calculate the expected benefits of a multi-benefit incentive program. Approximately 6,000 acres of MAR-suitable fields were identified. Assuming a $100,000 annual investment over ten years, fields were ranked based on infiltration potential. Results are summarized in **Table 8-9**.

Table 8-9: Hypothetical Rain-MAR Program for the Northwest Focus Area: Estimated volumetric benefits (AF)

	Cost Efficient Program Scenario ($100,000 annually, optimized for maximum infiltration)	
Total Project Acreage	1,098	
Number of Fields	13	
	Total	*Per acre*
Annual additional infiltration, wet year (AF)	860	0.78
Annual additional infiltration, critical year (AF)	466	0.42
Prevented annual runoff, wet year (AF)	1,011	0.92
Prevented annual runoff, critical year (AF)	548	0.50
10-year Cost*	$969,404	$882
Average annual cost*	$96,940	$88

**Methods and details of cost estimates are described below in Section 8.4.3.10 ("Cost Factors")*

<u>Modeling of Hypothetical Rain-MAR Program in Northwest Focus Area</u>

To estimate the effect of this program on the groundwater budget and groundwater levels in the Northwest Focus Area, a potential configuration of the hypothetical Rain-MAR program was modeled in the Solano IHM. The hypothetical model scenario was conceptualized recognizing that a Rain-MAR incentive program should be open to most or all growers willing to participate, particularly those whose fields are potentially suitable for recharge. The modeling scenario was thus developed to estimate the total potential recharge from areas that could participate in the Rain-MAR program, including areas beyond just the cost-efficient program scenario optimized for maximum infiltration (described in the previous section).

The hypothetical Rain-MAR program model scenario was developed assuming that up to 50 percent of growers with fields suitable for recharge would participate in the program in an average year. Areas that are potentially suitable for recharge were identified primarily by recharge potential and cropping. Recharge potential was quantified based on the area-weighted SAGBI rating of fields in the Northwest Focus Area, considering only fields with a SAGBI rating of "moderately good" or higher. Crop areas suitable for recharge were evaluated based on 2018 Land IQ spatial land use data (Land IQ, 2021), filtering land areas by crop type to exclude permanent crops, rice, crops with growing seasons unsuited to rainfall capture, and non-agricultural areas. Based on these criteria, the total potential recharge area assumed to participate in the Rain-MAR program was estimated to be approximately 6,100 acres.

The Rain-MAR program was simulated in the Solano IHM by retaining the simulated runoff of precipitation on selected fields within the Northwest Focus Area that correspond to crop types and areas identified as suitable for recharge. Across the 6,100 acres estimated to participate in the Rain-MAR program, the average annual simulated increase in deep percolation of precipitation captured on participating fields was approximately 3,000 AF/yr. This additional recharge helped to stabilize simulated groundwater levels over the projected future water budget period.

8.4.3.7. Timetable for Implementation

This is a voluntary PMA that is intended to inform protocols for the implementation of Rain-MAR projects on a programmatic scale. As such, the demonstration projects would ideally occur in the early years of GSP implementation.

Once funded and initiated, willing landowners will be recruited, and site-specific implementation and monitoring designs will be developed for demonstration sites. Installation of berms and sumps should occur after fall harvest prior to the late fall/winter precipitation to retain maximum rainwater for infiltration, generally following the timeline in **Table 8-10**.

Table 8-10: Rain-MAR Demonstration Project: Implementation Timeline

Timeline Activity	Start	End
Participant Applications	April-May	August-September
Site Selection	June-July	July-September
Site Preparation and Monitoring Design	June-July	July-September
Operation (Field Flooding)	November-December	February-March
Financial Incentive Payment (If Applicable)	October	June

8.4.3.8. Notice to Public and Other Agencies

The general public, stakeholders, impacted users and other agencies will be engaged in project implementation activities through outreach and communication channels, as identified in Section 9 of the GSP.

8.4.3.9. Legal Authority, Permitting Processes, and Regulatory Control

These Rain-MAR projects use no other sources of surface water, and they leverage common and existing agricultural practices to manage precipitation to reduce flood peaks. The following agencies may have roles for recharge projects in general: the respective GSA, Solano County, and the State Water Resources Control Board (SWRCB).

State and local public agencies in California are required to comply with the California Environmental Quality Act (CEQA) when they take discretionary actions, including implementing a project or program that makes a significant change to the environment. The demonstration project is exempt from CEQA under a class 6 categorical exemption for data collection. However, any resulting program will need to comply CEQA, potentially an initial study with a mitigated negative declaration.

8.4.3.10. Cost Factors

Methods for Cost Estimates. Cost estimates for Rain-MAR are derived from crop enterprise budgets from the University of California Davis, the most recent NRCS cost scenarios for the respective practices, and peer-reviewed literature, with adjustments made for local circumstances in the Solano Subbasin based on technical reports and communication with local growers or other technical experts. All values were transformed into a per acre (variable) or per practice (fixed) values. Cost estimates are based on the following factors:

- *Planning and Design:* Planning and design costs are based on NRCS practice standard 142 - Fish and Wildlife Habitat Plan – Written, Scenario #26 - Fish & Wildlife Habitat Management CAP (2 Land Uses).
- *Capital Costs:* Capital costs include materials and labor for installation of flashboard risers. Cost estimates assume participating growers will already have the necessary machinery and equipment (plows, tractors, and excavators) to create and maintain berms and sumps.
- *Operations and Maintenance:* Operations and maintenance costs consist of labor costs for grading fields, cleaning trash racks, maintaining access, excavating the top layer of accumulated sediment, etc.

Opportunity costs and impact mitigation. Cost estimates assume that the sump does not replace any land currently used to grow crops. The feasibility assessment used to identify suitable fields attempts to eliminate fields where the practice may cause flood damage or would negatively impact agricultural production or crop yield. Therefore, opportunity costs or costs to mitigate potential impacts associated with Rain-MAR practices are not included in the project cost estimates.

Data limitations. Cost estimates may overestimate actual implementation costs. The cost model assumes all fields would require new construction of sumps or berms, even though some fields already have sumps or berms that are used during summer irrigation. For the fields that have existing sumps (tailwater recovery pits) and berms, nearly all the establishment (Year 1) costs would be eliminated. Another potential area for reduced costs would be if a grower owns multiple neighboring fields that all drain into a single sump (as is typically the case with practice for tailwater recovery ponds).

Cost Estimate for Demonstration Project. The demonstration project will involve recruitment of willing participants and implementation of Rain-MAR on at least two fields, one using sumps, the other berms. Estimated annual and 10-years costs are summarized in **Table 8-8** above.

Example Cost Scenario for Potential Multi-Benefit Incentive Program in Northwest Focus Area. Results for programmatic implementation of Rain-MAR throughout the Northwest Focus Area are summarized in **Table 8-9**. This example program scenario assumes $100,000 is available annually to implement Rain-MAR practices within the targeted portion of Northwest Focus Area over ten years. The resulting optimized landscape-level scenario includes 13 fields and results in an additional 466 AF to 860 AF of additional infiltration per year, depending on precipitation. The most cost-efficient feasible projects were included in this optimized scenario, which included five projects using the berm method of Rain-MAR and eight projects using the sump method. Overall, the cost of achieving additional infiltration is approximately $113/AF in a wet year and $208/AF in a critical dry year. The program would also result in flood mitigation via prevented annual runoff during the rainy months.

8.4.3.11. Project Uncertainty

The Rain-MAR practice is designed as an alternative to methods of MAR that require applying excess surface waters to fields (Flood-MAR, Ag-MAR). MAR methods that rely on the delivery of surface water have the potential to infiltrate larger volumes of water on a given field because the volume of applied water is not constrained by precipitation. However, these methods also require more infrastructure for water diversions, conveyance, and on-farm distribution and must address constraints relating to surface water rights, access to excess flows, establishing legal authority, and procuring permits. Conversely, Rain-MAR is immediately implementable across a significantly larger number of fields.

The Westside Streams project (Section 8.4.2) proposes to work with willing landowners to divert excess winter flows from local streams to fields in the Northwest Focus Area. As such, the Westside Streams PMA will help to address constraints to the use of surface water for Flood-MAR on fields in the Solano Subbasin.

A future program in the Northwest Focus Area will incorporate lessons learned from both the Westside Streams and Rain-MAR PMAs to offer a portfolio of practices that can maximize multi-benefit outcomes and tailored to the needs of local growers. Likewise, GSAs may work with Solano Irrigation District, private irrigation systems and drainage districts, and local growers to apply these lessons learned to develop MAR practices that deliver excess surface waters for strategic groundwater recharge.

8.5. Potential Projects and Management Actions

In addition to the ongoing PMAs and PMAs developed for implementation identified in Sections 8.3 and 8.4, if needed, the conceptual PMAs presented below can be developed further for implementation to support groundwater sustainability within the Solano Subbasin.

8.5.1. Other Groundwater Recharge Opportunities

8.5.1.1. Ulatis Creek Projects

In addition to the multi-benefit recharge projects developed for implementation, several conceptual recharge projects were identified along Ulatis Creek to support ongoing groundwater sustainability in the Solano Subbasin. These projects are referred to as Ulatis Projects 1, 2, 3, and 5.

Together Ulatis Projects 1, 2, 3 and 5 could pump water upstream from check to check (dam to dam) up Ulatis Creek from the Delta to the southern portion of the SID service areas. This conveyance system could allow for possible water exchanges between SID and other entities by allowing the water obtained by other agencies (and possibly individuals) to be conveyed to the southern portion of the SID service area. The SID water formerly delivered to those lands could instead be delivered to lands upstream in the Northwest Focus Area. The potential for exchanges needs to be explored through further discussions, and a feasibility study of the proposed conveyance system is needed. Through these exchanges, these projects have the potential to help stabilize groundwater level trends in the Northwest Focus Area.

This project is currently in the early conceptual phase. Thus, the anticipated timeline, costs, and benefits of project implementation have yet to be determined and could be refined during future project development.

8.5.1.2. The Nature Conservancy Multi-Benefit Groundwater Recharge Program

The Nature Conservancy (TNC) has provided GSAs with guidelines and support to implement on-farm, multi-benefit groundwater recharge programs. The program would build on the successful TNC BirdReturns program by strategically flooding agricultural fields with the dual goals of: (1) recharging groundwater supplies, while (2) simultaneously creating critical winter habitat for shorebirds migrating along the Pacific Flyway. GSAs could consider offering financial incentives to growers to compensate them for recharging groundwater through field flooding in the course of normal farming operations, with multiple potential benefits to the underlying aquifer system, waterbirds migrating along the Pacific Flyway, and other beneficial users of groundwater in the Subbasin. The program could be structured to pay for field preparation, irrigation, and water costs to encourage grower participation. Benefits to small farmers could also be prioritized.

If implemented, the multi-benefit groundwater recharge program would occur in multiple phases in the Solano Subbasin, with expansion of the program over time as voluntary grower participation increases. Multi-benefit recharge would be implemented at selected sites, with multi-benefits to groundwater recharge and temporary wetland habitat formation. Recharge and wetland habitat benefits in the early phases of the project would be analyzed, reported, and used to inform development and later implementation of the program.

Implementation of this project could commence with selection of sites suitable for multi-benefit recharge, and initiation of any necessary permitting and environmental documentation. GSAs could use resources in the GSP and also provided by TNC to identify fields with soil and cropping conditions conducive to groundwater recharge and temporary wetland habitat formation. In later phases of project implementation, other suitable fields could continue to be identified following similar criteria, with refinement according to lessons learned from early project implementation.

The primary constraints on the operation of this project are (1) the availability of sufficient surface water supply, and (2) the participation of growers with fields conducive to groundwater recharge. Surface water used in this project is expected to be available from existing surface water rights contracts. Existing diversions and conveyance infrastructure would be used to supply surface water for multi-benefit groundwater recharge. The following agencies have potential permitting roles for the multi-benefit groundwater recharge project: Solano and Sacramento Counties, SWRCB, and USBR. If necessary, the GSA would obtain land grading permits from the County and would apply or facilitate applications for permits required from the SWRCB for diversion of surface water to the extent that diversion is not already permitted under existing water rights and contracts. Recharge projects may also require an environmental review process under CEQA. If required, this project would need either an Initial Study with a Negative Declaration or Mitigated Negative Declaration.

Suitable project sites would be selected by the following characteristics:

- Existing agricultural fields with flood irrigation system infrastructure;
- Soil characteristics that are conducive to recharge;
- Crop types that are conducive to high-quality, open wetland habitat suitable for bird stopovers when flooded (i.e., not orchards);
- Crop types that are suitable for recharge (i.e., suitable for flooding in mid-July through mid-October, and conducive to deep percolation), such as field crops, alfalfa, pasture, grain, and fallowed land;
- Water supply and infrastructure characteristics that are suitable for flooding (i.e., existing flood irrigation infrastructure, existing surface water supply); and
- Sites that provide other potential community benefits such as flood attenuation in flood-prone areas, protection of small water systems and private domestic water supply wells, and economic opportunities for small farmers.

The process for identifying and enrolling suitable fields in the program is documented extensively on the TNC BirdReturns project website (https://birdreturns.org/).

Outreach to local growers would be needed to identify willing participants that irrigate fields where multi-benefit groundwater recharge can be implemented. Outreach would be conducted through existing communication pathways described in Section 9. Participant responses would be gathered and organized through surveys that request information regarding:

- Field characteristics (location, size, cropping, field preparation methods);
- Existing water supply characteristics (water supply source(s), timing of water source(s));

- Existing measurement and monitoring infrastructure (flow meters, groundwater well); and
- Other relevant information.

GSAs, with potential support from TNC, would coordinate with participating growers to implement on-farm, multi-benefit groundwater recharge. Following initial site selection and completion of any necessary permitting and environmental documentation, fields would be prepared for flooding and monitoring. Prior to field flooding, GSAs could facilitate a survey of the fields and install pressure transducers or flow meters at inlets and outlets and in adjacent wells to facilitate measurement of applied water depths and changes in groundwater depth. The program could be designed to pay for field preparation, irrigation, and water costs through a GSA-planned incentive structure.

Actual participation in the program would vary from year to year, depending on grower interest, water availability, changes in cropping, and other factors. The total eligible area suitable for the multi-benefit recharge project would be evaluated based on recharge potential and cropping. Recharge potential would be quantified based on the area-weighted SAGBI rating of fields in the Subbasin, considering only fields with a SAGBI recharge rating "moderately good" or higher (UC Davis, 2021). Crop areas suitable for multi-benefit recharge could be evaluated based on 2018 land use data (Land IQ, 2021), filtering land areas by crop type to exclude permanent crops, rice, crops with growing seasons unsuited to the flooding window, and non-agricultural areas.

If implemented, slightly higher costs are typically incurred in the first year a site participates in the program, as more coordination and site preparation are typically required. As a site continues to participate in the program, lower costs are anticipated from year to year. Costs per site may vary depending on future changes in program requirements and incentives. The total costs of the program would vary over time, depending on the number of sites enrolled and the extent to which new sites are enrolled or returning sites continue to participate in the multi-benefit recharge program.

8.5.2. Grower Education Relating to On-Farm Practices for Sustainable Groundwater Management

A grower education and outreach program is a potential management action for the Solano Subbasin. The program could provide growers with educational resources that help them to plan and implement on-farm practices that simultaneously support groundwater sustainability and maintain or improve agricultural productivity. Education and outreach programs could be targeted to benefit small farmers and other at-risk growers.

Grower education programs could add value to other groundwater sustainability efforts during GSP implementation. Because on-farm water management decisions affect groundwater sustainability, implementation of grower education programs would be anticipated throughout GSP implementation, with planning efforts beginning the first year of GSP implementation. Over time, programs would be tailored to reflect current technologies and best practices in on-farm water management.

Implementation of these on-farm practices would be documented, along with estimated or measured benefits to groundwater sustainability resulting from these practices. The grower education program could be accomplished by GSAs through partnerships with agencies and/or NGO partners. GSAs and partner agencies could develop and distribute educational materials on topics relevant to local agricultural practices and groundwater conditions. Grower responses to specific educational topics would be assessed and monitored through pre- and post-workshop surveys. These surveys would be designed to identify the extent to which growers adopt recommended practices.

Implementation of grower education activities would be expected to benefit groundwater levels, groundwater storage, and water quality. Encouraging growers to implement on-farm water management practices that maximize surface water use and reduce non-beneficial ET would be expected to provide in-lieu recharge benefits to the groundwater system. Encouraging soil management to enhance infiltration would be expected to enhance direct groundwater recharge. Both in-lieu and direct recharge would be anticipated to benefit groundwater levels and groundwater storage. Encouraging growers to implement precision nutrient management would also be expected to help manage nutrient loading in the Subbasin, with benefits to water quality. Targeting small and at-risk growers will have an added benefit of increasing job security and economic resilience for the local community.

Four categories of on-farm practices, or on-farm management actions, that may be covered in this program include:

1. Maximizing the use of surface water,
2. Managing soils to improve infiltration and root zone soil moisture storage,
3. Reducing (and minimizing) non-beneficial evapotranspiration (ET), and
4. Precision nutrient management.

Maximizing Use of Surface Water

The use of surface water for irrigation whenever it is available is a crucial practice to support sustainable groundwater management. The use of surface water both offsets local groundwater demand through reduced groundwater pumping (“in-lieu” recharge) and increases groundwater recharge through the deep percolation of the applied surface water to the underlying aquifer system. The on-farm practices to maximize the use of surface water include implementing a dual-source irrigation system, reducing tailwater resulting from irrigation, and other actions to promote the conjunctive management of surface water and groundwater. This education program could be coupled with an incentive program to encourage additional use of surface water in-lieu of pumping groundwater. This approach would be particularly effective in instances where groundwater is, from the perspective of the grower, effectively cheaper than surface water.

A dual-source irrigation system is capable of utilizing surface water for irrigation from a surface water conveyance system when available and utilizing groundwater if surface water is unavailable. Developing a dual-source irrigation system generally involves upgrading the on-farm irrigation system, that currently uses groundwater, to the surface water distribution system. The benefits of this practice are that every acre-foot of surface water that is utilized is an acre-foot of groundwater that remains in the aquifer ("in-lieu recharge"), supporting sustainable groundwater levels and maintaining groundwater storage. Additionally, excess applied surface water generally results in some direct groundwater recharge through deep percolation. These positive impacts will occur in groundwater directly beneath the grower's lands. The potential drawbacks to this system are the initial construction costs and higher maintenance costs associated with a more complex irrigation system, as well as the potential for sediments in surface water to obstruct irrigation systems. If the dual-source irrigation system is designed to accommodate this, surface water and groundwater could be intermixed during irrigation to mitigate these effects.

The on-farm management practice of reducing tailwater from irrigation and holding that water within the irrigated area will either increase the ET, increase the deep percolation, or some combination of the two. The practical steps taken to hold the water will vary from field to field. If irrigation uniformity issues occur in certain parts of the field (over- and under-irrigation), addressing these issues will promote tailwater reduction. Also, if there are low-lying portions of a field or border strips that are not in agricultural production, excess applied surface water can be directed to these areas where it can be contained by topography or the construction of low berms and allowed to infiltrate the ground and recharge the underlying groundwater system, rather than flowing off the field.

The two practices above are examples of conjunctive management, which recognizes that surface water and groundwater are interdependent and seeks to combine and balance the beneficial use of both water sources to promote sustainable water use while minimizing any negative economic or environmental impacts that have the potential to occur (Dudley and Fulton, 2006). Conjunctive management is often practiced on a larger scale, but it can be applied by individual growers through the practices above (and others) to maximize surface water usage when available and promote groundwater sustainability.

Managing Soil to Improve Infiltration and Root Zone Soil Moisture Storage

Another on-farm practice that could promote groundwater sustainability is management of soil at the ground surface and within the root zone to improve infiltration of applied water and reduce runoff or ponding on the ground surface. These benefits can be achieved through a variety of on-farm practices including planting cover crops or utilizing crop rotations to increase organic matter content in the root zone, application of manure or other organic material, limiting soil compaction by minimizing use of heavy equipment, and if there is a restrictive layer near the ground surface, potentially using deep ripping or tillage to improve infiltration past the restrictive layer (Sanden et al, 2016; USDA-NRCS, 2014). Improving infiltration will result in increases in direct recharge and improve soil moisture storage and slightly reduce the required volume and frequency of irrigation. GSAs can identify optimum fields for cover crops and estimate potential benefits using the Solano Agricultural Scenario Planning System (see 8.6 Tools to Support PMA and GSP implementation).

Reducing Non-Beneficial Evapotranspiration

This section describes two potential methods for reducing non-beneficial ET through altering and carefully controlling the timing and volume of applied water as well as discussing nutrient management.

Precision irrigation scheduling has the potential to benefit both grower and sustainable groundwater management. Precision irrigation scheduling enables growers to accurately identify the timing and volume of irrigation water to apply to maximize crop productivity while minimizing water application. It typically requires real-time or near real-time information on soil moisture and weather conditions and is crop dependent. When effectively implemented, precision irrigation scheduling promotes sustainable groundwater management through increased water use efficiency; water that otherwise would have been applied to the field remains in the groundwater system or is available for use elsewhere.

Regulated deficit irrigation applies irrigation water during important drought-sensitive growth stages for a crop and reduces applied irrigation water (i.e., deficit irrigation) during other growth stages where there will be little to no effect on crop yields. This on-farm management practice needs to be applied prudently, but it has the potential to reduce applied water and associated irrigation costs while having little to no impact on crop yields. It promotes sustainable groundwater management through reduced consumptive use; water that otherwise would have been applied to the field is not consumed and remains in the groundwater system or is available for use elsewhere.

Precision Nutrient Management

Another negative impact to the groundwater system that can result from irrigated agriculture is the degradation of groundwater quality due to excess application of nutrients (i.e., nitrogen, phosphorus, etc.), pesticides, and herbicides. As applied water infiltrates the ground and percolates to the aquifer, it can transport excess nutrients, pesticides, and herbicides applied on the land surface during crop production. Improving on-farm nutrient management and the application efficiency will save on-farm costs and reduce the nutrient influx to the groundwater system.

In aggregate, these on-farm practices could promote both agricultural productivity and economic benefits along with sustainable groundwater management[9]. **Table 8-11** identifies the measurable objectives that will be supported by each category of on-farm management actions.

[9] In most cases, not all on-farm practices will be able to be implemented. Also, some practices will not work in tandem with one another. For example, maximizing the use of available surface water and precision irrigation scheduling are not possible on the same field at the same time.

Table 8-11: Measurable Objectives Benefitted by On-Farm Management Actions.

On-Farm Management Action	Measurable Objectives Benefitted
Maximizing surface water use	groundwater levels, groundwater storage
Managing soils to improve infiltration and root zone soil moisture storage	groundwater levels, groundwater storage
Reducing non-beneficial ET	groundwater levels, groundwater storage
Precision nutrient management	water quality

8.5.3. Demand Management

Recognizing the importance of sustainable groundwater management to the region and the inherent uncertainty in modeling future conditions under climate change, the GSAs have included a potential demand management program as a "backstop" to other PMAs (i.e., considered after implementation of other feasible and cost-effective projects). Events that may trigger the demand management action are consistent with CCR Section 354.44(b)(2) and include, but are not limited to, continued land use change that increases groundwater pumping; severe, prolonged drought conditions resulting in groundwater levels approaching minimum thresholds in specific parts of the Solano Subbasin; other PMAs are not achieving the expected level of benefits; or new information about projected future conditions show that sustainability objectives will not be met.

A demand management program would potentially provide a benefit to all measurable objectives in the Subbasin. The specifics of the demand management program would be defined under future GSA planning efforts. Potential types of demand management could include:

- **Allocation**. Under an allocation, the different sources of groundwater are quantified and allocated to individual parcels, wells, or entities (such as, for example, farming operations). Defining the quantities of groundwater available to individuals can incentivize reductions in use and development of new recharge opportunities. An allocation is a rigid method for implementing demand management and limits water use at a well, parcel, or on an operation basis. This method could require idling land or switching crops on lands that have insufficient allocation to meet the irrigation demand, which imposes costs on water users (e.g., growers). To increase the flexibility of allocations to reduce the costs of demand management, allocations could be defined as an average over a period of time rather than a fixed amount every year, or users could be allowed to carry over unused allocation into the next year. GSAs must carefully evaluate fair and equitable allocation structures that do not overly burden or disadvantage any particular groundwater use or user, with special protections for already at-risk users, such as small farmers and small community water systems.
- **Allocation + Water Market**. An allocation that is less than historical water use can be coupled with a water market. A groundwater market is another way to increase the flexibility of an allocation to reduce costs of demand management. A market is an institution that allows willing buyers and sellers to exchange groundwater allocation ("credits"). More broadly, a market creates a means to exchange allocation with another groundwater user, whether for a single season or for multiple years. Willing sellers release a part of their allocation to willing buyers in exchange for a payment that the seller expects will exceed the return he/she would have earned

from using the water for irrigation. This additional flexibility reduces the cost to individuals of achieving demand reduction under an allocation. Development of a water market institution is a complex process that encompasses more than defining the groundwater allocation. This investigation would be initiated by the GSAs in the future, if needed. Water markets must be carefully developed so as to protect already disadvantaged and/or at-risk groundwater uses and users, such as groundwater dependent ecosystems, small farmers, and small community water systems.

- **Land Repurposing**. Land repurposing programs are more targeted than an allocation or market program, but maintain flexibility for participants by its voluntary nature. Such a program would provide a financial incentive to willing participants for currently irrigated lands to be repurposed into other, non-irrigated uses. Programs can focus on short-term drought conditions, or they can provide multi-year reductions in demand if that is needed under some conditions. For longer-term programs, lands can be repurposed to achieve other multi-benefit objectives - for example, to create habitat corridors or to support local endangered species. Land repurposing programs must be developed with multiple priorities in mind so as to avoid unintended consequences. Incentives for land repurposing should not inequitably benefit or negatively impact any particular groundwater use or user, with special protections for already at-risk users, such as small farmers and small community water systems.
- **Other financial incentives**. Demand management can also be achieved through a range of other financial incentives to reduce consumptive groundwater use. A financial incentive could also include groundwater extraction fees that disincentivize groundwater use. Any financial incentive must be carefully evaluated to ensure that it does not inequitably benefit or negatively impact any particular groundwater use or user, with special protections for already at-risk users, such as small farmers and small community water systems.
- **Strategic Targeted Demand Management.** A targeted demand management program could use one or more of the above mechanisms to achieve a reduction in groundwater demand in specific areas of the Subbasin. For example, the program could focus on specific drought-affected areas with sustainability challenges. This would be voluntary and would provide financial incentives (payments) to encourage participation. Payment terms and other conditions would be specified as part of program design. Two potential structures for a targeted demand management program are: (i) participating groundwater-using lands in selected areas in the Subbasin would be idled and the quantified groundwater saved would be left in the ground to alleviate sustainability challenges, or (ii) participating surface water-using lands anywhere in the basin would be idled, and the saved surface water would be conveyed to replace groundwater pumping in other areas of the basin with groundwater sustainability challenges.

Depending on how the demand management program is structured, it has the potential to benefit all measurable objectives in the Solano Subbasin. The demand management program would result in targeted reductions in groundwater pumping in specific areas, or broadly across the Subbasin. These areas (and the program) would be selected, in part, based on monitoring for measurable objectives in the Subbasin.

The monitoring networks described in this GSP will be used to monitor the outcomes of a demand management program. The specific metrics would be developed as part of program design but are expected to include changes in groundwater levels in areas where demand management is implemented.

Demand management will only be triggered if required in the future as GSAs monitor Subbasin conditions and measurable objectives. The following principles would guide development of the demand management program. The GSAs recognize that tradeoffs exist among these principles:

- Minimize the economic impacts of any demand management programs;
- Maintain established water rights;
- Incentivize investment in water supply infrastructure;
- Incentivize economically efficient water use;
- Complement other PMAs such as direct and in-lieu recharge projects in aggregate, and in specific regions;
- Allow sufficient program flexibility for groundwater pumpers to adjust over time;
- Ensure access for domestic water users (de minimis domestic use as defined by SGMA is less than two AF annually per user); and
- Protect other community and stakeholder priorities such as ensuring small farmers can remain in production, providing economic opportunity and resilience for local community members, protecting or enhancing groundwater quality, and providing habitat for groundwater dependent ecosystems.

Demand management program cost considerations generally include the following:

- Program design and administration by the GSA or other managing entity;
- Fiscal and economic studies to develop initial program incentives;
- Direct costs to growers (or other entities) for reducing irrigated acreage;
- Offsetting costs from demand reduction incentive payments;
- Potential regional indirect and induced economic impacts as a result of changes in irrigated acreage (or other water using sectors) under the demand management program;
- Ongoing program monitoring, updates, and revisions to the incentive structure; and
- Potential third-party costs for monitoring or market administration (if a groundwater trading market is included).

Program costs would be assessed as part of initial program design through a public process involving stakeholder input.

8.5.4. Other Ongoing and Potential Projects and Management Actions

This section describes other ongoing and potential activities the Solano Collaborative may consider to support GSP implementation.

8.5.4.1. Education and Collaboration

Groundwater and water resources education within the Solano Subbasin represent an important element in implementing activities to support the sustainability of the Subbasin. Educational and collaborative activities are already conducted through existing agencies and NGO partners, such as the following:

- The Solano Resource Conservation District (SRCD), TFT and LGC created and delivered hands-on groundwater education lessons to 307 students in schools across Dixon, Rio Vista, and Vacaville. This collaborative team has developed an educational video that focuses on groundwater uses, users, stewardship, and community planning efforts. This video is being shown in schools across the County and also shared with the public.
- RD 2068 provides and operates several grower education programs and water conservation practices for its surface water operations, including a district-wide water recovery and reuse system.
- Other water resource conservation programs such as Project WET (Water Education Today)[10], which provides training and workshops to teachers with the goal of providing them with the tools, skills, and knowledge to teach their students about their local watershed and water conservation.

8.5.4.2. Well Owner Outreach and Education

Part of the preparation of the GSP has included outreach to well owners and other stakeholders. In addition to a Domestic Wells section under “Frequently Asked Questions,” the Solano Subbasin GSP website directs users to the “Groundwater Guide: Solano Subbasin” website, which contains links to resources for well owners:

- “A Guide for Private Domestic Well Owners” (SWRCB Groundwater Ambient Monitoring and Assessment Program, 2015)[11]: This document educates readers on well construction, water quality testing, water quality protection, water quality treatment, and well destruction. This document also has an extensive resource guide for private domestic well owners.
- “Domestic Well Users and the Sustainable Groundwater Management Act” (SWRCB and DWR)[12]: This brochure summarizes SGMA and how it affects domestic well users, including GSA powers and authorities, metering of domestic wells, and monitoring and reporting of domestic wells.

[10] https://www.watereducation.org/project-wet
[11] https://www.waterboards.ca.gov/water_issues/programs/gama/docs/wellowner_guide.pdf
[12] https://www.waterboards.ca.gov/water_issues/programs/gmp/docs/resources/dom_well_brchr.pdf

- "Well Owner's Manual/Manual del propietario de pozos" (Water Systems Council)[13]: This document provides specific guidance on well maintenance and protection, as well as additional resources related to water supply conservation and the protection, maintenance, testing of wells.

8.5.4.3. Participation in Other Local Water Resources Management Programs

Section 2 of this GSP describes existing water management agencies and programs within the Solano Subbasin. Implementation of the Solano GSP will require coordination with these efforts, such as:

- Westside Sacramento Integrated Regional Water Management Plan. Westside Regional Water Management Group meetings can serve as an additional venue for discussing implementation of the Solano GSP PMAs, and alignment with other multi-benefit efforts.
- Urban Water Management Planning. These plans are required every five years by the State of California to document water supply reliability information, including: hydrology and groundwater conditions; implications of local, state and federal regulations; water supply and demand conditions and projections; and other issues pertinent to each urban water supplier that may impact water supply management.
- Agricultural Water Management Plans. These plans are required every five years by the State of California to report on water supply conditions; prepare a water supply and demand balance; identify water management objectives; document a quantification of water use efficiency; establish a drought preparedness plan; and address other issues impacting water supply management.

8.6. Tools to Support PMA and GSP Implementation

The GSAs in the Solano Subbasin need to manage groundwater resources to meet multiple objectives and maintain sustainability across the Subbasin. The impacts of climate change are likely to bring new water management issues to the Subbasin. GSAs will need to carefully prioritize conservation actions to achieve the most beneficial outcomes while avoiding unnecessary economic and social impacts on water users. This section describes tools that could be used to support GSAs in the prioritization, development, and implementation of PMAs.

8.6.1. Groundwater Crediting and Market-Based Supply and Demand Management

MAR includes actions designed to promote groundwater recharge, benefiting the supply-side of water budgets. In the Solano Subbasin, GSAs and their partners may want to create incentives for implementing specific forms of MAR, where farm management increases the retention of precipitation or increases the application of surface waters on or adjacent to agricultural fields.

[13] https://www.watersystemscouncil.org/water-well-help/well-owners-manual/

Likewise, GSAs could create incentives for demand-side improvements, such as water use efficiency (e.g., irrigation upgrades) and certain forms of cover cropping, to generate similar or greater agricultural returns with less water. These distributed land management actions are often discussed in the context of a market-based system that would create incentives by crediting farmers for groundwater-beneficial activities. These infrastructure-independent, distributed land management actions could be incorporated into groundwater trading programs and incentive-based recharge programs to benefit both the supply side and demand side of water budgets.

TFT has developed a framework for Groundwater Crediting and Market-Based Supply and Demand Management to create financial incentives for distributed groundwater recharge actions (supply) and a potential groundwater marketplace (Appendix 8d).

8.6.2. Solano Agricultural Scenario Planning System

The Solano Agricultural Scenario Planning System (SASPS) is a web-based application that GSAs and other local agencies can use to design voluntary programs to engage agricultural producers in on-farm sustainable groundwater management projects. Developed by TFT, with support from the USDA Natural Resources Conservation Service (NRCS) and in collaboration with the Dixon and Solano RCDs, the SASPS is customized for the Solano Subbasin.

GSAs that need to engage the agricultural community in on-farm sustainable groundwater management projects can use the SASPS to view key agricultural metrics in their area of interest, design custom programs to meet their management objectives or budget targets and identify optimal areas for efficient recruitment of landowners. Practices covered by the tool focus on distributed recharge including MAR and cover crops—and demand reduction via irrigation efficiency upgrades. GSAs can identify specific agricultural fields where these practices are feasible, view the site-specific economic cost burden to farmers implementing these practices (over 10 years), and see the impact across a suite of water resource metrics, including farm-level changes in the annual volume of: (i) groundwater or surface water use, (ii) infiltrated water, and (iii) runoff. GSAs can use these data to develop programs that contribute to sustainable groundwater management (Appendix 8e).

8.7. Project Financing

Covering the costs of PMAs and general GSP implementation requires evaluating both financing and funding sources. Financing relates to identifying sources of capital (typically bonds and bank loans) to pay for project capital expenses. Funding relates to sources of money required to cover capital repayment (pay back the debt financed projects) as well as project O&M, GSA administration, and other annual expenses.

GSAs and project proponents will need to identify sources of financing to pay for capital projects. This includes, but is not limited to, grants, bonds, and private bank or other low interest loans. GSAs will also identify sources of funding to cover project studies/development, capital repayment, and operating costs. Funding sources may include but are not limited to, groundwater extraction fees, water rates, and other assessments. The funding mechanism will vary by project and the legal authority of each proponent. A general description of how the cost of each PMA will be covered is presented with each PMA. This section provides an overview of funding mechanisms that apply to all PMAs and GSA operating expenses.

The methods for raising revenues described below are available to GSAs to fund projects, studies, and operations. Groundwater extraction fees and groundwater permit fees are specifically included in the SGMA legislation (California Wat Code 10730 et seq.), but all other revenue methods may be available to individual Solano Subbasin GSAs, depending on the agency's authorities under law. All methods adopted must comply with the requirements of statute and the California Constitution.

Potential sources of financing for capital projects and studies include a range of state and federal grant and revolving fund programs. The California Clean Water and Drinking Water State Revolving Funds (SRFs) provide funding for planning, design, and construction of projects related to decentralized wastewater facilities and private drinking water treatment, respectively. These sources do not cover project operations and maintenance (O&M) costs. SRFs and state bonds are typically targeted to particular types of projects. For example, the 2020 Proposition 68 funding for GSP projects emphasized multi-benefit projects and projects that would provide specific benefits for disadvantaged communities. Capital financing sources include the following options:

1. Grants and loans
    a. Department of Water Resources Integrated Regional Water Management grants
    b. Other funding programs in Proposition 1, Proposition 68 (or future bonds) for groundwater management
    c. US Bureau of Reclamation WaterSmart Grants
    d. USDA, including Natural Resources Conservation Service
    e. SRFs
2. Bond issuance (depends on legal authority)
3. Private funding including environmental easements
4. Other private borrowing

Ongoing operations, monitoring, reporting, administration, and repayment of borrowed capital funds are typically funded under alternative sources. Funding sources can include local ratepayers and other entities that directly benefit from the ongoing operation of the project. Example sources include the following:

1. Extraction and permit fees (Water Code 10730(a))
2. Other funding sources that the GSA may legally adopt in accordance with statute and subdivisions (a) and (b) of Section 6 of Article XIII D of the California Constitution (Water Code

Sections 10725, 10726.8(a), 10730.2(e), 10730.4, 10730.8, and 10754). These could include taxes, fees and charges, benefit assessments, or fines and penalties.

3. Specific revenue methods pay for project capital, operating, administration, and other related expenses through a local revenue stream. Specific revenue methods include:
    a. Property-related taxes that are not directly related to proportionate special benefit or cost of service
        i. Ad valorem tax
        ii. Parcel tax
4. Charges and fees to cover costs related to provision of services
    a. Per acre charge
    b. Extraction fee – fixed, volumetric, or combination
    c. Permit fee
    d. Other basis consistent with Article XIII D of the California Constitution
5. Benefit assessment to cover costs of providing special benefits, such as for costs of recharge projects
    a. Agency must distinguish between general benefit and special benefit
    b. Generally assessed by property tax parcel and may be calculated uniquely for individual parcels or for categories of parcels, provided that the assessment is appropriately related to the quantified special benefit received

The procedure to adopt new fees or assessments generally involves determining the costs to be covered, broken out by categories that would allow apportionment among water users by either benefit received, or cost imposed. The steps for a fee or assessment are:

1. Decide on the method or methods – fee or assessment – to use to cover costs of specific projects or components of the overall cost of implementing and administering the GSP.
2. Determine the procedural requirements for adopting each method – for example, whether the fee or assessment would be exempt from Constitutional voting requirements.
3. Prepare a study that relates benefits or costs to different areas and/or customer groups that may include or be augmented by a separate rate study.
    a. A benefit assessment could be used to recover the cost of a project. For example, benefits of a recharge project might accrue differentially to GSAs and landowners across the area covered by a GSP. The assessment would be in proportion to the special benefit received (by subarea and/or user class), as calculated in the Rate Study.
    b. For fees and charges (including extraction and permit fees), the Engineer's Report would calculate the cost of providing the service to each parcel or to categories of parcels.

Categories would be based on costs imposed on the program and could be based on location, level of use, or other characteristics related to costs.

Under existing court interpretation, Article IIID of the California Constitution appears to limit the use of a volumetric extraction fee as a demand management tool to ration groundwater use. A fee can only be imposed to cover defined costs and in proportion to cost of service. A benefit assessment covers defined costs and is assessed in proportion to special benefit received.

The Solano Subbasin GSAs will evaluate each of the funding/financing mechanisms for appropriateness for each GSP project. An important consideration, and core concept for most approaches, is the allocation of project and GSA costs.

An important consideration for GSA financing plans is the allocation of different types of costs to entities or areas. Cost allocation is a multi-step process that determines how costs of GSP implementation components would be spread among and recovered from entities and areas covered by the GSP. For example, the implementation plan includes several categories of activities that must be paid for: administration, projects and management actions, monitoring, and studies. The categories may have their costs spread in different ways (among different entities and areas) depending on discussions and policy decisions. Considerations would include who is responsible for a cost, who benefits from an activity, what is fair, what is legally allowed or possible, and what are the requirements for determining and justifying a cost allocation. Project costs are calculated as part of preliminary engineering design. For cost-allocation purposes, costs should be expressed on a life-cycle basis, and include any in-kind contributions (e.g., contribution of privately owned land for recharge basins). Project benefits require additional economic analysis to monetize and allocate to individual parties. The primary project benefit is typically groundwater (either recharge, in-lieu, or reduced pumping). However, projects can also provide broader benefits to the Subbasin, including reductions in pumping lifts and management to prevent other undesirable effects such as land subsidence, streamflow depletion, or well dewatering. Projects targeted to specific areas will also help the entire Subbasin stay in compliance with SGMA and achieve goals specified in the GSP. Therefore, the specific location, design, and size of projects affect the distribution of benefits.

Project funding and financing will consider the distribution of costs of projects (both geographically and among categories of users) that are equitably related to costs of providing the benefits to that user or to the benefits received. Solano Subbasin GSAs will evaluate project costs and quantify and monetize associated project benefits. It is anticipated that this cost allocation process would be on a project-by-project basis.

APPENDIX 8a

Summary of Potential Parties Impacted/Affected by Solano GSP PMAs

[Under development]

APPENDIX 8b

Summary of Projects and Management Actions Considered

	PMA #	Agency to Implement	Project or Management Action Name	Project Description	Description of Benefit to the Solano Subbasin (Please note type of benefit: habitat restoration, in-direct recharge, direct recharge, etc.)	Project or Management Action?	WIRWM Project Type	Geographic Extent of Applicability	Quantified/Relative Benefit, (e.g. AF/Yr., Acres habitat restored OR High, Medium, Low)
	PROJECTS								
Stormwater Capture and Recharge (Smaller Scale)	1		Increase Use of Stormwater	Investigate feasibility of capturing and/or diverting excess storm water from waters (e.g. creek and sloughs) in the subbasin for direct use or recharge.	Direct Recharge, Habitat, Public Access and Joint Uses	Project	Feasibility Study	Entire Subbasin? Applicable to areas with runoff AND where surface recharge benefits the aquifer	High
	2		Increase Use of Stormwater	-Construct projects to capture/divert most accessible stormwater surplus, identified under PMA #1 -Evaluate the use of large diameter infiltration wells in lieu of detention basis in location with limited area or reduced access	Direct Recharge, Habitat, Public Access and Joint Uses	Project	Structural	Entire Subbasin? Applicable to areas with runoff AND where surface recharge benefits the aquifer	High
	6	City of Dixon	Dixon Northeast Quadrant Detention Basin	Construct new detention basin for drainage mitigation in and near Northeast Dixon; basin could provide detention storage, habitat, groundwater recharge, and/or irrigation water supply	Direct Recharge, Habitat, Public Access and Joint Uses	Project	Structural	Northeast Dixon	175 ac-ft / year
	7	Dixon Resource Conservation District and possibly City of Dixon	North of Interstate-80 on-site basin	Within the Dixon Resource Conservation Service's Tremont 3 drain watershed upstream of Interstate 80, construct small on-site detention basins that capture peak stormwater flows and recharge the groundwater basin	Direct Recharge, Habitat	Project	Structural	Dixon Tremont 3 Drain watershed	Medium
	8	City of Dixon	Dixon Pond A Operation	Modify the operation this Detention Basin to hold more stormwater in the Spring and Summer to increase groundwater recharge. Perform annual disking of the basin bottom to increase recharge.	Direct Recharge, Habitat	Project	Operational	Dixon Pond A	
	9	City of Dixon	Dixon Pond B Operation	Modify the operation this Detention Basin to hold more stormwater in the Spring and Summer to increase groundwater recharge. Perform annual disking of the basin bottom to increase recharge.	Direct Recharge, Habitat	Project	Operational	Dixon Pond B	
	10	City of Dixon	Dixon Pond C Operation	Modify the operation this Detention Basin to hold more stormwater in the Spring and Summer to increase groundwater recharge. Perform annual disking of the basin bottom to increase recharge.	Direct Recharge, Habitat, Public Access and Joint Uses	Project	Operational	Dixon Pond C	
	11	City of Vacaville	City of Vacaville Detention Basins	Conduct and operational assessment with the City of Vacaville, to evaluate detention basins for operational changes to increase groundwater recharge	Indirect Recharge, Habitat, Public Access and Joint Uses	Project	Operational	Vacaville detention basins	Medium
	47	RDs, RCDs, Solano County & others	Groundwater Recharge Infiltration Wells	Evaluate the use of large diameter infiltration wells (stormwater infiltration/dry wells or other similar small-footprint GW recharge points) in lue of detention basins in locations with limited area or reduced access. Assess recharge areas based on soil properties, conveyance, and other, willing property owners, and land use conditions.	Provides direct groundwater recharge in focused areas of concern based need, soil properties, willing landowners, etc. Smaller footprint than detention basins	Project	Structural	Solano Subbasin - focused on Northern portion of subbasin or areas with highest need and high potential for recharge	high

	PMA #	Agency to Implement	Project or Management Action Name	Project Description	Description of Benefit to the Solano Subbasin (Please note type of benefit: habitat restoration, in-direct recharge, direct recharge, etc.)	Project or Management Action?	WIRWM Project Type	Geographic Extent of Applicability	Quantified/Relative Benefit, (e.g. AF/Yr., Acres habitat restored OR High, Medium, Low)
Groundwater Recharge (Larger Scale)	3		Construct Groundwater Recharge Basins	Investigate and prioritize locations withing the subbasin to construct groundwater recharge basins to recharge excess surface water when available. Study to investigate both the construction of large recharge basins and small basins on local grower land	Direct Recharge, Habitat, Public Access and Joint Uses	Project	Feasibility Study	Entire Subbasin? Applicable to areas with runoff AND where surface recharge benefits the aquifer	High
	4		Construct Groundwater Recharge Basins	Construct groundwater recharge basins to recharge excess surface water based on prioritized projects identified under PMA #3	Direct Recharge, Habitat, Public Access and Joint Uses	Project	Structural	Entire Subbasin? Applicable to areas with runoff AND where surface recharge benefits the aquifer	High
	30	City of Vacaville	Aquifer storage and recovery (ASR)	-Investigate feasibility of using surface water in the subbasin for direct use or recharge. -Can combine with project 31	Direct recharge	Project	Feasibility Study	Entire Subbasin	High
	31	City of Vacaville	Aquifer storage and recovery (ASR)	Construct projects using surface water in the subbasin for direct use or recharge.	Direct recharge	Project	Structural	Entire Subbasin	High
Recycled Water Use	13	City of Dixon	City of Dixon Recycled Water Use	Conduct a feasibility study to identify the most cost effective alternatives for supplying recycled water to new recycled water users.	Reduce groundwater use	Project	Feasibility Study	Dixon area	
	14	City of Dixon	City of Dixon Recycled Water Use	Based on the outcomes of PMA's 12 and 13, construct recycled water pipeline from the Dixon Wastewater Treatment Plant (WWTP) to the City and within the City to allow use of recycled water within the City, in Detention Pond B, or on the cropland between the WWTP and the City.	Reduce groundwater use	Project	Structural	Dixon area	
	15	City of Vacaville	City of Vacaville Recycled Water Master Plan	Prioritize and develop and implementation schedule of projects identified in the City of Vacaville Recycled Water Master Plan for use of recycled water for recharge.	Alternative supply, reduce reliance on groundwater and reduce groundwater use	Project	Institutional	Vacaville area/SOI?	Medium
	32	City of Vacaville	City of Vacaville Recycled Water EWWTP Improvement Projects	Based on the outcomes of PMA 15, construct identified recycled water Infrastructure at the EWWTP.	Reduce groundwater use	Project	Structural	Vacaville area	Medium
	33	City of Vacaville	City of Vacaville Recycled Water EWWTP pipeline Projects	Based on the outcomes of PMA 15, construct identified recycled water Infrastructure to convey recycled water to the City of Vacaville.	Reduce groundwater use	Project	Structural	Vacaville area	Medium

	PMA #	Agency to Implement	Project or Management Action Name	Project Description	Description of Benefit to the Solano Subbasin (Please note type of benefit: habitat restoration, in-direct recharge, direct recharge, etc.)	Project or Management Action?	WIRWM Project Type	Geographic Extent of Applicability	Quantified/Relative Benefit, (e.g. AF/Yr., Acres habitat restored OR High, Medium, Low)
Infrastructure Improvements	18	SID	Install additional regulating reservoirs in SID and Maine Prairie Water District	Construct additional regulating reservoirs to improve surface water delivery service and reduce canal spills		Project	Structural	SID/MPWD	
	19	SID	Install Additional Canal Automation (in SID and Maine Prairie WD)	Construct additional canal automation to improve surface water delivery and reduce canals spills		Project	Structural	SID/MPWD	
	34	City of Vacaville	Expand Surface Water Treatment Capacity and Conveyance.	-Investigate feasibility of expanding the City of Vacaville's surface water Treatment plants and distrubution system to facilate treating more surface water -Can combine with PMA 35	Reduce groundwater use	Project	Feasibility Study	Vacaville area	Medium
	35	City of Vacaville	Expand Surface Water Treatment Capacity and Conveyance.	Based on the outcomes of PMA 30, construct identified Infrastructure to treat and convey additional surface water to the City of Vacaville.	Reduce groundwater use	Project	Structural	Vacaville area/SOI	High
	36	Solano County Water Agency	Improvements to Solano Project Facilities	Today, the Solano project provides irrigation and municipal water to over 400,000 people in Solano County. However, the Solano Project is 60 years old and is in need of upgrades, repairs, and modernization.	Little, if any, "new" water, but important to maintaining surface water use.	Project	Structural	Entire Subbasin?	High
	37	Solano County Water Agency	NBA Infrastructure and Capacity Improvements	The North Bay Aqueduct (NBA) is in need of infrastructure and capacity improvements to increase capacity and minimize WQ impacts, to ensure a reliable water supply for Napa and Solano counties.	Potential to bring in new water.	Project	Structural	Entire Subbasin?	High
	38	Solano County Water Agency	North Bay Aqueduct Alternate Intake Project	The NBA AIP includes the construction and operation of a new intake and pumping plant on the Sacramento River, conveyance pipeline, and inline storage to divert and convey water from the Sacramento River connecting to the existing NBA pipeline near the North Bay Regional Water Treatment Plant in Fairfield.	Potential to bring in new water.	Project	Structural	Entire Subbasin?	High
	39	Solano County Water Agency	Improve Solano Project SCADA infrastructure	This project is to install contiguous dedicated power and data lines from the top end of the Solano Project system to the bottom. This would allow monitoring of the entire system simultaneously from a central location and could allow automated remote control.	Little, if any, "new" water, but important to maintaining surface water use.	Project	Structural	Entire Subbasin?	High
	45	RDs and Levee Maintain Agencies	Delta Levee restoration	Restore delta levees to reduce flood risk from sea level rise and protect land from innudation and water quality impacts (salinity intrusion)	reduces flood & water quality impacts to neighboring islands and communities (Rio Vista)	Project			high benefit to neighboring communities/lands protected by levees

	PMA #	Agency to Implement	Project or Management Action Name	Project Description	Description of Benefit to the Solano Subbasin (Please note type of benefit: habitat restoration, in-direct recharge, direct recharge, etc.)	Project or Management Action?	WIRWM Project Type	Geographic Extent of Applicability	Quantified/Relative Benefit, (e.g. AF/Yr., Acres habitat restored OR High, Medium, Low)
Infrastructure Improvements	43	RWMG with selected Lead Agency	Regional Capital Improvement Plan	Create Regional asset management plan to identify and prioritize key water management infrastructure.	Little, if any, "new" water, but important to maintaining surface water use.	Project	Feasibility Study	Entire Subbasin?	High
	48	SID	Ulatis Project 1	Conveyance project to move water above Maine Prairie WD Dam #3. Includes 10,000 LF pipe and a pumping station.		Project	Structural		
	49	SID	Ulatis Project 2	Conveyance project to move water above Maine Prairie WD Dam #2. Includes 8,000 LF pipe and a pumping station.		Project	Structural		
	50	SID	Ulatis Project 3	Conveyance project to move water above Maine Prairie WD Dam #1. Includes 9,000 LF pipe and a pumping station.		Project	Structural		
	51	SID	Ulatis Project 4	Conveyance project to redistribute drain water west of the SID Brown-Alamo Recovery Dam. Includes 22,000 LF pipe and pumping station modifications.		Project	Structural		
	52	SID	Ulatis Project 5	Conveyance project to move water above SID McCune-Sweeny Recovery Dam. Includes 9,000 LF pipe and a pumping station.		Project	Structural		
	53	SID	Lake Solano Project 1	-Groundwater Stabilization Project at the Lake Solano Park area to install a robust domestic water supply well for the benefit of the Quail Canyon Public Water System. -Improves reliability during times of drought when the water table is drawn down prior to recharge during wet years. Increases reliability of domestic water supply.	Improves reliability during times of drought when the water table is drawn down prior to recharge during wet years. Increases reliability of domestic water supply.	Project	Structural		
Planning Documents	16	City of Vacaville	City of Vacaville Water Master Plan (on-going)	Coordinate with the City of Vacaville Water Master Plan Preparation Team (West Yost Associates).		Project	Institutional	Vacaville area/SOI?	Low
	41	RWMG with selected Lead Agency	Regional Invasive Mussels Management Plan	This project will include the formation of an Invasive Species Task Force/Subcommittee to prepare a Regional Invasive Mussels Species Prevention Plan that evaluates existing programs to prevent invasive species that could be leveraged, and identifies supplemental programs to be developed to fill gaps in existing programs to manage invasive species. Special high priority emphasis will be placed on prevention of water body infestation by Quagga Mussels.	Little, if any, "new" water, but important to maintaining surface water use.	Project	Institutional	Entire Subbasin?	High

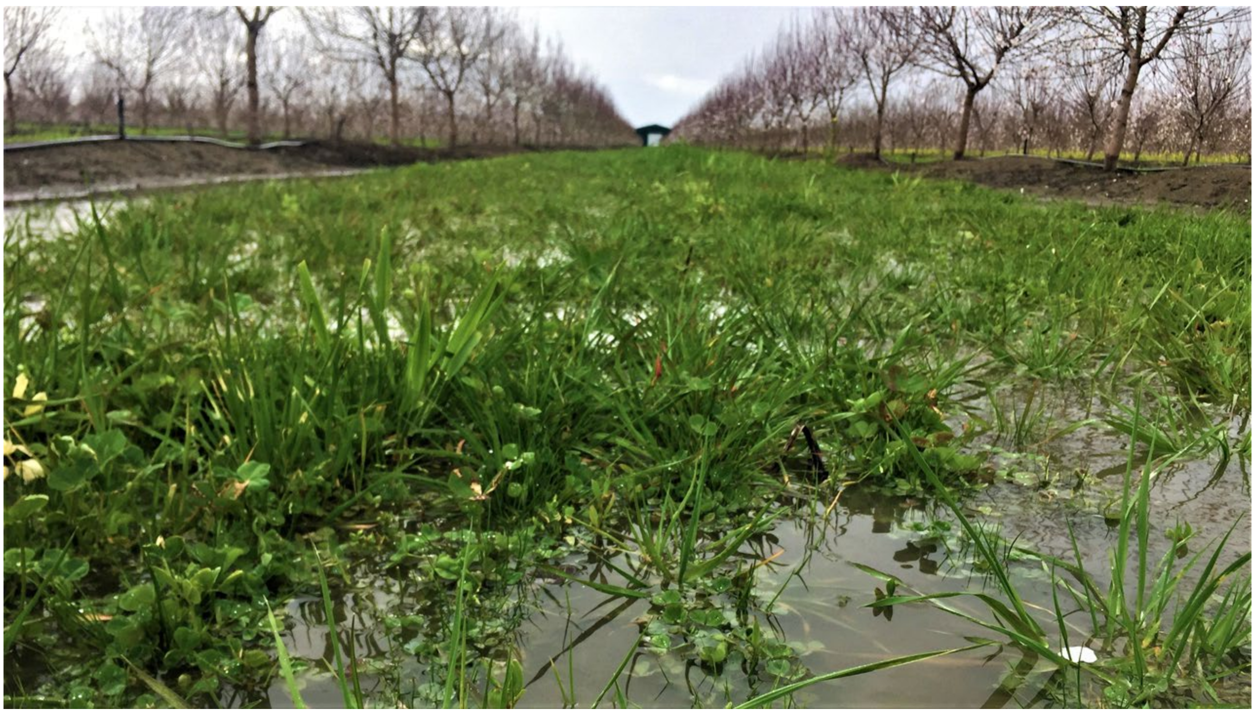
	PMA #	Agency to Implement	Project or Management Action Name	Project Description	Description of Benefit to the Solano Subbasin (Please note type of benefit: habitat restoration, in-direct recharge, direct recharge, etc.)	Project or Management Action?	WIRWM Project Type	Geographic Extent of Applicability	Quantified/Relative Benefit, (e.g. AF/Yr., Acres habitat restored OR High, Medium, Low)
	MANAGEMENT ACTIONS								
Public Outreach for WUE/RW	12	City of Dixon	City of Dixon Recycled Water Use - Public Outreach	Identify and contract new recycled water users in the City of Dixon. PMA includes the public outreach program to help educate potential new users on the benefits of recycled water.	Reduce groundwater use	Management Action	Educational/ Outreach	Dixon area	
	23	NRCS (Vacaville field office), Dixon RCD	Ag Water Use Efficiency Outreach & Implementation	Develop Outreach materials and incentives for agricultural water users to increase waster use efficiency	In-direct recharge, habitat	Management Action	Educational/ Outreach	Entire Subbasin	High
	24	City of Vacaville	Municipal & Industrial Water Use Efficiency Outreach & Implementation	Develop Outreach materials and incentives for municipal and industrial water users to increase waster use efficiency	Reduce groundwater use	Management Action	Educational/ Outreach	Urban Areas of Entire Subbasin	Low
Markets/Incentives	5		Incentivize Winter Flooding of Suitable Crop Lands	Incentivize the spread of uncontrolled seasonal water or other temporarily excess winter supplies on suitable cropland for direct recharge		Management Action	Institutional	Entire Subbasin? Applicable to areas with runoff AND where surface recharge benefits the aquifer	
	22	SID	Develop Online System for Trading Groundwater Allocations	Automated trading system ensures allocation of limited groundwater to highest uses, and are not exceeded in aggregate	In-direct recharge	Management Action	Institutional	Entire Subbasin?	Medium
	25	SID	Ground water market	Allocation based on safe yield by 2030		Management Action		Entire Subbasin?	
	26	SID	Drought preservation storage for later use during a prolonged drought.	This refers to the 7th-10th year or beyond		Project		Entire Subbasin?	
	27	SID	Crop planting sustainability program	-In areas that do not have a reliable surface water supply, prior to the installtion of a permanent crop a water sustainability plan must be established and approved -Suggest incentivizing willing landowner through participating in developing a Land Repurposing Strategy -This relates to an allocation based market		Management Action		Entire Subbasin?	
	29	City of Vacaville	Develop Online System for Trading Surface Water Allocations within Solano Subbasin	Automated trading system ensures that all surface water allocations are utilized (some surface water allocations do not get fully used under existing conditions)	Reduce groundwater use, improve surface water management	Management Action	Institutional/ Operational	Entire Subbasin	Medium

	PMA #	Agency to Implement	Project or Management Action Name	Project Description	Description of Benefit to the Solano Subbasin (Please note type of benefit: habitat restoration, in-direct recharge, direct recharge, etc.)	Project or Management Action?	WIRWM Project Type	Geographic Extent of Applicability	Quantified/Relative Benefit, (e.g. AF/Yr., Acres habitat restored OR High, Medium, Low)
Other Management Actions	40	Solano County Water Agency	Risk Assessment of Delta Water Supplies	This project would entail a risk assessment of Delta Water supplies, and would look at the impacts of unforeseen circumstances such as: - Earthquakes - Delta levee failure - Sea level rise - and others as needed		Management Action	Feasibility Study	Entire Subbasin?	High
	42	RWMG with selected Lead Agency	Climate Change Adaptation Study	Regional study to advance understanding of the effects of climate change and consider potential modifications to the water management system.	GSP will provide some insight	Management Action	Feasibility Study	Entire Subbasin?	High
	44	Solano County	Cache Slough HCP	HCP and ultimately Incidental Take Permit for delta water diverters in the Cache Slough region that aligns with the North Delta Water agency to continue water operations.	Allowing continued surface water diversions reduses reliance on groundwater.	Management Action			may result in 200 - 300 acres of habitat restored
	46	Land Trusts, Solano County, and Others	Conservation Easement	land preservation from urban development through conservation easements with willing sellers	reduces reliance on groundwater. Allows direct/indirect recharge.	Management Action			high benefit to neighboring communities

APPENDIX 8c

Feasibility of Recharge in Northern Solano Subbasin

Managed Aquifer Recharge Opportunities in the Solano Subbasin
Technical Report



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APPENDICES

1. INTRODUCTION

1.1. Purpose

The Sustainable Groundwater Management Act (SGMA)[1] requires Groundwater Sustainability Plans (GSPs) to develop Project and Management Actions (PMAs) to support groundwater sustainability and avoid undesirable results in groundwater basins. This Technical Memorandum (TM) analyzes distributed recharge practices on agricultural fields in the Solano Subbasin (DWR, 2020, Bulletin 118), focusing on agricultural fields where managed aquifer recharge (MAR) has potential to benefit groundwater sustainability and to achieve multiple benefits. The memo summarizes TFT's practice selection process, presents analytical methods and results, and discusses scenarios and tools that GSAs can use to develop PMAs in the Solano Subbasin.

The following introductory sections acknowledge grants that have supported this analysis, its connection to the Solano GSP planning process, and briefly summarizes physical, hydrologic, economic, and social characteristics of the Solano Subbasin relevant to analyzing groundwater management actions on local farms.

1.2. Grant Funding, Tasks, and Deliverables

This work is supported by a Sustainable Groundwater Planning Grant from DWR (Proposition 68 funding, project titled *Solano Subbasin GSP Development and Well Installation Project*) with matching funds and California Natural Resources Conservation Service (NRCS) through a Conservation Innovation Grant (CIG Grant # NR209104XXXXG007). Final documentation of the methods will be available to the public through the respective grant reports in January 2022.

1.3. GW Sustainability Planning in Solano Subbasin

The Solano Collaborative is a group of Groundwater Sustainability Agencies (GSAs)[2], each having authority for portions of the Solano Subbasin, working through a Collaboration Agreement (Collaborative, 2019) to develop a GSP for the entire Solano Subbasin. The Solano GSA Collaborative is made up of the five GSAs located in the Solano Subbasin: the Solano GSA, the City of Vacaville GSA, the Sacramento County GSA, the Solano Irrigation District GSA, and the Northern Delta GSA (Appendix A-1).

As noted in the GSP, groundwater in the northwest portion of the subbasin has declined by approximately 10 feet or more between the period of 1988 and 2018 (LSCE Team, 2021, GSP Figure 3-19). Therefore, the Solano GSP Team recommended the Northwest Focus Area (Appendix A-1) as an area of focus for multi-benefit recharge projects. Within the Northwest Focus Area, multiple analyses were done in conjunction with the Solano Collaborative technical team to optimize the PMA actions and locations.

[1] SGMA is a three-bill legislative package composed of AB 381739 (Dickinson), SB 1168 (Pavley) and SB 1319 (Pavley), which is codified in Section 10720 et seq. of the 39 California Water Code.
[2] The Solano Collaborative's website is: https://www.solanogsp.com/solano-collaborative/

1.4. Overview of Agricultural Resources in the Solano Subbasin

This section provides a synopsis of physical, economic, and social characteristics of the Solano Subbasin of relevance to the agricultural sector, largely drawing on other portions of the Solano GSP, with additional data from other local sources as noted. The purpose of this section is to provide context for the development of distributed groundwater conservation practices on farm fields.

1.4.1. Physical and Hydrological Landscape

Study Area. The study area for this project comprises the cultivated agricultural areas of the Solano Subbasin (*Figure A-1. Areas of Study*). The Solano Subbasin includes the southernmost portion of the Sacramento Valley Basin and extends into the northern portion of the Delta. Subbasin boundaries are defined by Putah Creek on the north, the Yolo County line on the east, the North Mokelumne River on the southeast (from Walnut Grove to the San Joaquin River), and the San Joaquin River on the south (from the North Mokelumne River to the Sacramento River). The western Subbasin boundary, which extends through a portion of Vacaville, is partly defined by the groundwater divide between the San Francisco Bay and Sacramento River Hydrologic Regions as described by Department of Water Resources (DWR (2016)). DWR reports that the location of the divide is roughly delineated by the English Hills and the Montezuma Hills.

Topography and Hydrology. Most of the Solano Subbasin topography is relatively flat, with elevations within the Subbasin ranging from 700 feet above sea level in the more northern and western areas of the Subbasin abutting the Coast Range to 20 feet below sea level within the Delta. Historically, groundwater use within the region is more concentrated in the northern part of the Subbasin. There are higher densities of groundwater wells in this area that serve both urban and agricultural needs. The southern portion of the Subbasin relies more heavily on surface water. Generally, there has been no documented in-elastic subsidence within the Subbasin, and long-term groundwater level trends have remained relatively stable with shorter-term fluctuations including increases in Wet Years and decreases during drought conditions (LSCE Team, 2021, Chapter 3).

The Solano GSP notes that the Subbasin is "hydro-geologically complex with influences from a variety of surface water features and tidal influences (e.g., Sacramento-San Joaquin Delta) and encompasses both shallow and deeper groundwater resources. The primary sources of surface water for the subbasin are watersheds in the lower elevation Coast Range Mountains, which lack significant snowpack." Prevailing groundwater flow directions in the Subbasin within the Alluvial Aquifer and Upper Tehama zone tend to be from west/northwest to east/southeast away from the English Hills and Montezuma Hills towards the Sacramento River and Delta. This context is relevant to estimating the benefit of infiltrated water as it pertains to ecosystems and communities (LSCE Team, 2021, Chapter 1).

Groundwater recharge and discharge are key components of the Subbasin. Groundwater recharge within the Solano Subbasin occurs primarily through infiltration and deep percolation of precipitation falling directly on the landscape within the Subbasin and through applied water (e.g., irrigation), seepage from natural surface waterways, seepage from water conveyance systems such as leaky canals, ditches, and pipes, and deeper subsurface recharge from adjacent and upland recharge source areas outside of the Subbasin (LSCE, 2021, Chapter 3). These are important mechanisms to consider when designing projects and management actions related to agricultural working lands.

Surface water. Another level of hydrologic complexity is the surface water resource management in the Solano Subbasin. The Solano Project on Putah Creek, which features the Monticello Dam at Lake Berryessa and the Putah Diversion Dam at Lake Solano. Similarly, the State Water Project has licenses to use water originating from the Sacramento River which was originally stored in Lake Oroville and provided using the North Bay Aqueduct. Lastly, the Delta portion in southern Solano Subbasin includes many direct diversions from local rivers, creeks, and sloughs from pre-1914 riparian rights claimants and post 1914 appropriative rights claimants. In addition to groundwater and surface water resources, Solano Irrigation District and individual agricultural water users recycle tailwater on their fields (LSCE, 2021, Chapter 2).

Groundwater contamination. The GSP identifies migration of contaminated groundwater as a potential concern in the Solano Subbasin. The third chapter of the GSP (LSCE 2021) describes how typical well depths vary across the Subbasin, which imply varying levels of vulnerability to contamination. For example, domestic wells are generally shallower than other well types with most domestic wells ranging between 100 and 300 feet deep (OSCWR, 2021). Agricultural wells in the Subbasin tend to be relatively deeper with average agricultural well depths greater than 300 feet deep across most of the Subbasin. Public water supply wells and industrial wells also tend to be somewhat deeper with average well depths typically greater than 300 feet.

The GeoTracker website (GeoTracker, 2021) identified approximately 260 potential groundwater contamination sites in the Solano Subbasin, including 34 sites associated with former military operations. Nearly 70% of all sites were designated as leaking underground tank cleanups and the remainders as cleanup or another program. Over 80% of all sites were classified as closed or eligible for closure (3), including 4 sites with land use restrictions. Nearly 50 sites remain open with the status of inactive (4), assessment (27), remediation (13), or verification monitoring (5). These sites are not included in TFT's Subbasin-wide analyses because there is wide variability in the size and condition of sites, however, future MAR-project selection may require further analysis of potential contamination arising from these sites to avoid mobilizing potential plumes.

Groundwater Dependent Ecosystems. Groundwater connectivity is affected by the depth to groundwater, which changes based on annual precipitation. The Solano GSP Technical Memorandum on Surface Water and Groundwater Conditions (LSCE, 2021), identifies most of the likely GDEs in the southern portion of the Subbasin, where depth to water has generally been less than 10 feet during the past 20 years. In the northern portion so of the Subbasin, a GDE dataset created by TNC (Klausmeyer, 2018) includes potential GDEs along the upper reaches of Sweany, Putah, Ulatis, and Alamo Creeks. LSCE's analysis for the Solano GSP shows that conservative estimates of surface water and groundwater connectivity indicate the likelihood of disconnected conditions along much of Putah Creek. Groundwater conditions along Putah Creek are of high interest because of the greater reliance on groundwater in this part of the Subbasin, which is one of the underlying reasons that the GSP planning Team recommended the Northwest Focus Area as an area for a focused PMAs.

1.4.2. Agricultural Sector

Economics. A full 29% of Solano's farm gate value is generated from fruit and nut crops, 22% from vegetable crops, 19% from animal production, and 17% from field crops (Solano County Agricultural Commissioner, 2020). Almonds were the top grossing crop in 2020, followed by processing tomatoes, nursery products, cattle, alfalfa, and walnuts. By acreage, field crops (including alfalfa, pasture, and rangeland) accounted for 278,310 acres in Solano County in 2020. Almonds accounted for 18,300 acres, followed by walnuts (10,720 acres), tomatoes (10,400 acres), sunflower (6,610 acres), and grapes (4,000 acres). Crop compatibility is an important determinant in the feasibility of managed aquifer recharge (MAR) on farm fields.

Demographics. Drawing on outreach and research conducted by TFT and the Local Government Commission (LGC), the Solano Subbasin Snapshot (Solano Snapshot, 2020) was created which described the following relevant demographic parameters:

- Groundwater provides ~24% of the total irrigation supply in the Solano Subbasin, for an estimated ~170,000 irrigated acres of farmland use
- Approximately 50,000 residents depend on groundwater for their drinking water. The Solano Subbasin has a total of ~4,086 wells, an estimated 130 public supply wells for drinking water, and an estimated 1,400 domestic wells
- Linguistic Isolation: Linguistic isolation, which is defined as any household in which all members aged 14 years and older speak a non-English language at home and speak English less than "very well", ranges from 2 to 15% throughout communities within the subbasin (American Community Survey 2012-2016)

In summary, Solano County has a robust agricultural sector with a wide range of crops, excellent soils for growth, moderate winter rainfall, and reasonably reliable sources of irrigation water.

2. AGRICULTURAL PRACTICE SELECTION

This section summarizes the steps TFT took to research, formulate, and ground-truth MAR practice scenarios prior to developing analytical models. In general, this includes working with stakeholders to set goals and objectives, researching suitable practices, developing practice scenarios that align with NRCS Practice Standards, and conducting on-farm site visits to discuss practice scenarios with local growers.

During prior projects also funded through NRCS's Conservation Innovation Grant program, TFT worked with Dixon RCD, Solano RCD, and NRCS to identify three priority conservation practices in the Solano Subbasin: cover crops, irrigation efficiency, and managed aquifer recharge (MAR). The present analysis focuses on MAR as a strategy to recharge groundwater in the Solano Subbasin.

2.1. Goals and Objectives

Goal: Prevent undesirable outcomes in the Solano Subbasin by identifying optimal locations for specific, voluntary agricultural management practices that have the potential to increase shallow aquifer recharge benefits and generate associated flood water reduction benefits in areas of localized groundwater level decline.

Objectives:

- Quantify the (a) economic implementation costs and (b) groundwater and surface water benefits of distributed recharge actions on suitable agricultural fields in the Solano Subbasin
- Provide analytical tools for GSAs to develop programs for targeted outreach, technical assistance programs, and incentives for distributed on-farm recharge practices in specific locations with maximum return on investment

2.2. Managed Aquifer Recharge

Types of Managed Aquifer Recharge. Managed Aquifer Recharge (MAR) is not currently defined by statute or regulation in California, but "groundwater recharge" is defined by statute as "the augmentation of groundwater, by natural or artificial means."[3] MAR represents a groundwater supply augmentation approach to improve aquifer conditions by capturing excess surface water and/or precipitation and moving this water through controlled conditions into aquifers. As an intentional management approach, MAR projects typically aim to meet one or more of the following objectives:

- Increase volume, rate, or both of groundwater infiltration
- Provide water security and resiliency against future droughts and climate change through storing excess surface water below ground
- Work towards Sustainable Groundwater Management Act (SGMA) compliance by reducing overdraft and increasing supply, both in the long- and short-term
- Support groundwater dependent ecosystems (GDEs) by ensuring wetland and riparian areas are not adversely affected by cones of depression

[3] CAL. WATER CODE § 10721(i).

As this approach to improving groundwater conditions has become more widespread, it has taken on various forms.[4] TFT currently models the following two MAR practices within its scenario planning system, which it defines as “Ag-MAR" and “Rain-MAR". These are primarily distinguished by the respective source of water used for recharge: Ag-MAR is intended to divert excess surface water flows from rivers or drainage canals onto agricultural lands and working landscapes for infiltration. By contrast, Rain-MAR is intended to maximize the infiltration of precipitation that falls on agricultural fields. The modeled practices are defined below.

NRCS Practice Standards.

TFT developed practice scenarios for modelling that align with the following NRCS Practice Standards:

- *NRCS Interim Practice Standards for groundwater recharge*. NRCS has prepared two interim practice standards (815[5] and 817[6]) relating to groundwater recharge. These are currently still being tested and reviewed, and not yet eligible for general use in NRCS projects. These new practice standards were integrated into the scenarios selected by TFT
- *Related practices*. In addition to the two NRCS draft practice standards mentioned above, the MAR practices that TFT models are also based on or incorporate elements of NRCS Practice Standards 378 (Pond), 477 (Tailwater Recovery), 644 (Wetland Wildlife Habitat Management), and 356 (Dike)

Modeled practices. TFT analyzed the following MAR practices for fields within the Solano Subbasin:

- *“Rain-MAR.”* Rain-MAR, a term coined by TFT, refers to a form of MAR that involves maximizing the retention or collection of precipitation on or adjacent to agricultural fields, without any application of delivered surface water. Two variations of Rain-MAR are modeled by TFT:
  - *Berms*: relying on existing or newly graded 18” berms on the field perimeter that collect water for infiltration on the cropped area of a field
  - *Sumps:* excavating (or re-purposing) field-adjacent sumps, trenches, or tailwater recovery systems for infiltration
- *“Ag-MAR.”* Ag-MAR is the practice of delivering surface water to an agricultural field for the purposes of infiltrating water to the aquifer. Ag-MAR is generally expected to occur in the winter when crop water demands are lowest. Two variations of Ag-MAR are modeled, one assuming delivery of 2 acre-feet (AF) of water for each acre treated (plus modeled seasonal precipitation) between December and March, and the other assuming delivery of 1 AF of water for each managed acre (plus modeled seasonal precipitation) over the same period. The simulated application volumes are conservative due to uncertainties about the annual availability of excess flows, the feasibility of delivering surface water during winter, and the period of ponding on fields.

[4] For specific examples of each type of MAR project, see: Central Coast Reg’l Water Quality Control Board, Staff Report on Managed Aquifer Recharge in the Central Coast Region (June 21, 2017), www.waterboards.ca.gov/rwqcb3/board_info/agendas/2017/july/item11/item11_stfrpt.pdf.

[5] NRCS Practice Standard 815 is Groundwater recharge basin or trench: An off-channel impoundment with a permeable base underlain by an unconfined aquifer.

[6] NRCS Practice Standard 817 is On Farm Recharge: The periodic application of surface or stormwater to cropland with connectivity to an unconfined aquifer.

Stakeholder input. TFT conducted field visits with four growers in the Dixon Resource Conservation District (a drainage district within the Solano Subbasin) with large agricultural holdings north of I-80 to better understand their perceptions of two potential Rain-MAR practices: berms and sumps. A fifth grower in the same region was interviewed by phone. The growers indicated where their existing sumps and/or tailwater recovery systems are located, and they were asked a series of questions about benefits and risks to their operations, maintenance implements, and economics. The growers represent large land holdings and variable crop and irrigation systems including perennial orchards and asparagus, and annual tomato, sunflower, and grain rotations. The growers have furrow, sprinkler, and drip irrigation systems, and most of them already are familiar with berms and tailwater systems.

Perceptions of MAR with berms. In general, the growers interviewed were averse to using berms to manage stormwater directly on their fields in winter, regardless of potential incentives or penalties. The primary concerns cited include the potential for anoxic soil conditions, reduced yields, and increased disease pressure due to MAR. One grower was open to using berms on fields with row crops (tomatoes and sunflowers), provided he could drain the water in time to till the soil in spring.

Perceptions of MAR with sumps. All interviewed growers were open to using sumps to manage stormwater; however, several expressed a preference for using cover crops to infiltrate water and mitigate flooding, especially on orchards. Each of the growers interviewed had fields with existing tailwater pits and were familiar with the concept. In cases with a pre-existing sump, implementation costs would be lower, and no land would be taken out of production. While several growers noted that re-purposing existing sumps for Rain-MAR would require investment for operations and maintenance, in general, their feedback indicated that using sumps may be worth the added complexity if it earned them “credit” in the event that limits were placed on the apportionment of groundwater water in the future, or if it allowed increased irrigation flexibility or regulatory relief.

2.3. Relationship to SGMA

TFT analyzes the potential benefits and impacts from the prioritized field-level implementation of distributed groundwater conservation practices. The primary benefit would be increased aquifer storage, resulting from supply augmentation via MAR. TFT also analyzes the potential benefits of shallow aquifer recharge in various locations on groundwater dependent ecosystems (GDE) and drinking water in Severely Disadvantaged Communities (SDACs).

Widespread implementation of distributed groundwater conservation actions has the potential to prevent or reverse the following SGMA Undesirable Results in the Solano Subbasin:

- Chronic lowering of groundwater levels
- Reduction in groundwater storage
- Land subsidence that interferes with surface land uses
- Water quality degradation
- Depletion of interconnected surface waters

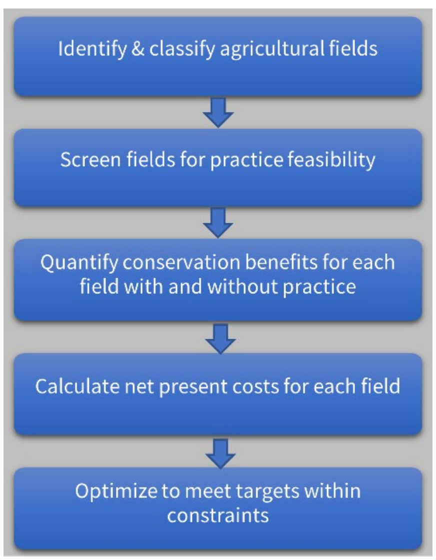
3. METHODS AND RESULTS

3.1. Analytical Approach

MAR opportunities are presented at two scales in the present analysis (Appendix A-1). The two areas of interest (AOIs) are as follows:

- Areas of the subbasin containing cultivated fields with suitable groundwater depths for MAR. For this portion of the analysis, TFT delineated the northern and eastern boundaries of the Subbasin, the southern boundary of the Solano Resource Conservation District (RCD), and the western boundary of Solano Irrigation District
- *Northwest Focus Area*. based on feedback from the Solano GSP Technical team, developed a Project and Management Action (PMA) for Rain-MAR in the Northwest Focus Area (see Solano GSP, draft Chapter 8, August 2021)

This section summarizes the methodological approach for these MAR analyses. TFT used a similar method to analyze irrigation system upgrades and cover cropping in the Solano Subbasin. All of these practices can be analyzed at a field scale in the Solano Agricultural Scenario Planning System (Section 5.5 below) which will be summarized in a subsequent report.



In general, TFT's analytical approach aims to determine where to implement distributed groundwater conservation actions in the subbasin for the maximum benefit at the least implementation cost. To do this, a spatially explicit database is created that can store and pass characteristics of farms through various models. Once an area of interest is defined, multiple spatial datasets are sourced to classify environmental and management conditions at the agricultural field level. Next, each agricultural field is assessed to determine whether the target practice is feasible on each field. The feasible fields are then modeled with and without the practice to quantify conservation benefits and net present cost of the practice. Finally, fields are optimized by cost efficiency to design programs based on objectives and constraints provided by stakeholders.

3.2. Data

Individual agricultural fields are TFT's primary unit of analysis for modeling conservation practices This section describes the datasets used to characterize environmental and management conditions of each individual agricultural field. Our classification model characterizes current conditions of agricultural fields within an area of interest by ingesting various types of spatial datasets and attributing the relevant data to each field. In California, TFT uses a recent DWR field boundary dataset for the spatial polygons. Field attributes are derived primarily from publicly available datasets from the USDA, USGS, NRCS, UC Davis, and others as shown in Appendix A-2 through A-6 (data visualizations) and Appendix A-12 (data sources).

3.2.1. Data Aggregation and Field Classification

TFT's classification model characterizes current conditions of agricultural fields within an area of interest by ingesting field-level attributes from a wide variety of spatial datasets (Appendix A-12) and assigning the relevant datum to each agricultural field polygon. The resulting field-scale spatial dataset incorporates attributes in Table 1 into an ArcGIS geodatabase for further analysis and modeling.

Table 1. Field Classification

Attribute	Source	Purpose
Crop Type	CropScape 2018	Feasibility, predicting irrigation type
Irrigation Type	TFT	Feasibility, water use estimation
Irrigation Source	TFT	Feasibility
Latitude	LandIQ	Calling CIMIS weather database
Longitude	LandIQ	Calling CIMIS weather database
Acreage	LandIQ	Cost factor, benefit factor
SAGBI	SAGBI	Feasibility
Soil Hydrologic Group	SSURGO	Infiltration calculation
Slope	DEM	Feasibility
kFactor	SSURGO	Infiltration calculation
Average Porosity	SSURGO	Infiltration calculation
Distance to GDE	TFT	Benefit type
Average Soil Texture	CVHM Texture Model	Feasibility
Winter GW Depth	LSCE	Feasibility, GDE connectivity
Field Elevation	DEM	GDE connectivity
Average Hydraulic Conductivity	SSURGO	Feasibility, Infiltration calculation
Field Perimeter	LandIQ	Sump dimensons

Agricultural Field Boundaries & Acreages. Boundaries and acreages were determined using the California Department of Water Resources' Statewide Crop Mapping dataset (LandIQ, 2016). This dataset was originally developed by Land IQ, LLC and subsequently revised, as needed, by DWR Regional Office Land Use staff, using a combination of aerial photography, remote sensing multi-spectral imagery, agronomic analysis, and ground verification. Areas that appeared to have non-agronomic land uses are excluded from field polygons. Fields typically contain a single crop type and are not intersected by, or inclusive of, any other features, such as houses, irrigation and fertilization structures, barns, roads, canals, etc. Each field's acreage was then calculated using ArcGIS.

Crop Type. The crop or crops grown on each field are classified according to the USDA Cropland Data Layer (Han, 2014). The majority crop type for each field polygon is used when this dataset shows multiple crops within a field polygon. Intra-annual rotations are classified, but inter-annual rotations are not, as the SPS is intended to be updated annually for planning purposes.

Crop QA/QC. Remotely sensed crop data from the sources described above went through a Quality Assurance/Quality Control (QA/QC) procedure and ground-truthing process. First, TFT checked a random subset of these datasets against 2019 satellite imagery and Google Earth "street view" images to look for inconsistencies (i.e., orchards or vineyards identified as row or field crops, evidence of misclassified irrigation systems based on visible infrastructure, summer-time green fields identified as non-irrigated, etc.). Second, TFT performed 'reasonableness' checks between the crop types identified on all individual fields to identify unlikely combinations (e.g., "alfalfa" irrigated with high efficiency irrigation, non-irrigated orchards, etc.). Finally, TFT's NRCS and RCD project partners checked the correctness in crop and irrigation type for a random subset of Solano County fields based on their own knowledge of the area. The project partner input, aerial imagery analysis, and Google Earth "street view" imagery was used to rectify data issues identified through the above procedures.

Soils & Field Slope. The majority slope within each field polygon is calculated in ArcGIS using the U.S. Geological Survey 10-meter digital elevation model (DEM), and the majority soil type within each field polygon is determined using the NRCS SSURGO Database (Soil Survey Staff, 2021).

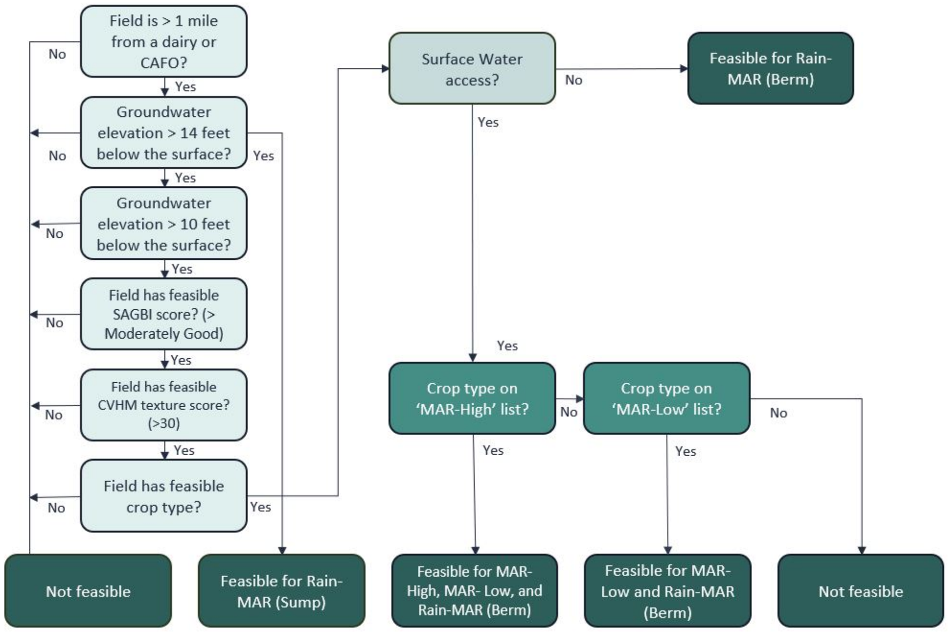
Surface Suitability for Recharge. The Soil Agricultural Groundwater Banking Index (SAGBI) dataset is used to assess suitability for NRCS practices aimed at recharging groundwater. A team of researchers at the University of California Davis and the UC Cooperative Extension developed SAGBI, which incorporates soils and topography data to compute a spatially explicit index of the suitability for groundwater recharge. The SAGBI is calculated using five major factors that are critical to successful agricultural groundwater banking: deep percolation, root zone residence time, topography, chemical limitations, and soil surface condition. The SAGBI is derived from parameters like slope classes, soil electric conductivity (EC), and soil hydraulic conductivity (Ksat) from the SSURGO Database. A modified SAGBI score (provided by UC Davis) is used in the SPS that accounts for six-foot 'deep tillage', eliminating near-surface confining soil layers.

Source of Irrigation Water. For Ag-MAR, each field's source of irrigation water is classified as surface water, groundwater, or "mixed" (i.e., the field has the potential to be irrigated by both surface and groundwater). Using the classification methods, the likelihood that a field is irrigated with surface water increases with proximity to a surface water diversion location, based on the State Water Resources Control Board's Electronic Water Rights Information Management System (eWRIMS8), or to water conveyance infrastructure (based on the US Fish and Wildlife Service's National Wetlands Inventory). Surface water access is also highly likely for fields located within a water district that supplies surface water from the California State Water Project or other water management project (water district boundary source: California Water District Layer). Similarly, the likelihood of irrigating with groundwater increases with proximity to a groundwater well that is part of DWR's California Statewide Groundwater Elevation Monitoring (CASGEM) Program (DWR's Periodic Groundwater Levels Dataset). TFT verifies irrigation source classifications using the DWR California Land Use Surveys dataset. The surveys used to develop irrigation source data were conducted in 2003, 2000, and 2008 for Solano, Sacramento, and Yolo counties, respectively.

3.3. Managed Aquifer Recharge

3.3.1. Feasibility Analysis

TFT's feasibility model excludes fields from analysis by defining thresholds for factors that would constrain recharge, impact farm operations, or pose a potential risk for flooding or drinking water quality. For example, recharge is neither advised on fields with identified mounding risk (shallow groundwater elevations, low SAGBI scores, fine textured soils), nor on crops intolerant to flooding, nor on fields which pose nitrogen leaching risk from dairies (details below). As noted above, TFT did not analyze other groundwater quality constraints, such as contaminant plumes due to the wide variability between potential contamination sites. These, and other legal/regulatory constraints (e.g., zoning, permitting, easements, etc.) would need to be assessed at a site level during the project implementation phase. Figure 1 below illustrates the logic that is applied to each field in order determine which actions are feasible.



3.3.2. Screening Potential Constraints and Risk Factors

There are several risk factors associated with MAR practices that TFT screens to ensure that all fields are suitable for the practice. Three of these factors, mounding risk, crop compatibility, and water quality, are common to both MAR practices. Ag-MAR has additional constraints associated with access to surface water. Only fields classified as using surface water (either fully or in conjunction with groundwater) are considered feasibly for Ag-MAR.

Mounding risk. There are three metrics that inform mounding risk for MAR: Soil Agricultural Groundwater Banking Index, known as SAGBI (O'Geen, 2015), groundwater elevation, and the soil texture.

First, SAGBI is a spatially explicit index of the suitability for groundwater recharge of land in all agricultural regions in California. It uses five metrics to provide preliminary guidance about the locations where groundwater recharge on agricultural land is likely to be feasible: deep percolation, root zone residence time, topography, chemical limitations, and soil surface condition. There is an optional modification that recalculates SAGBI based on percolation changes resulting from "deep tillage." TFT uses this modified SAGBI due to the prevalence of deep tillage in these Solano agricultural areas. TFT considers fields with a SAGBI rating of Excellent, Good, or Moderately Good as feasible to implement MAR.

Second, groundwater elevation informs the mounding risk from MAR. Solano groundwater elevations were provided by Luhdorff and Scalmanini for the Solano Subbasin for the year 2005, which was chosen based on the fact it was an above average Water Year (as classified by DWR) and provides a conservative mounding risk feasibility criterion.

Third, the Central Valley Hydrological Model, known as CVHM, (Faunt, 2009) uses a soil texture model which is vertically and horizontally interpolated to inform MAR mounding risk. The texture model has one-mile pixels with 46 layers which are each 50 feet deep. TFT used a machine learning algorithm to relate the CVHM coarseness percentage to high resolution hydraulic conductivity data provided by the GSP technical team. Generally, a higher coarseness percentage indicates higher hydraulic conductivity. The feasibility threshold of hydraulic conductivity and texture were set to ensure that the volume of a NOAA Atlas 14 (Perica, 2014) "10-year storm" to infiltrate fully within 2 days. The selection of a 10-year storm was based on an above average storm, and the selection of two days was based on sensitivity to the crop flooding tolerances described above. Only the fields that could theoretically infiltrate that type of storm within two days (based on that field's texture and hydraulic conductivity metrics) were considered feasible for Rain-MAR.

Crop Compatibility. Crop feasibility criteria for Rain-MAR are 1) the crop's ability to withstand temporary saturated soil/anoxic conditions of 48 hours, and 2) no identified land use (crops or livestock grazing) during winter/early spring months during the MAR implementation period. Crop suitability criteria are 1) the amount of time the crop can withstand saturated soil, and 2) the crop's rooting depth (shallow rooting depths are less susceptible to water logging) and 3) crops with planting dates earlier than March 15th. The MAR flood tolerance metrics are taken from three published papers: one which tested alfalfa only (Dahlke, 2014), and another which tested pistachio, almonds, wine grapes, alfalfa, and fallow before the planting of summer crops (Bachand et al., 2018). Both studies occurred on soils with high percolation rates. A future crop application could be to use the Nitrogen Hazard Index (Dzurella et al., 2015) to eliminate crops which typically apply large amounts of (leachable water soluble) nitrates.

On fields where growers are also implementing cover crop rotations during winter months, infiltration of precipitation or applied water may be increased even higher. This phenomenon is shown in numerous peer-reviewed California agroecological studies (Rath et al., 2021; Mitchell et al., 1999; Folorunso et al., 1992; Joyce et al., 2002).

Water Quality Risk. Though MAR (and especially Rain-MAR) can improve groundwater quality via dilution in certain circumstances, it has the potential to increase groundwater quality risks via mobilization. Nitrate, a water-soluble contaminant which causes numerous health issues (Ward et al., 1996, Weyer et al., 2001), can impact aquifers in agricultural settings. Indeed, according to the seminal Nitrate Report *Addressing Nitrate in California's Drinking Water* (Harter et al., 2012), 96% of human-generated nitrate sources to groundwater were from cropland. This nitrogen applied to crops, but not removed by harvest, air emission, or runoff, is leached from the root zone to groundwater via natural percolation processes, which could be exacerbated by MAR implemented in certain circumstances.

Of this 96% figure, the Harter Report found that land-applied manure and liquid slurry from dairies caused 33% of nitrogen in the aquifer below the southern Central Valley; therefore, proximity to dairies is an important metric to consider when implementing MAR. There are environmental justice implications in this research question, because although nitrate concentrations can be reduced through blending or treatment, Severely Disadvantaged Communities (SDACs) and unincorporated communities are more vulnerable to nitrate contamination (London, 2011). This is because it is more difficult for small water systems to pass the cost of major infrastructure improvements on to low-income customers. Similarly, private domestic drinking water wells were not required to be regularly monitored for nitrate in Solano County until January 2022 (ILRP, 2021).

Some groups are doing work on this topic, such as the Community Water Center who released a comprehensive webtool (Gailey, 2020) to understand domestic well prevalence, well depths, and contaminants found in monitoring wells. The State Water Resources Control Board also developed a useful Aquifer Risk Map webtool (Houlihan, 2020). One gap in the analyses undertaken by these groups is the effects of agricultural practices on drinking water quality risk for SDACs using small community systems or private wells. Even though variability in individual farmers' past and present fertilizer and water management practices contributes to different legacy salt and nitrate loads in the vadose zone (Bachand et al., 2016) these individual farm-level management data are unknown at this time.

Therefore, to add to these SDAC drinking water quality efforts in an agricultural context, TFT used another feasibility criterion to reduce the likelihood that MAR negatively impacts community water systems or drinking water wells. TFT has identified the locations of known CAFOs and dairy operations (CRWQCB, 2016) in Solano County and removed fields within 1.0-mile from eligibility for Rain-MAR to protect groundwater quality. This method is derived from one study in Merced and Stanislaus counties (Lockhart et al., 2013) that found elevated nitrate levels in domestic wells with shallow (≤ 21 m) water tables (which are common in areas of Solano County), and within 1.0 mile of a dairy or CAFO-derived animal waste applications.

A promising development to this evolving science is the generation of contaminant risk maps (Podgorski & Berg, 2020; Fakhreddine et al., 2021) as they pertain to MAR implementation.

<u>Access to Surface Water</u>. In contrast to Rain-MAR, Ag-MAR involves the application of surface water to the field for recharge. This introduces several constraints, including the need to verify water rights, the need for surface water delivery infrastructure, coordination with an irrigation district to utilize and time the delivery of water, and obtaining regulatory permits if water is diverted from streams. The availability of surface water is incorporated into TFT's field classification process (Section 3.2). Additional constraints, such as water rights, permitting requirements, and delivery infrastructure require site specific analyses beyond the scope of this report.

3.3.3. Infiltration Analysis - Methods

Once fields are classified and unsuitable fields are ruled out, the fields where MAR is feasible are analyzed for their relative infiltration capacity. TFT uses a water balance equation that incorporates precipitation data, evapotranspiration, and NRCS' Runoff Curve.

<u>Water Balance equation</u>. TFT's infiltration model uses a water balance equation at the field level to estimate the changes in water distribution given the implementation of agricultural conservation practices. The water balance approach is a flexible method that allows various component water sources and sinks to be defined for a unit of analysis (ag fields in this case) and manipulated to estimate how modelled actions impact the distribution of water. The model uses field specific input volumes of precipitation and irrigation to estimate the various discharges through crop evapotranspiration, surface runoff, subsurface flows, and percolation to groundwater aquifers

<u>Precipitation</u>. Daily precipitation depth (P_{tj}) is estimated for each agricultural field using an inverse distance weighted average total daily precipitation from the three nearest California Irrigation Management Information System (CIMIS) reporting stations (Appendix A-14). The spatial centroid of each field is used to determine the three nearest stations and the distance to them. Using an inverse distance weighted average is a scientifically accepted approach that avoids extreme values that may

otherwise be observed by simply taking data from a single nearby station yet preserves the influence of distance-from-measurement overall.

Evapotranspiration. Crop evapotranspiration represents the volume of water that a crop uses for growth and cooling. This is estimated using a modified version of the Consumptive Use Program Plus (CUP+ version 6.1), developed by the California Department of Water Resources (Orang, 2005). Irrigation inputs are the predominant source of non-precipitation water entering the water balance equation, but given the range of conservation actions, applications could also include the volume of water applied for MAR. Irrigation is assumed to be applied in situations where crop demand exceeds precipitation; this excessive demand is also referred to as Et_{aw}. To meet Et_{aw}, it is assumed that producers apply this volume, plus an amount equal to the inefficiencies of a given irrigation system. We assume efficiencies of 65%, 75%, and 90% for flood/furrow, sprinkler, and drip irrigation, respectively.

Runoff Curve. The quantity of water leaving the field as runoff is estimated using the runoff curve method as described in the National Engineering Handbook (NEH, 2004). Runoff curves estimating the quantity of direct runoff (surface, channel, and subsurface flow) are defined for various curve numbers (CN), which are a function of a hydrologic soil group (Chapter 7), land use class (Chapter 8), and the hydrologic condition (Chapter 9). Hydrologic soil group describes the types of soil underlying an area of interest by assigning a letter identifier ranging from A-D retrieved from the NRCS web-soil survey, where A soils have the lowest runoff potential, and D soils have the highest (Soil Survey Staff, 2021). Soil types are estimated for a given field using zonal statistics to calculate a majority soil type of that field. Land use class describes the type of use occurring on a given field in terms of the general crop class (row, grass, orchard, etc.) and the treatment (practices like conservation tillage, no-till, contour farming, etc.) occurring on that field which affect runoff. Land use classes are derived from CropScape data during the field classification stage. Treatment class is a function of the practices we are modeling and the crop type as tillage method is a crop-based assumption in our model. Hydrologic condition qualitatively (good, fair, or poor) describes the infiltration potential of a field as a function of land cover (both density and frequency), field slope, crop residue, and grazing intensity. An additional adjustment is made to the initial assignment of CN to account for 5-day antecedent precipitation and irrigation. This adjustment, called the antecedent runoff condition (ARC), is made to account for the increased likelihood of soils either being saturated or dried out. The adjustment is made to the CN and shifts is down in the case of low precipitation which lowers expected runoff, and up in the case of high precipitation, which increases expected runoff (Schiariti, 2021).

Given the mass balance requirement of water in the hydrologic cycle, the remaining volume of water is assumed to be storage in the soil and groundwater. Given the inclusion of the antecedent rainfall in the runoff equation, TFT is confident that we are accounting for a significant portion of soil storage. Following the definition of runoff using the CN method, a portion of that runoff represents subsurface flow. Therefore, we assign the remaining balance to the atmosphere and groundwater, with 85% of the storage value to groundwater, and 15% to remaining storage.

Calculations for Sumps. The inclusion of sumps on a Rain-MAR field adds an additional complication to the calculations as we need to account for water entering the sump, infiltration rates, and a sump's water holding capacity

Due to lack of reliable data for which fields have existing sumps, we assume that when this practice exists as a feasible alternative, a sump is added to the edge of the field. Adding sump requires the following assumptions be made:

1. Length of the sump is ¼ the perimeter of the field area as determined using GIS
2. Width of the sump is 40 ft.
3. Depth of the sump is variable with the field's winter ground water depth, with a limiting condition that there remains 10 ft. between the bottom of the sump and the water table estimate. The sump is assumed to have 1:2 slopes on the side and represents a trapezoidal/v shaped sump.
4. Infiltration rate of the sump is equal to the field's average daily vertical k_{sat} from SSURGO.

The impact of these assumptions is evident beyond the infiltration modeling as will be seen in the following cost analysis section

3.3.4. Infiltration Analysis - Results

The foregoing methods were applied to all suitable fields to determine the relative efficacy of MAR across the Solano Subbasin. This section summarizes the results of that step in the analysis.

A map of the feasibility of Rain-MAR and Ag-MAR in the Solano Subbasin are presented in Appendix A-7. In general, the feasibility of Rain-MAR was higher because Ag-MAR has many more implications for standing water on cropped fields. Additionally, Rain-MAR is not restricted by access for surface water delivery.

Further analysis was conducted on Rain-MAR-feasible fields to visualize the distributions of resulting infiltration volumes. Histograms and boxplots were generated for both infiltration volumes (acre-feet) and infiltration in linear feet (in other words, infiltration volume normalized by field area) as shown in Appendix A-15 and A-16. Here, infiltration refers to *additional* infiltration resulting from Rain-MAR practices (compared to existing farm management without Rain-MAR).

The left and right histogram distributions are to be expected for volume and feet (respectively) of infiltration, with most fields infiltrating smaller volumetric amounts because they are smaller in acreage. However, examining the summary statistics below, more than half of the fields produced zero additional infiltration (e.g., the median infiltration is 0). This finding is true for volumetric infiltration and infiltration controlling for field area.

Table 2. Summary Statistics of Infiltration Benefits and Costs

	Min	1st Quantile	Median	Mean	3rd Quantile	Max
Acre Feet	0	0	0	1.79	0.22	94.56
Feet	0	0	0	0.05	0.04	1.06
10-yr. Costs	0	0	0	$36,089	$61,222	$403,539

This finding is likely related to the antecedent runoff condition (ARC) within the NRCS Runoff Curve method described in the earlier infiltration methods section, and the fact that TFT models infiltration in a "Critical" Water Year (dry) and a "Wet" water year (see monthly precipitation means in Appendix A-

14). The estimated benefits include a range of values in representative DWR Water Years, "Critical" and "Wet", as classified for the Sacramento Valley (CDEC, 2021). CIMIS data from Water Years 2015 and 2017 were used to represent a Critical and Wet Year, respectively, representing both ends of the precipitation spectrum.

As described in the methods section above, the ARC is an improvement made to the Runoff Curve method which refers to the preceding five days' rainfall patterns to estimate soil moisture. TFT models most short and infrequent rainfall events (the most common rainfall event during drier years) as not generating any runoff, because the soil moisture is so low that the small precipitation volume infiltrates and remains in the vadose zone. This low soil moisture in drier water years mean that implementing Rain-MAR during those years would not produce any *additional* infiltration (or prevented runoff) benefits for many fields. By recalculating these summary distributions for Wet Years and Critical Years separately (normalizing by field area), this ARC effect becomes clearer, as seen in Appendix A-16.

3.3.5. Cost Analysis - Methods

TFT's cost model uses a cost-benefit analysis framework[7] to inform priority-setting and investment decisions in planning agricultural conservation actions. It aggregates annual costs with conservation action implementation over a defined period. The economic components of adding conservation practices to a farming operation is dependent on several field level details and existing practices. Aggregated annual values are output as a net present value (NPV), using a 3% discount rate of implementing a single or multiple conservation actions over a defined period; for the purpose of this analysis, 10-years is used. Field level costs and benefits are evaluated as private (incurred/realized by producers), resulting in a more comprehensive analysis that is useful to producers, conservation planners, and various state and federal agencies. Researching, organizing, standardizing, and aggregating the data needed to complete the cost/benefit analysis requires a wide variety of sources. Crop enterprise budgets from the University of California Cooperative Extension and NRCS practice standards provided the basis for many of the values used in the module, but technical reports, peer-reviewed literature, professional opinion, and USDA data were used to develop the final values. All values were transformed into standardized units.

Net benefits. The model development starts with identifying the net benefits associated with any given conservation action on an annual basis. We employ a partial budgeting approach (Weyer, 2001) to describe/quantify the changes in expected cash flows, given the implementation of a conservation action; this results in a baseline cost of $0. When benefits are not monetized, the resulting net benefit is negative, indicating a cost.

The economic components of adding MAR to a farming operation depend on numerous unobserved field level details and existing practices. Therefore, the costs considered are expected to represent a conservative situation where the field has no existing/useable infrastructure and is not currently performing any of the necessary operation/maintenance tasks needed for this practice. The MAR practice is analyzed in two contexts (Ag-MAR and Rain-MAR), with multiple economically unique

[7] As applied, with no monetized benefits, the analysis functions as a present value cost analysis, and the reporting metric is the net present cost.

scenarios in each dependent on the management method (sump or berm) and the MAR source (applied water or precipitation).

The model calculates the present value of costs over the defined period based on various combinations[8] of the following components:

Rain-MAR (Sump)

- Operation (Sump Preparation)
    - This is an annual cost for clearing vegetation from the sump via mowing. Costs are informed by both California NRCS practice standards and interviews with landowners in Solano County.
- Operation (Sump Excavation)
    - This is an establishment cost for initial excavation of a sump. Because there is insufficient data to determined which fields have a sump, we assume all fields need a sump constructed to use this practice. Excavation costs are based on $/cubic yard estimates from California NRCS practice scenarios.
- Operation (Field Preparation)
    - This is an annual cost for grading land after harvest of annual crops to facilitate water flowing into the sump. The cost estimates are based on multiple sources for general field operations, and do not represent the use of any specific implement or method.
- Maintenance
    - This is an annual cost to remove sediments that are loaded into the sump and eventually decrease its holding capacity. The current assumption is that the maintenance is performed annually, but it may be the case sumps only require clean-out every 5 yrs. Excavation costs for cleanout are estimated as 20% of initial excavation costs.
- Flashboard Riser
    - Flashboard riser is assumed to be necessary in each sump. This is to prevent flooding on adjacent fields and control the water levels in the sump. Cost estimates are applied from California NRCS practice scenarios.

Rain-MAR (Berm)

- Operation (Field Preparation)
    - Field preparation is assumed to consist of construction of temporary berms/checks to retain precipitation in the field area. The costs are taken from the California NCRS practice scenario for the construction of temporary habitat ponds through “Separat[ing] portions of a field with a newly constructed internal levee.” It is assumed these berms would be dismantled with normal field preparations, so no additional costs are incurred.

[8] See Appendix A-13 for cost schedules used in the analysis

3.3.6. Data Limitations/Uncertainties/Issues not Addressed

Field data resulting from TFT's analysis were quality-checked to determine if the values were within an appropriate and expected range and re-analyzed as needed. However, there are several data limitations and sources of uncertainty that cannot be addressed with the data available, as discussed below.

Water Rights. The screening tool does not take into account water rights that may be required to do MAR. Some practices, particularly Ag-MAR, would require the verification of water rights, or permission to use private or district-owned canal systems. This would need to be done on a case-by-case basis and is not included in TFT's analysis, and therefore represents a possible future cost to the practices affected water right constraints. The following agencies may have roles for recharge projects in general: the respective GSA, Solano County, the State Water Resources Control Board (SWRCB), and USBR (if using CVP contract supply).

Regulatory Permits. The screening tool does not review regulatory permits that may be required for certain forms of MAR. State and local public agencies in California are required to comply with the California Environmental Quality Act (CEQA) when they take discretionary actions, such as implementing a project or program that makes a significant change to the environment that is not otherwise exempted. Likewise, diversions from creeks and streams may require federal or state regulatory permits.

Water rights. Some practices, particularly, would require the verification of water rights, or permission to use private or district-owned canal systems. This would need to be done on a case-by-case basis and is not included in TFT's analysis.

Existing sumps: Through direct farmer outreach, TFT identified existing sumps on numerous fields, however, no comprehensive dataset is available to positively identify sumps across the subbasin. Due to the lack of data and/or methods to estimate existing sumps, TFT assumes no fields currently have sumps and thus require establishment of new sumps. This assumption may overestimate the excavation costs of implementing sumps, on fields where sumps already exist.

Other Physical Conditions. Our assessment of conditions used in the feasibility analysis is limited to the quality and reliability of the data we have access to. TFT is unable to accurately assess existing infrastructure in many cases. Land uses change over time, which can affect the feasibility criteria, and/or the physical characteristics (size, shape) of delineated field areas. Currently, land ownership records do not exist in a state that would allow us accurately combine fields into more efficient units of analysis. Only on the ground verification in the program implementation phase can inform these critical pieces of information.

3.4. Assessment of Potential MAR Benefits

TFT has developed methods to assess whether the infiltration resulting from MAR activities on any given field is likely or unlikely to support resources of importance under SGMA. This section presents methods and analyses of potential benefits to groundwater dependent ecosystems (GDEs) and Drinking Water Wells in SDACs. These tools can be applied in the implementation phase of the GSP to model the potential benefits of MAR activities for specific habitats or drinking water systems within the Subbasin.

3.4.1. Potential Benefits to Groundwater Dependent Ecosystems (GDEs)

GDEs are ecological communities or species that depend on groundwater emerging from aquifers or on groundwater occurring near the ground surface (The Nature Conservancy, 2019). Groundwater levels fluctuate over time and space due to California's Mediterranean climate (dry summers and wet winters), climate change (flood and drought years), and subsurface heterogeneity in the subsurface. Many of California's GDEs have adapted to dealing with intermittent periods of water stress; however, if these groundwater conditions are prolonged, adverse impacts to GDEs can result.

Following the Solano GSP, TFT uses the NCCAG dataset (Klausmeyer, 2018) which uses phreatophyte vegetation and the surface expression of groundwater (such as springs and seeps) to estimate potential GDE polygons (Appendix A-8). *Identifying GDEs under SGMA: Best Practices for using the NC Dataset* (TNC, 2019) includes six best practices to identify GDEs. The first is establishing a connection to groundwater, noting "it is important to consider local conditions (e.g., soil type, groundwater flow gradients, and aquifer parameters) and to review groundwater depth data from multiple seasons and water year types (wet and dry) because intermittent periods of high groundwater levels can replenish perched clay lenses that serve as the water source for GDEs." Indeed, SGMA requires GSAs to describe current and historical groundwater conditions when identifying GDEs. TFT addressed this analytically by modeling two extreme cases (3 consecutive drier years 2014-2016, and 3 consecutive wetter years 1997-1999). The DWR Chronological Reconstructed Sacramento and San Joaquin Valley Water Year Hydrologic Classification Indices (California Data Exchange Center, 2021) were used to choose the wetter and drier periods.

DWR's Periodic Groundwater Level Measurements dataset (Periodic Groundwater Level Measurements, 2021) was used for interpolating groundwater elevations. Wells screened below the elevation of a confining layer were removed to eliminate false readings, as described in best practice #4 of TNC's GDE guidance document. The CVHM user manual indicates that the average elevation for the confining layer in the Sacramento Valley is 2,300 feet. (Faunt, 2009)[9] For the purposes of this analysis, all elevations from wells screened below 2,300 feet were eliminated, and wells screened above retained.

Following *Identifying GDEs under SGMA*, the 2nd best practice is to characterize seasonal and interannual groundwater conditions. This was addressed by further classifying the NCCAG polygons by their connectivity to an aquifer. To do this, the groundwater elevations were selected during a winter wet month and summer dry month of a representative Wet Year and Critical Year. Following TNC's best practice #5 method on how to contour depth-to-groundwater around surface water features and GDEs, these groundwater elevations were compared to the digital elevation model (DEM) surface elevations of GDEs by taking the elevation differential (Appendix A-9). If GDE > GW elevation, the GDE is unconnected, and if GW > GDE elevation, the GDE is connected. Any combination of connectivity in summer/winter months in Wet or Critical Years is classified as having borderline connectivity and prioritized for restoration (Table 2).

[9] Fogg, Graham, Ph.D., Professor of Hydrogeology and Hydrogeologist, UC Davis, personal communication, April 2020. The CVHM average is used as a rule of thumb for the subbasin wide analysis. Nonetheless, there are likely perched aquifers, clay lenses, and fissures to deep aquifers that are shallower than that, for which public data are not available.

Table 3. Connectivity of Groundwater Dependent Ecosystems (GDEs)

Connectivity type	Critical Year (Jan-Mar)	Critical year (Jul-Sep)	Wet Year (Jan-Mar)	Wet Year (Jul-Sep)
Connected	GW* > GDE**	GW > GDE	GW > GDE	GW > GDE
Unconnected	GW < GDE	GW < GDE	GW < GDE	GW < GDE
Borderline	GW > GDE	GW < GDE		
	GW < GDE	GW < GDE	GW > GDE	GW > GDE
			GW > GDE	GW < GDE

A workflow embedded in ESRI[10] ArcGIS 10.7 based on Darcy's Law[11] was used to estimate and model direction and distance of groundwater flow and distance to GDEs from each agricultural field in the subbasin (see map below). When determining each field's MAR benefit type, fields whose infiltrated water eventually flows to a GDE are considered to be MAR fields that benefit GDEs. The output of these workflows produces a numeric "hydraulic distance to GDE" metric that is either zero or nonzero. If the field's GDE distance metric is non-zero, that field gets classified as MAR-GDE benefit.

3.4.2. Drinking Water Wells for Severely Disadvantaged Communities (SDACs)

In a related Proposition 1 Sustainable Groundwater Planning Grant funded by a Department of Water Resources (DWR), TFT identified and engaged with groundwater-dependent severely disadvantaged communities (SDACs) in the Solano Subbasin to inform the Groundwater Sustainability Plan. Subsets of disadvantaged communities and geographically isolated communities dependent on small water systems or private wells, such as domestic well users, were identified as being most vulnerable to groundwater impacts. Prevalent concerns are that rural wells may be impacted from poorly maintained septic systems, chemical storage facilities, and agricultural and industrial waste exacerbated by lower groundwater elevations. Likewise, small public water systems are resource-limited and may not have the technical expertise, managerial resources, or financial resources to identify or respond to similar water quality risks (EKI, 2020).

Summary of SDAC Outreach. TFT and Local Government Commission (LGC) engaged with groundwater-dependent communities that may be most vulnerable to changing conditions to ensure their needs and concerns are incorporated in the development of the GSP. Using publicly available datasets, TFT and LGC conducted a detailed geospatial analysis of the Solano Subbasin to identify the distribution of groundwater dependent SDAC communities[12]. The initial analysis included federal and state datasets and an analysis of socioeconomic vulnerability indicators (Houlihan, 2020; County Drought Advisory Group, 2021). Vulnerability indicators and more information about wells and public water systems within the Solano Subbasin can also be explored at groundwaterguide.com/map.

Findings from this outreach generated questions from community members about shallow domestic wells going dry, inter-basin coordination on groundwater planning efforts, groundwater-surface water interactions (e.g., stormwater run-off impacting groundwater quality), water quality monitoring for

[10] ESRI. 2019. *Cost Path (Spatial Analyst).* https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-analyst/cost-path.htm
[11] ESRI. 2019. *What is Darcy flow analysis?* https://desktop.arcgis.com/en/arcmap/10.7/tools/spatial-analyst-toolbox/what-is-darcy-flow-analysis.htm
[12] Please see Webmap created by TFT for this purpose here: https://freshwatertrust.maps.arcgis.com/apps/MapSeries/index.html?appid=b7f3791641dc4f3e8719d3ecde3a071c

private domestic wells, and land-use impacts on groundwater (particularly in relation to new housing developments). Quantitative analyses are possible to address these qualitative findings. For example, Marwaha et al. (2021) developed a framework to target MAR near rural communities to potentially stabilize groundwater tables and maintain or improve groundwater quality in domestic supply wells using similar biophysical and socio-economic feasibility metrics as TFT.

Following the same ESRI workflows described above for GDE benefits, TFT assessed the potential for infiltrated water from MAR to support communities who rely on shallow domestic wells. DWR's Online System for Well Completion Reports (OSWCR, 2021) was used as the data input for domestic wells (Appendix A-10). The OSCWR dataset has been scaled to the Public Land Survey System (PLSS) section that the well is located in. By filtering the dataset to only include PLSS sections with domestic wells in Solano County, TFT estimated the potential for water infiltrating from MAR on a particular agricultural field to reach a PLSS section with domestic wells (Appendix A-11). This map indicated that 3,146 out of 3,217 of the analyzed fields do flow to a PLSS section containing domestic wells. The three semi-transparent circles show the three known dairies in Solano Subbasin, with a 1.0-mile radius buffer. These fields are excluded for MAR feasibility based on their water quality risk to shallow domestic wells.

3.4.3. Potential Benefits to Aquifer Storage

One of the primary intended benefits of MAR is the recharge of local aquifers for irrigation or drinking water storage. For the purposes of this analysis, aquifer storage is broadly defined as waters infiltrating primarily to unconfined aquifers. Likewise, any water that infiltrates beyond the root zone is considered a potential benefit for aquifer recharge and storage. This may result in interactions with alluvial aquifers or deep percolation to confined aquifers; however, these interactions are beyond the scope of this analysis based on lack of subterranean geologic fissures and other data.

A promising contribution to this emerging science is the Airborne Electromagnetic (AEM) studies and surveys being commissioned by the Department of Water Resources (DWR) in the near future (Dlubac, 2020). The AEM project provides state and federal agencies, groundwater sustainability agencies (GSAs), stakeholders, and the public with basin-specific and cross-basin geophysical data, tools, and analyses. During an AEM survey, a helicopter tows electronic equipment that sends signals into the ground which bounce back. The process has been compared to taking an MRI of the ground subsurface. The data collected is used to create continuous images that are interpreted for underground geology. The resulting information will provide a standardized, statewide dataset that improves the understanding of aquifer structures. It can also help with the development or refinement of hydrogeologic conceptual models and can help identify areas for recharging groundwater.

4. DISCUSSION

The preceding sections discuss TFT's methods for defining and modeling MAR practices at a field scale and preliminary results of MAR analyses in the Solano Subbasin. The following section demonstrates the potential application of these methods for developing projects to support groundwater management and tools that can be used to incentivize and prioritize MAR projects and other projects that benefit groundwater.

4.1. Applications to GSP

In June 2021, TFT presented its MAR analyses to the Solano GSP Technical Team. Following guidance from the team, TFT contributed information and data to the project and management action chapter of the Solano GSP. Collectively, these outputs provide an explanation of how distributed recharge strategies on farms can be used to provide groundwater management solutions, a potential demonstration project to field test this strategy using Rain-MAR, and management tools for GSAs to develop recharge programs during the implementation phase of the GSP. This section includes:

- Overview of Multi-benefit Recharge Projects (GSP Sec. 8.4.2) and field-level MAR data for PMA development
- A PMA for a proposed Rainfall Managed Aquifer Recharge Demonstration Project in Northwest Focus Area (GSP Sec. 8.4.2.2)
- A policy memo with a Credit Accounting Framework to support the Strategic Demand Management section (GSP Sec. 8.4.3.1). The framework provides a legal framework for crediting groundwater recharge actions to create incentives for practice adoption
- A summary of the Solano Agricultural Scenario Planning System, forthcoming in January 2022, in Tools for Implementation (GSP Sec. Sec. 8.6.2). This tool can be used by GSAs to develop cost-effective programs for implementing MAR and other conservation practices.

4.2. Rainfall Managed Aquifer Recharge (Rain-MAR) in the Northwest Focus Area

The Rainfall Managed Aquifer Recharge (Rain-MAR) PMA is a voluntary demonstration project intended to evaluate the use of specific MAR activities on local farms to generate multiple benefits for groundwater sustainability and stormwater management in the Northwest Focus Area (Appendix A-1). Rain-MAR was selected for assessment in this area because the practice can be implemented on an individual farm without the need for external water, delivery infrastructure, or permits, and because the implementation costs are lower than other forms of MAR. This analysis supports two components to the Rain-MAR PMA: (i) a demonstration project designed to test the practice on a small number of fields and (ii) a hypothetical MAR incentive program to illustrate the conservation benefits and practice costs associated with implementing distributed MAR practices across a larger landscape.

4.2.1. Demonstration Project

The Rain-MAR Demonstration Project will involve working with willing landowners to develop and test methods for reducing sheet runoff from agricultural fields during winter storm events and managing the water for infiltration. In addition to recent groundwater level declines, the Northwest Focus Area drains to areas identified in the Dixon Watershed Management Plan as having floodwater and stormwater management issues.

Applying the methods described in previous sections, TFT has identified 108 agricultural fields suitable for Rain-MAR within the targeted area of the Northwest Focus Area: five fields where both the sump and berm methods are feasible, and 103 fields where only the sump method would be feasible. The demonstration project will identify up to three fields where willing landowners will implement MAR to assess the benefits and costs on-the-ground within or in the vicinity of the Northwest Focus Area.

The objectives of the Rain-MAR Demonstration Project are to:

A. Implement two methods of Rain-MAR (each on at least one field): (i) using a pre-existing end of field sump or (ii) grading temporary 18-inch berms along the field edge, to reduce runoff and increase infiltration of rainwater between December and February for up to three years. Water will be sourced by capturing winter precipitation that falls directly onto the field.

B. Design Rain-MAR practices so that they avoid or minimize impacts to the normal use of the demonstration fields for growing healthy and abundant agricultural crops, and to avoid the potential for adverse impacts to neighboring fields.

C. Evaluate the (i) volume and rate of groundwater infiltration, and (ii) the volume of prevented runoff resulting from the practice on each demonstration field as compared with similar control fields where the practice is not applied.

D. Monitor and evaluate mounding, crop health, and nitrate risk on both demonstration and control fields.

F. Develop recommendations for a future management program that provides financial incentives and or market-based incentives to growers for voluntary practices to recharge groundwater and prevent runoff in conjunction with ongoing agricultural production in the Northwest Focus Area.

Demonstration Project: Expected Volumetric Benefits. Two representative fields were chosen to estimate the volumetric benefits of the proposed Rain-MAR demonstration project, including one field for the sump method and for the berm method. The sample fields were selected because they had among the largest modeled amounts of additional precipitation retained per acre (within each practice type). Table 2 summarizes the estimated volumetric benefits and implementation costs for each method on the demonstration fields.

The estimated benefits include a range of values in representative DWR Water Years, “Critical” and “Wet”, as classified for the Sacramento Valley. CIMIS data from Water Years 2015 and 2017 were used to represent a Critical and Wet Year, respectively, representing both ends of the precipitation spectrum.

The estimated costs include implementation and maintenance of the sump and berm practices on the representative treatment fields. The sump method assumes use of any pre-existing basin.

The costs estimate reflects expenses for implementation of the practice and does not include costs for outreach, recruitment, and the design and deployment of project monitoring. In general, an additional 20% should be added for these tasks.

As shown in Table 4, the volumetric benefit of both forms of Rain-MAR, even when optimal fields are chosen, result in less than one acre-foot of additional infiltration per year. To have an impact on groundwater level, baseflows, or GDEs—or to have co-benefits of floodwater accumulation downstream—MAR practices would need to be implemented on a substantial number of fields distributed across the Northwest Focus Area.

Table 4. Demonstration project: estimated volumetric benefits of Rain-MAR (acre-feet)

	SUMP		BERM	
	Wet Year	Critical Year	Wet Year	Critical Year
Field acres (typical field)	141		117	
Annual infiltration total (AF)*	95.9	53.0	65.6	40.7
Infiltration per acre (AF)*	0.68	0.38	0.56	0.35
Prevented runoff (AF)*	112.8	62.3	77.1	47.9
Total cost per year**	$13,270	$13,270	$1,975	$1,975
Cost per AF infiltration per year	$138	$250	$30	$49

***Additional volume over what would naturally occur without MAR*
***Cost estimation methods are described below in paragraph 8.5.3.2.6 (“Economic Factors”)*

4.2.2. Modeling a Hypothetical Rain-MAR Incentive Program

To illustrate the efficacy of distributed MAR practices over a broader area, a hypothetical scenario was developed for the Northwest Focus Area to calculate the expected benefits of a multi-benefit incentive program. To estimate the effect of this program on the groundwater budget and groundwater levels in the Northwest Focus Area, a was modeled.

Following the feasibility criteria described above, TFT used the results of its field-level Rain-MAR feasibility and cost-benefit analysis to simulate potential programmatic implementation of Rain-MAR throughout the Northwest Focus Area. Results are summarized in Table 5 below.

This example program scenario assumes $100,000 is available annually to implement Rain-MAR practices within the targeted portion of Northwest Focus Area over ten years. The resulting optimized landscape-level scenario includes 13 fields and results in an additional 466 acre-feet to 860 acre-feet of additional infiltration per year, depending on precipitation. The most cost-efficient feasible projects were included in this optimized scenario, which included five projects using the berm method of Rain-MAR and eight projects using the sump method. Overall, the cost of achieving additional infiltration is approximately $113/acre-foot in a Wet Year and $208/acre-foot in a Critical Year. The program would also result in a significant amount of flood mitigation via prevented annual runoff during the rainy months. The costs of achieving the additional infiltration will increase as recruitment of the most optimal sites is not achieved.

Table 5. Demonstration project: estimated volumetric benefits of Rain-MAR (acre-feet)

	Wet Year	Critical Year
Total program acres	1098	
Infiltration total (AF)*	860.0	466.0
Infiltration per acre (AF)*	0.78	0.42
Prevented runoff (AF)*	1011.0	548.0
Total cost per year	$96,940	$96,940
Cost per AF infiltration per year	$113	$208

**Additional volume over what would naturally occur without MAR*

In the PMA chapter, Davids Engineering developed a parallel model scenario that assumes that up to 50 percent of growers with fields suitable for recharge within the Northwest Focus Area would participate in the program in an average year.[13] The field selection was further filtered to exclude permanent crops, rice, and non-agricultural areas. Based on those criteria, they reported a total potential recharge area for the hypothetical Rain-MAR program in the Northwest Focus Area to be approximately 6,100 acres. Across the 6,100-acre area, their analysis simulated an average annual increase in deep percolation of precipitation on participating fields of approximately 3,000 AF/yr.

The volume per acre of infiltration resulting from both scenarios were in a similar range (TFT: 0.78 AF in a representative Wet Year and 0.42 AF in a Critical; and Davids Engineering: 0.49 AF average), indicating consistency across approaches. The additional recharge from either of these hypothetical programs could help stabilize simulated groundwater levels over the projected future water budget period.

Fields are typically optimized by cost-efficiency, which is completed by dividing each field's environmental benefit (modeled infiltration volume) by the estimated annual cost and sorting fields in descending order. TFT's cost estimates assume consistent costs from year to year, whereas environmental benefits vary based on Water Year. As indicated in Table 5, the annual cost efficiency rates are projected to be between $113 per acre-foot in a Wet and $208 per acre-foot in a Critical (dry) Year, assuming wide variation in precipitation from year to year.

A key purpose of the *demonstration project* proposed above is to identify site level infiltration benefits through observed infiltration measurements and verify on-farm implementation costs, thereby improving understanding of the benefits and costs of the practice on-the-ground and generating a more accurate understanding of the cost efficiency when developing incentive programs and forecasting results.

[13] TFT has developed a separate optimization model based on the assumed rate of recruitment success will affect cost, and therefore must be defined

4.3.Solano Agricultural Scenario Planning System

During the implementation phase of the GSP, Groundwater Sustainability Agencies can identify optimal fields to implement Rain-MAR, as wells other practices that benefit sustainable groundwater management, using a scenario planning tool customized for the Solano Subbasin.

The Solano Agricultural Scenario Planning System (SASPS), a web-based application that GSAs and other local agencies can be used to design voluntary programs to engage agricultural producers in on-farm sustainable groundwater management projects. Developed by TFT, with support from NRCS and in collaboration with the Dixon and Solano RCDs, the SASPS is customized for the Solano Subbasin. The SASPS was developed with funds from the Solano County Water Agency grant (Contract 18/19-08, funded by a Proposition 1 Groundwater Sustainability Planning Grant) and matching funds from a an NRCS Conservation Innovation Grant *Streamlining Regulatory Compliance and Conservation Planning: Data Analytics Applications for Producers, Planners, and Agencies* (Award Number 69-3A75-17-287).

GSAs that need to engage the agricultural community in on-farm sustainable groundwater management projects can use the SASPS to view key agricultural metrics in their area of interest, design custom programs to meet their management objectives or budget and identify optimal areas for efficient recruitment of landowners. Practices covered by the tool focus on distributed recharge, including managed aquifer recharge (MAR) and cover crops—and demand reduction via irrigation efficiency upgrades. GSAs can identify specific agricultural fields where these practices are feasible, view the site-specific economic cost burden to farmers implementing these practices (over 10 years), and see the impact across a suite of water resource metrics, including farm-level changes in the annual volume of: (i) ground or surface water use, (ii) infiltrated water, and (iii) runoff. GSAs can use this data to develop programs that contribute to sustainable groundwater management by reducing or delaying the need for expensive infrastructure-based projects, or by contributing complementary groundwater benefits in the hydro-geologic area of the project.

To develop the SASPS, TFT classified all farm fields across the Solano Subbasin by agricultural type, and irrigation system, and other physical characteristics (including soils, subsurface texture, and topography). Then a field-scale feasibility assessment was completed to determine which, if any, of these on-farm practices can be implemented on each field, either alone or in combination in the subbasin. Environmental and economic modeling were then completed for all potential on-farm "projects" and for multiple program design scenarios, which can be evaluated against comparable current condition scenarios.

The SASPS allows users to design a custom program, by (i) selecting a service area such as a GSA boundary, District boundary, area of potential groundwater depletion, etc., (ii) defining an environmental water resource target, (iii) setting a budget constraint, and/or, (iv) specifying the expected level of recruitment.

A User Guide for the SASPS will be provided to the Solano County Water Agency as a deliverable for the Prop 1-funded Solano County Water Agency contract in January 2022. The full data sets and methodologies that underly the SASPS are described in the final grant report for NRCS Conservation

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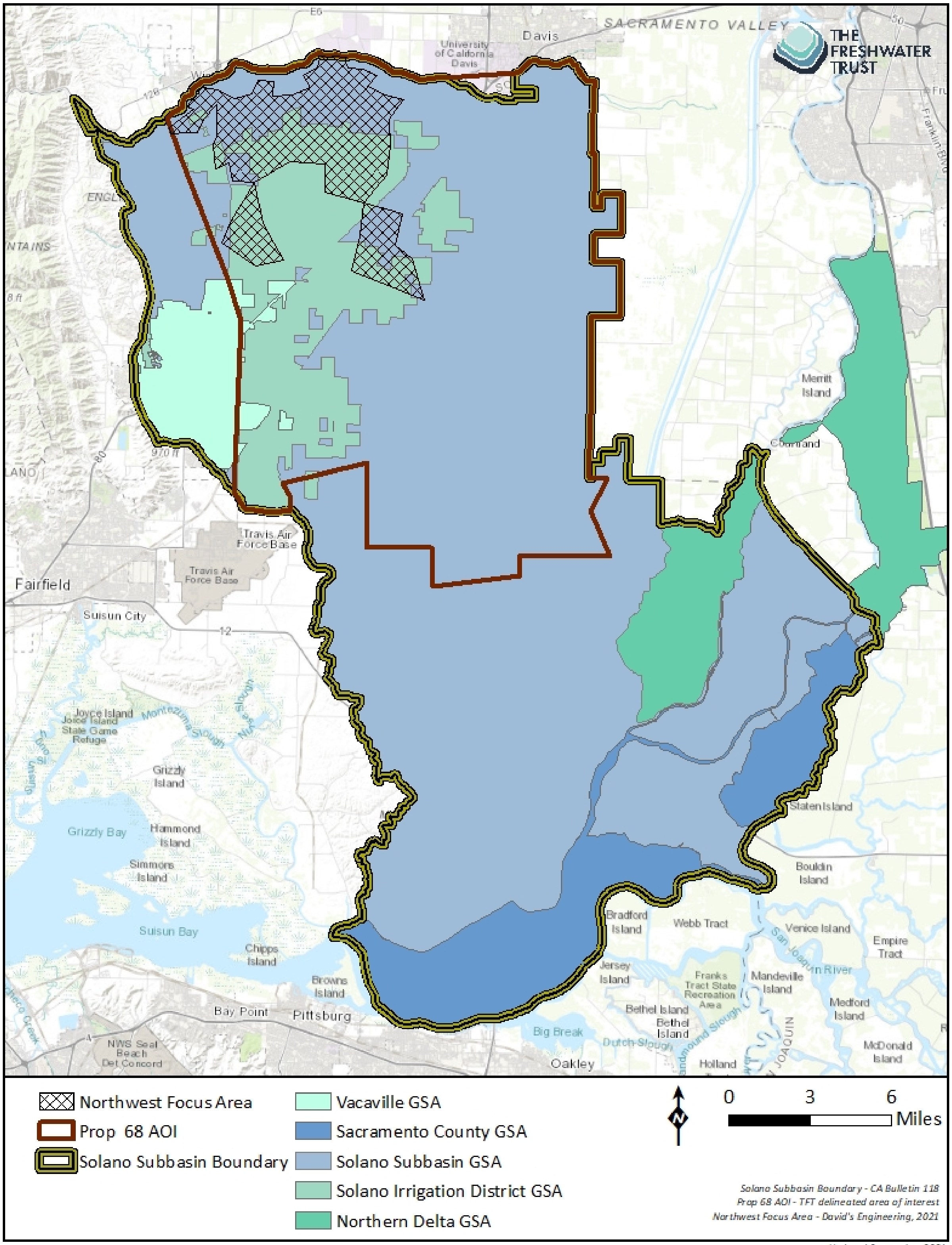
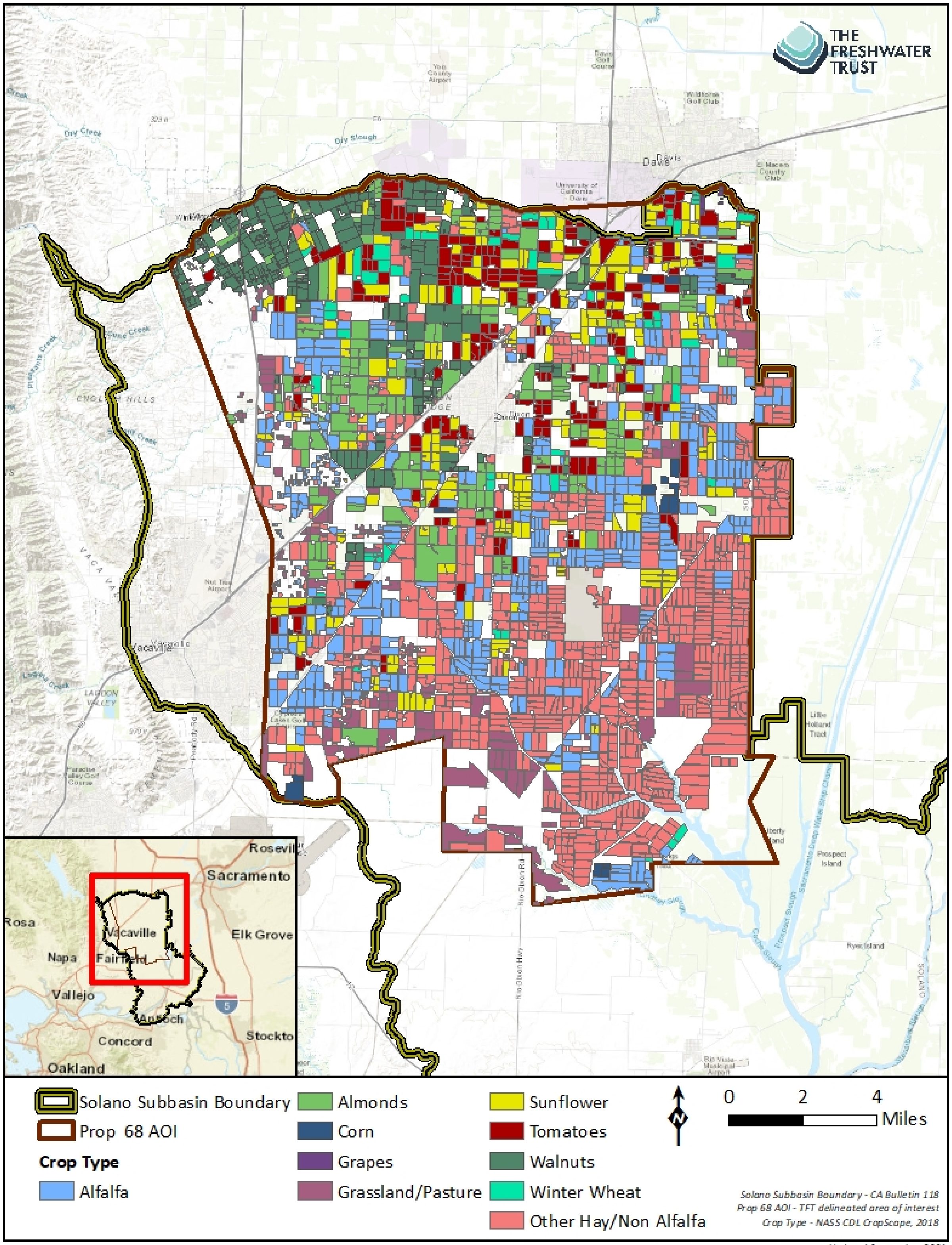
APPENDIX A - MAPS, DATA TABLES, AND SUPPLEMENTARY FIGURES

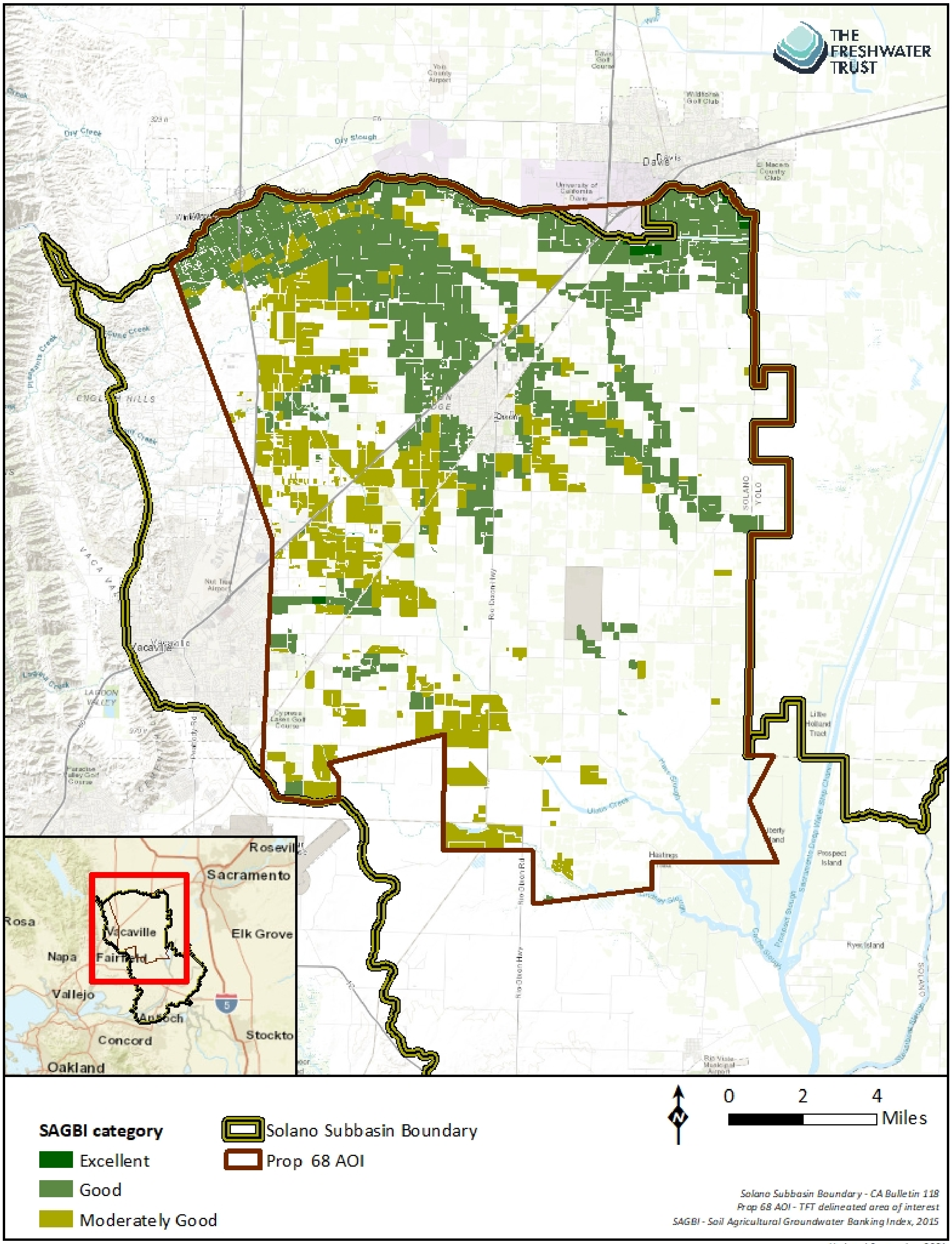
Appendix A-1. Areas of Interest. Solano Subbasin and Northwest Focus Area boundaries.



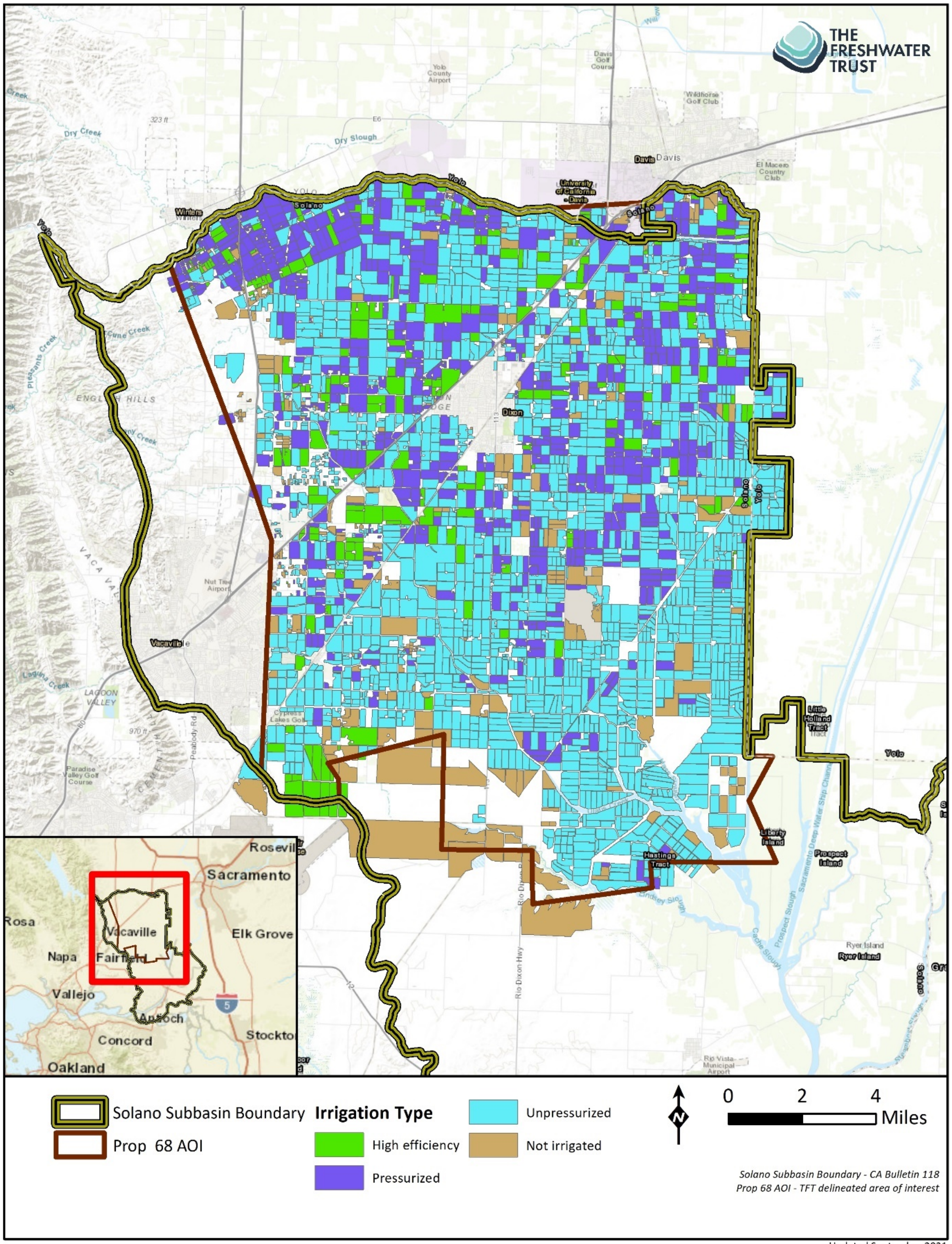
Appendix A-2. Crop Types in the Solano Subbasin. Each field's dominant crop type.



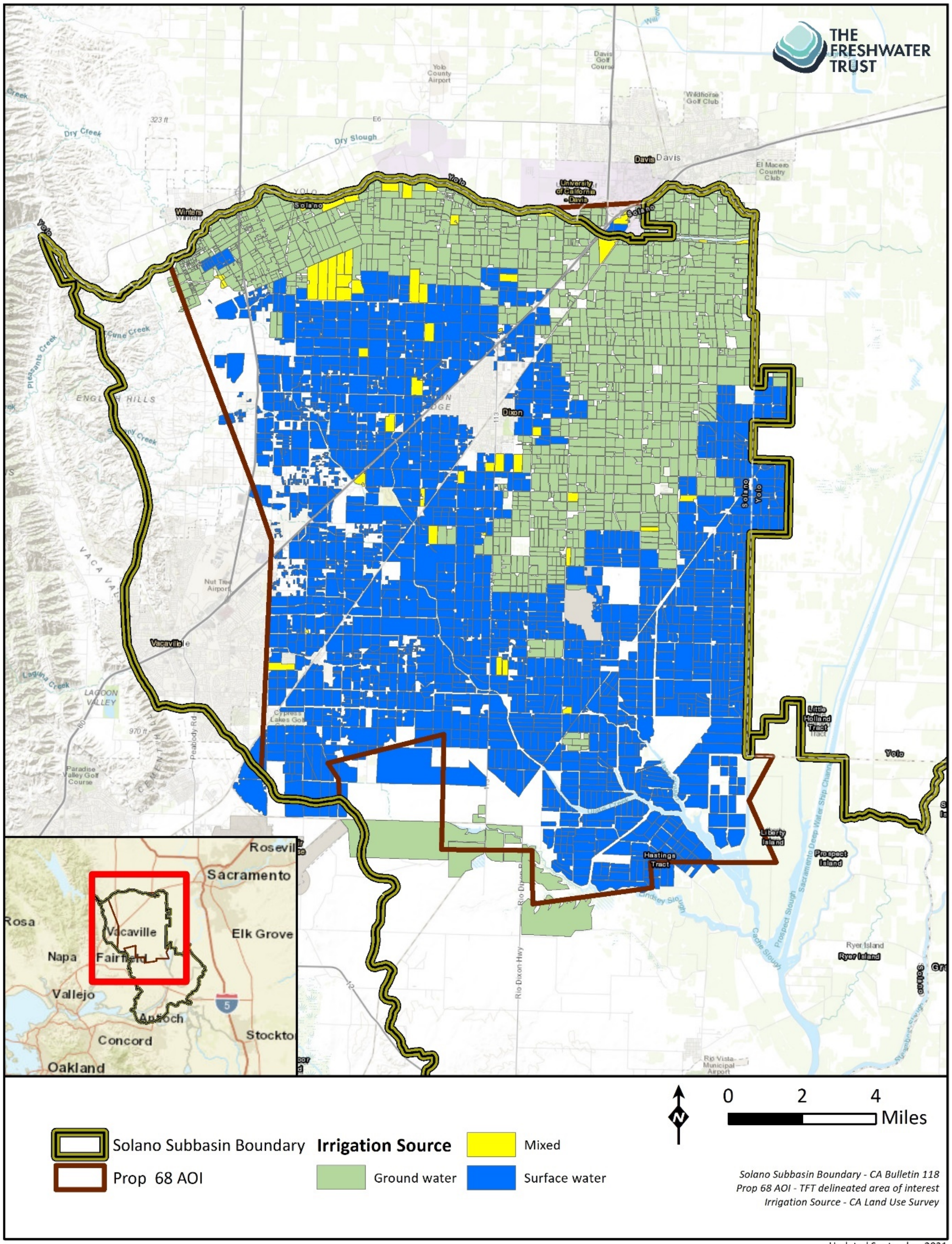
Appendix A-3. Soil Agricultural Groundwater Banking Index (SAGBI) in the Solano Subbasin. The only fields displayed are fields with a SAGBI rating of Moderately Good, Good, or Excellent.



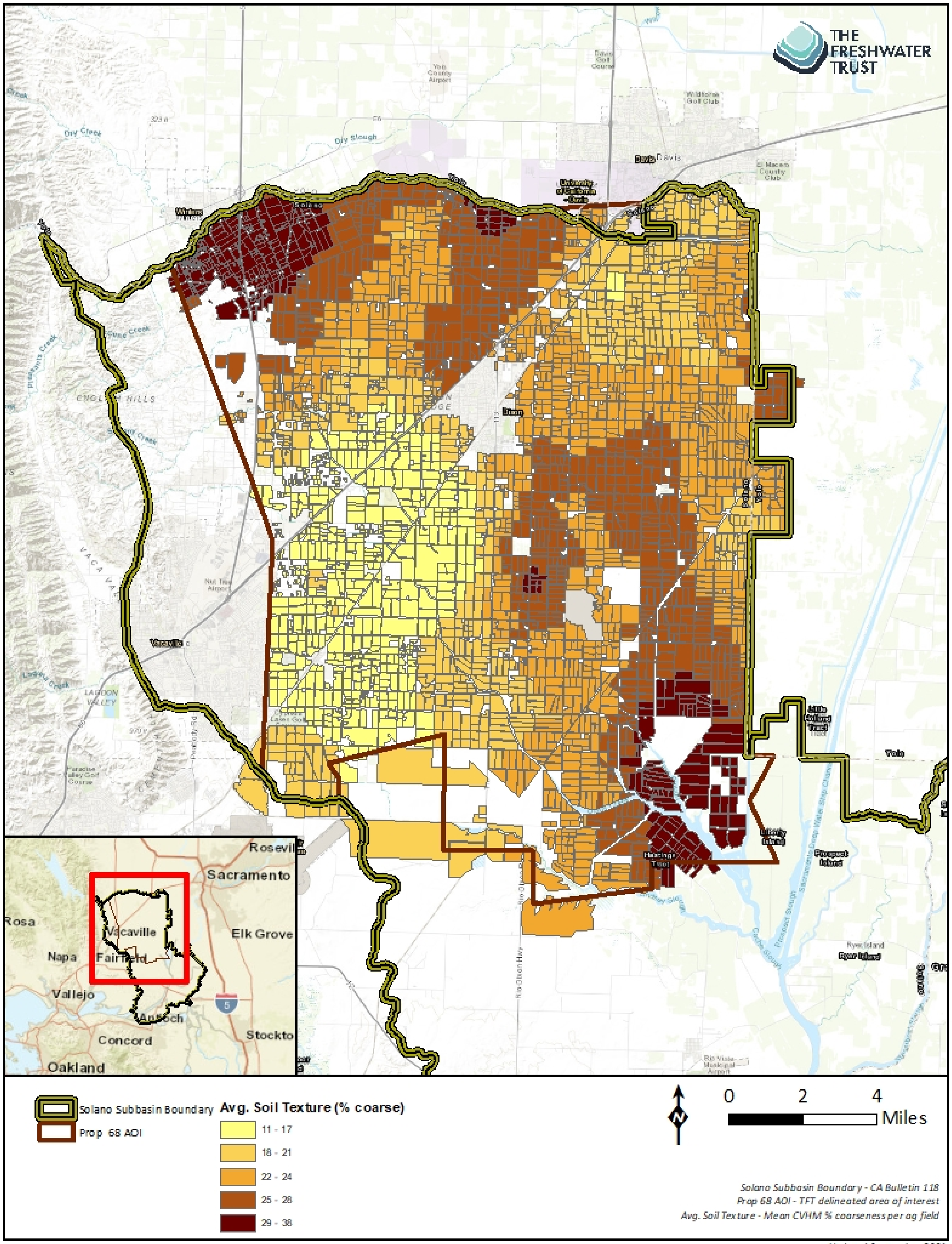
Appendix A-4. Irrigation Types in the northern Solano Subbasin. Irrigation type can be used as a proxy for berms because gravity systems (flood, furrow) often use berms to retain irrigation water.



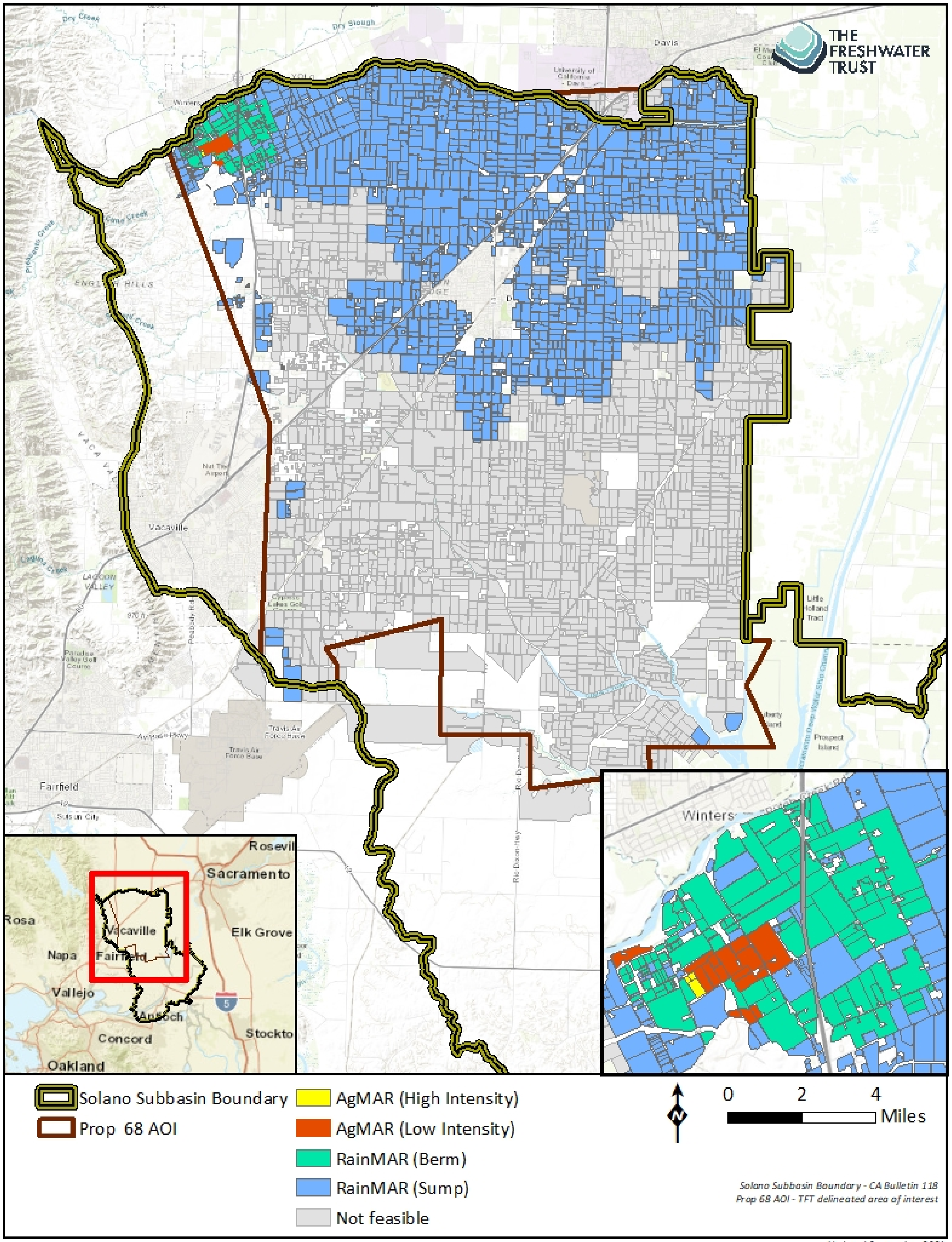
Appendix A-5. Irrigation Sources in the northern Solano Subbasin. Irrigation source is used to determine feasibility for Ag-MAR, since only surface water fields are eligible.



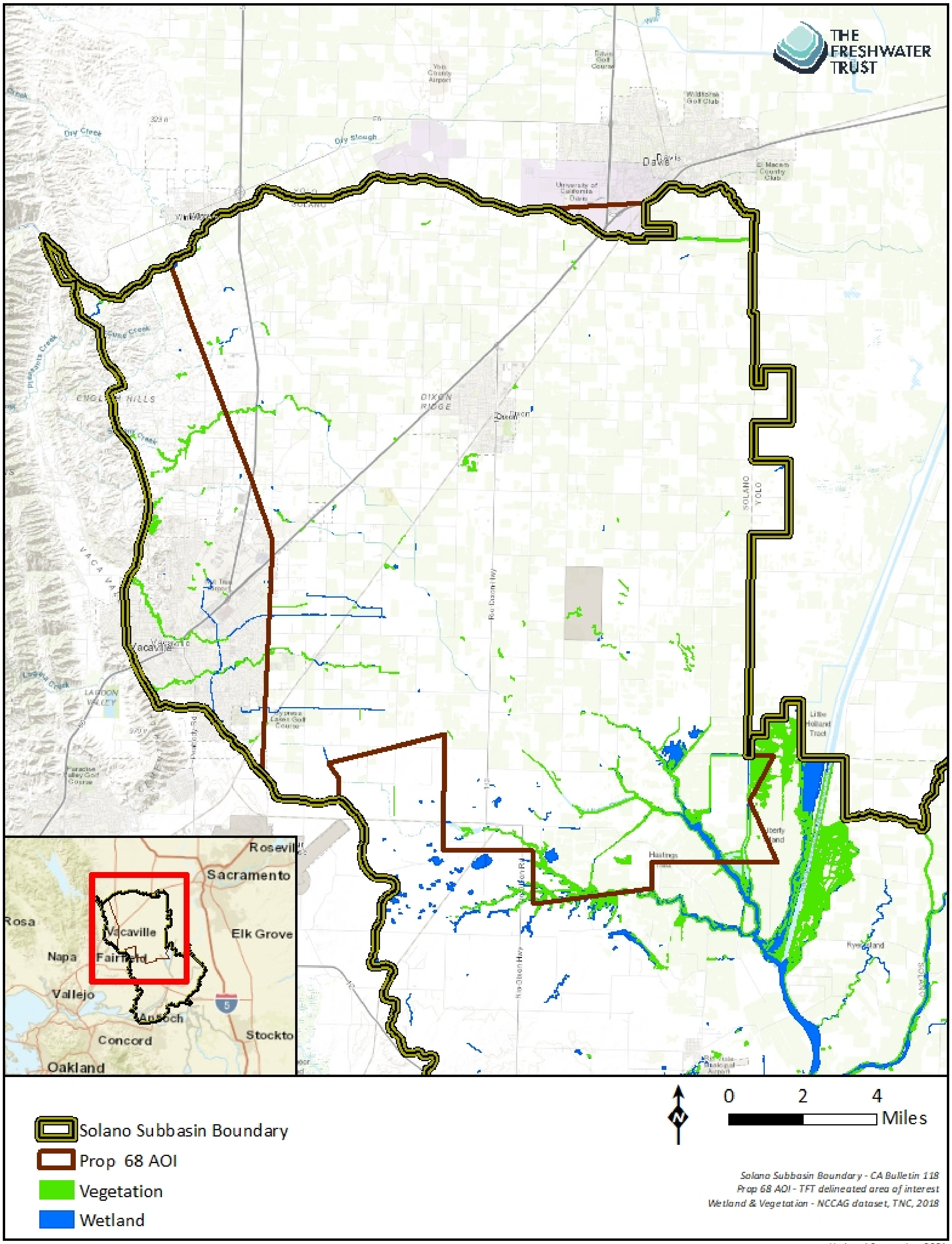
Appendix A-6. Average Soil Texture in the northern Solano Subbasin. Soil texture is a feasibility metric for infiltration.



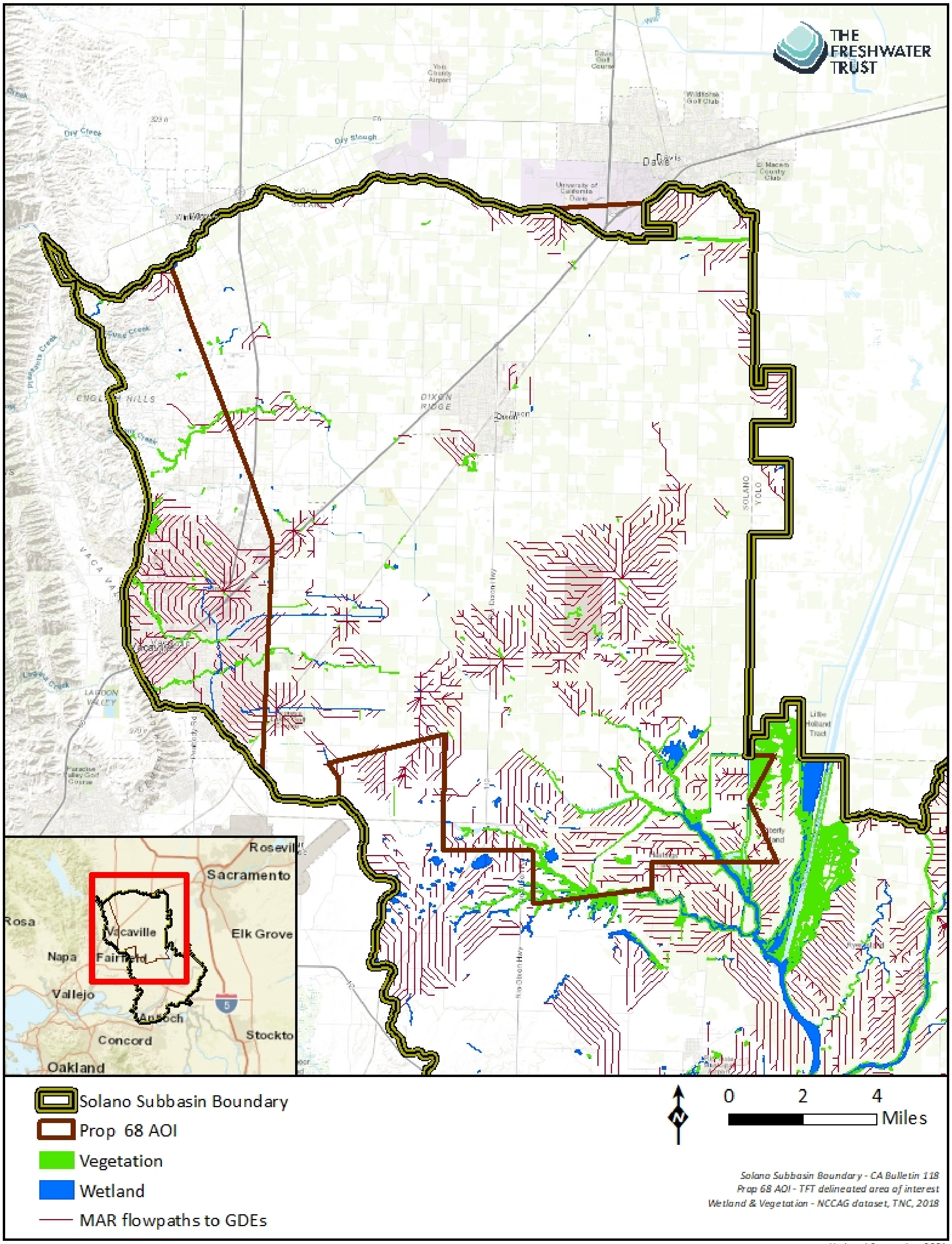
Appendix A-7. MAR Feasibility in the northern Solano Subbasin. The colors of the fields below represent which fields are feasible for various types of MAR.



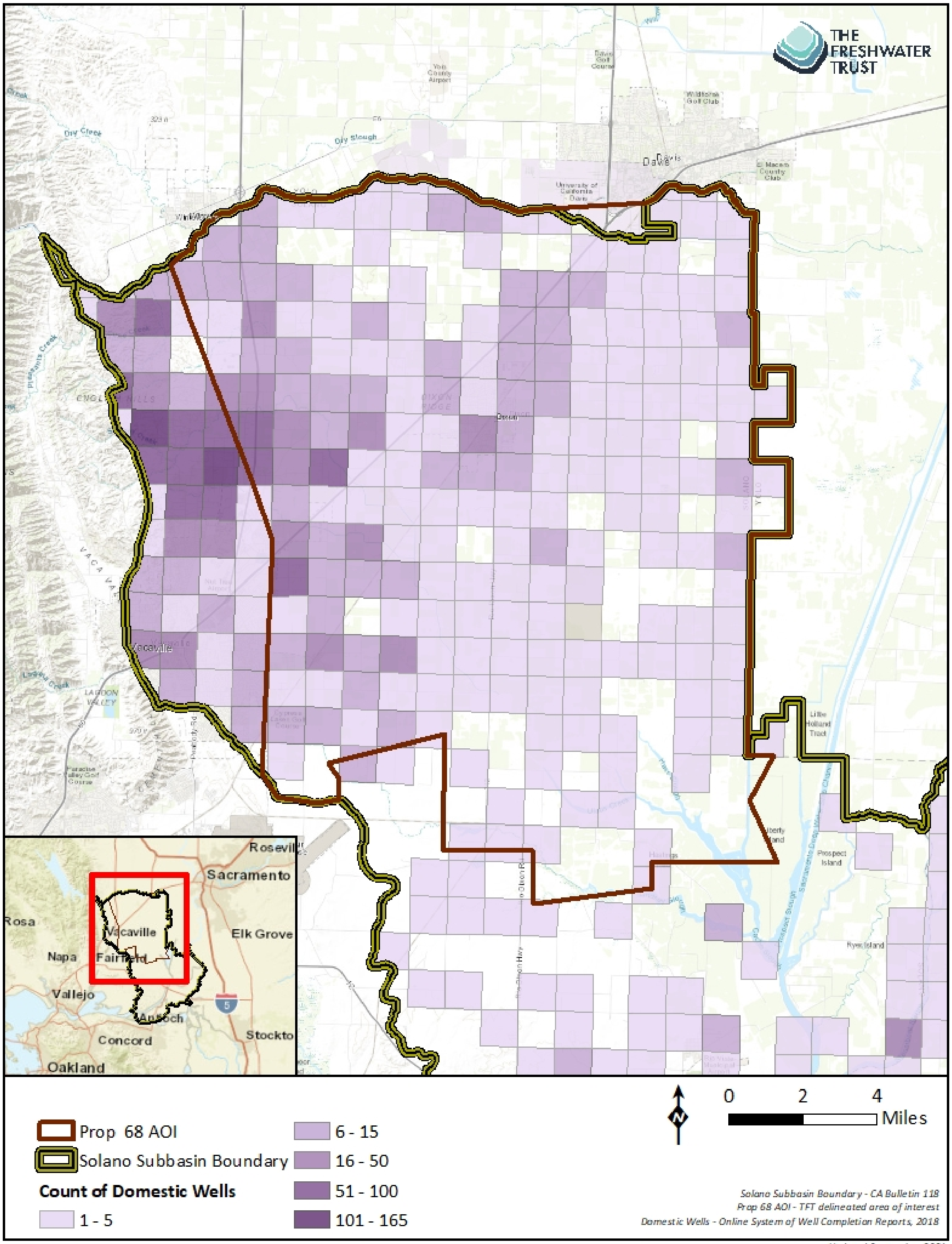
Appendix A-8. GDEs in the northern Solano Subbasin. The polygons below represent the groundwater dependent ecosystems in the northern Solano Subbasin.



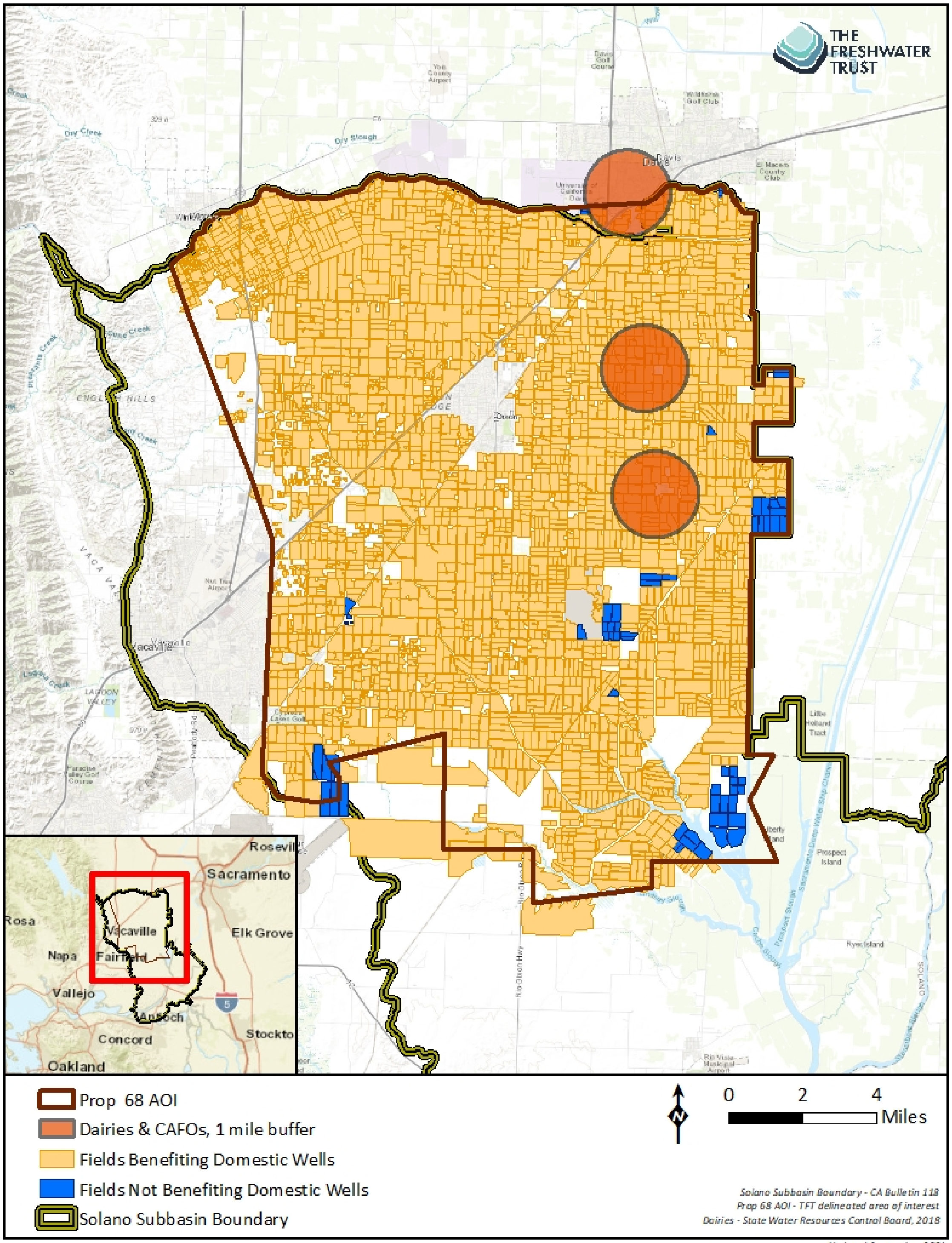
Appendix A-9. Potential MAR influence on GDEs. The lines below represent the of flow paths of infiltrated water that reaches a groundwater dependent ecosystem.



Appendix A-10. Domestic Wells in Solano Subbasin. The below shows PLSS sections containing at least one domestic well.



Appendix A-11. Potential MAR influence on Domestic Wells**.** In the Solano Subbasin, 3,146 out of 3,217 of the analyzed fields flow to a PLSS section containing at least one domestic well. The three red areas show the locations of a dairy/CAFO with a 1.0 mile radius buffer.



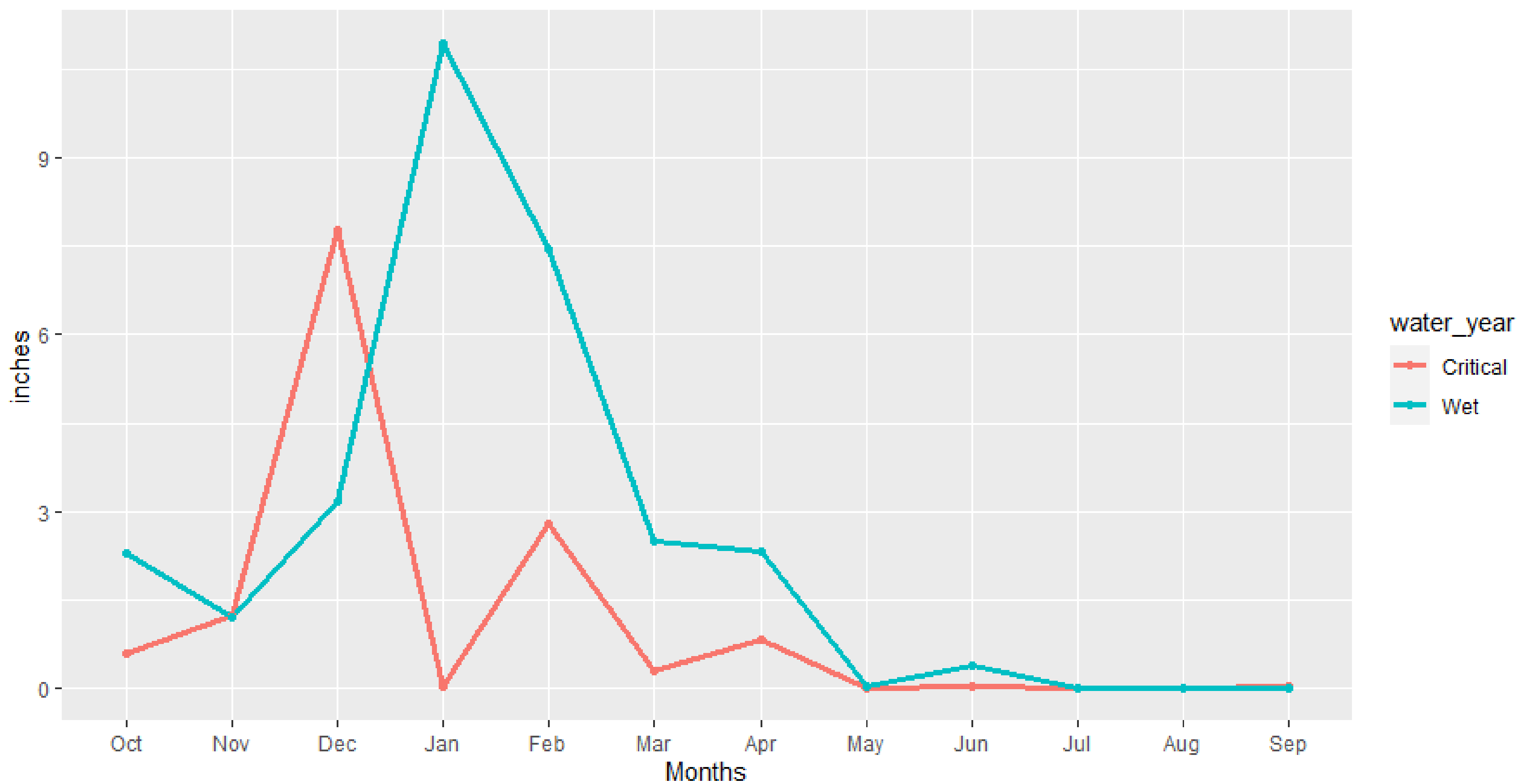
Appendix A-12. Data Sources Used in TFT's GIS Classification Model.

Metric	Dataset	Measured or Modeled Data	Spatial Extent
Agricultural Field Boundaries & Acreage	2016 Statewide Crop Mapping Dataset (DWR, LandIQ)	Blend	Statewide
Crop Type	USDA 2018 Cropland Data Layer (AKA Cropscape)	Modeled	Nationwide
Soil Hydrologic Group, Slope, Porosity, Soil Texture, Hydraulic Conductivity	NRCS Soil Survey Geographic Database (SSURGO)	Blend	Nationwide
Daily ET_0	Spatial California Irrigation Management Information System (CIMIS)	Modeled	Statewide
Daily Precipitation	Spatial California Irrigation Management Information System (CIMIS)	Measured	Statewide
Surface Recharge Feasibility	Soil Agricultural Groundwater Banking Index (SAGBI) Dataset	Modeled	Statewide
Groundwater elevation and depth	LSCE, DWR Periodic Groundwater Measurements	Blend	Regional, Statewide
Subsurface soil texture	CVHM Texture model	Modeled	Statewide
Groundwater Dependent Ecosystems (GDEs)	TNC National Communities Commonly Associated with Groundwater (NCCAG) Dataset	Blend	Statewide
Irrigation Water Source	Electronic Water Rights Information Management System (eWRIMS), National Hydrography Dataset (USGS), California Public Water Agencies Layer, CASGEM irrigation wells, Land Use Surveys dataset	Blend	Statewide, Nationwide
Proximity to domestic wells	Online System for Well Completion Reports (OSWCR)	Measured	Statewide
Dairy Locations	State Water Resources Control Board Dairy Locations	Measured	Statewide
Precipitation intensity, duration, & frequency	NOAA Atlas 14 Precipitation Frequency (PF) Estimates	Modeled	Nationwide

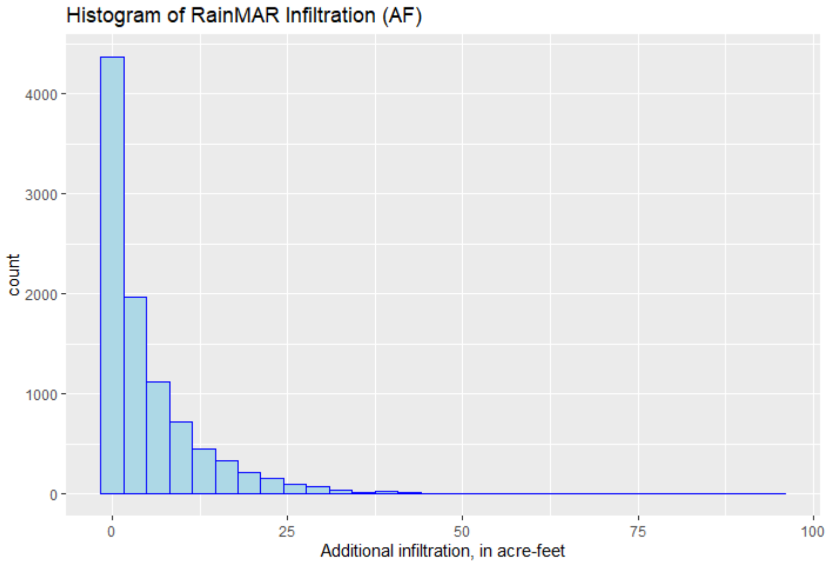
Appendix A-13. Cost schedules for Rain MAR Projects

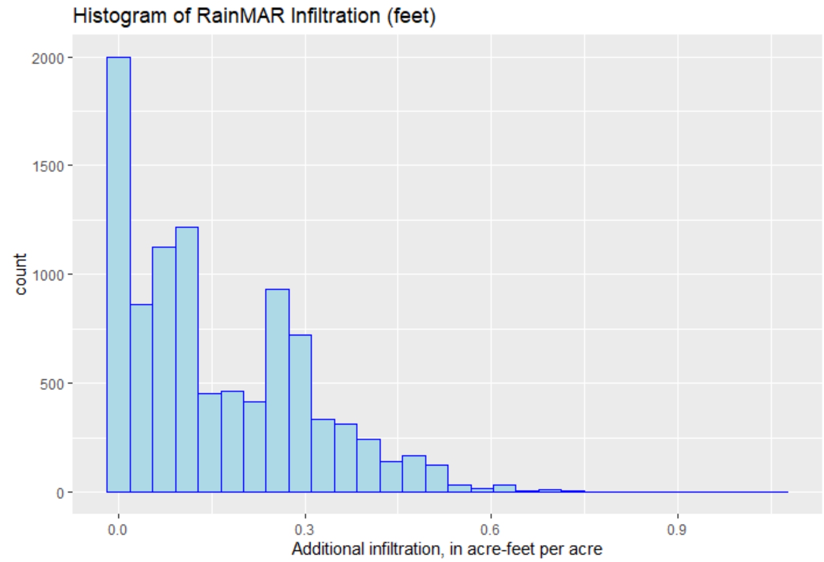
Scenario	Measure	Type	Unit	Frequency	0	1	2	3	4	5	6	7	8	9	10
Sump MAR	Operation (Sump Preparation)	Cost ($)	valuePer-SumpAcre	Annual	0	-56.16	-56.16	-56.16	-56.16	-56.16	-56.16	-56.16	-56.16	-56.16	-56.16
Sump MAR	Operation (Sump Excavation)	Cost ($)	valuePer-CubicYard	Establish-ment	-4.24	0	0	0	0	0	0	0	0	0	0
Sump MAR	Operation (Field Preparation)	Cost ($)	valuePerAcre	Annual	0	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
Sump MAR	Maintenance	Cost ($)	valuePer-CubicYard	Annual	0	-1.64	-1.64	-1.64	-1.64	-1.64	-1.64	-1.64	-1.64	-1.64	-1.64
Sump MAR	Flashboard Riser	Cost ($)	valuePerSite	Establish-ment	-17000	0	0	0	0	0	0	0	0	0	0
Berm MAR	Operation (Field Preparation)	Cost ($)	valuePerAcre	Annual		-149.42	-149.42	-149.42	-149.42	-149.42	-149.42	-149.42	-149.42	-149.42	-149.42

Appendix A-14. Precipitation. Precipitation means, by month, for a Critical Year and Wet Year. Rain-MAR is only simulated for the months of December, January, and February. Source: Precipitation data from CIMIS; Water years from CDEC: critical year: 2015; wet year: 2017.

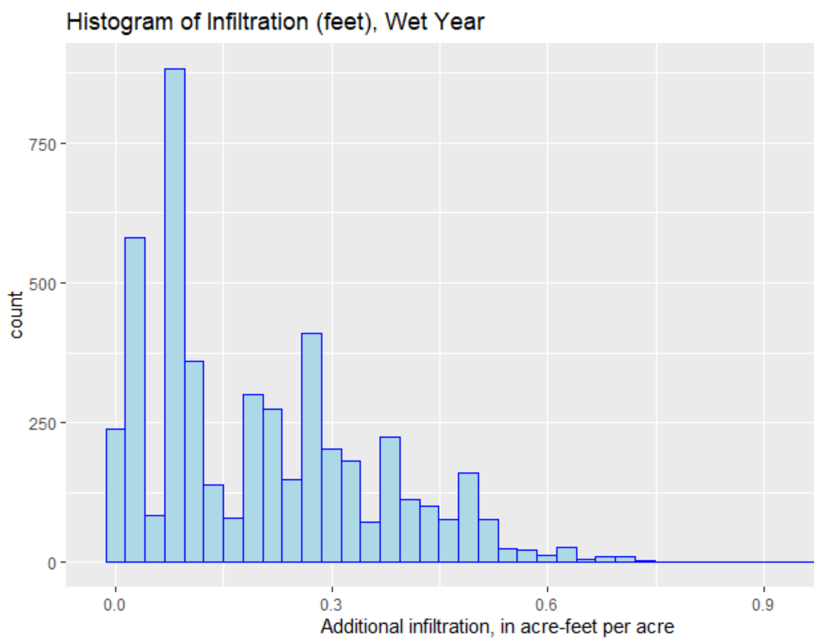


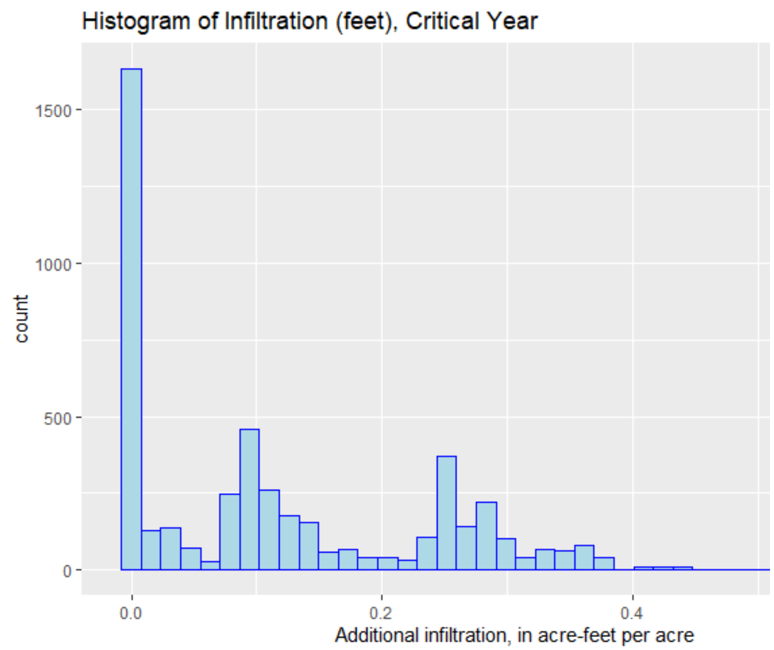
Appendix A-15. Summary statistics of infiltration. Summary statistics of additional infiltration on each field due to MAR implementation. Left histogram shows the count of fields with the acre-feet volumes on the y-axis, right histogram shows the count of fields with acre-feet per acre infiltration (e.g., the infiltration normalized by area).





Appendix A-16. Summary statistics of infiltration, AF/acre, by water year. Left histogram shows the count of fields in a wet year, right histogram shows the count of fields in a critical year (infiltration is normalized by area in both histograms). Over 1,500 fields had 0 infiltration benefits during the critical year.





APPENDIX 8d

Groundwater Trading System

INTRODUCTION

The Solano Collaborative received input on groundwater markets at a series of meetings over the Groundwater Sustainability Plan (GSP) development period. A groundwater market was considered to improve flexibility for a potential demand management program and was also considered as a potential way to facilitate exchanges in specific areas of the Solano Irrigation District to reduce pumping in these areas (effectively and in-lieu recharge program).

The GSP does not include plans to immediately develop and implement demand management or a groundwater market in the Solano Subbasin. The GSAs will continue to monitor Subbasin conditions, assess the need for a market, and engage stakeholders, the public, and technical experts in market design if needed in the future. Therefore, this appendix should be viewed as a high-level overview of options to increase flexibility and reduce costs associated with potential future demand management in the Solano Subbasin. The Collaborative, or other lead agency as appropriate, may initiate a study in the future to better define some of the concepts for application in the Solano Subbasin.

This appendix describes a groundwater market (sometimes called groundwater trading), components for market design, and considerations for implementation in the Solano Subbasin.

GROUNDWATER TRADING INSTITUTION

A market—for groundwater or any other good—is an economic institution that enables willing buyers and sellers to meet and transact business, trade goods and services in exchange for other goods and services or the exchange of money.

Groundwater markets can provide benefits for the participants, and they can help direct economic resources in a way that improves the economy as a whole. However, market transactions can also affect third parties - others not directly involved in the transaction, which is especially important when the market involves a natural resource like groundwater that affects lives and livelihoods in the Solano Subbasin in many ways. For a groundwater market to work well in the Solano Subbasin, participants must know what they have to trade and under what conditions or restrictions.

A groundwater market is an institution that specifies, enforces, and manages rules that:

- Ensure trading is consistent with the Solano Subbasin GSP, sustainability objectives, and desired outcomes.
- Define who can participate and the quantity that they can trade.
- Are consistent with the Solano Subbasin water budget and other projects being implemented.
- Assure the participants of what they are buying or receiving and that their transactions will be honored.

- Protect third parties from unintentional, significant harm, that would cause undesirable results in the subbasin.
- Allow the flow of information needed to conduct business (engage in transfers) and allow trades to be executed at relatively low cost.

A groundwater market is more than a storefront, accounting system, or online system for posting trades and should be tailored to conditions in the Solano Subbasin. An effective groundwater market would consider physical, legal, regulatory, economic, and political conditions, and be tailored to those conditions. Importantly, this process would include the sustainable management criteria for groundwater as defined in the GSP. **Figure Appendix 8d-1** illustrates and provides a brief description of the seven different components of a groundwater market institution, including subbasin conditions, allocation, trading structure, market rules, monitoring and enforcement, market administration, and market reporting. These components are described below.

Figure Appendix 8d-1: Groundwater Market Components

Substantial overlap occurs between many of the components. For example, monitoring and enforcement and reporting are linked because the ability to monitor the market depends on information that is reported to the market administrator. Modern software for trading structures (smart market electronic clearing houses) can integrate market rules, match trades, and report market information in real time to participants, thereby integrating three components of the groundwater market simultaneously.

Basin Conditions. An effective groundwater market must be appropriate for and tailored to local conditions, which encompass the physical, legal, economic, and social characteristics of the Subbasin. For example, hydrogeologic conditions affect minimum thresholds and measurable objectives and the checkerboard pattern of districts and other entities across the Subbasin. Political considerations would define the desired outcomes of a groundwater market, addressing localized areas with sustainability concerns and defining potential impacts to third parties so that those can be mitigated in the market. The legal institutions under which a water market operates includes California's system of water rights, requirements and authorities related to water trading under SGMA and other parts of the Water Code, and many other related issues, including California contract law and environmental law.

Allocation. A groundwater allocation specifies the quantities of available groundwater, and is essential for an effective groundwater market so that potential traders know what they have to sell or need to buy**.** Without an allocation, pumpers face no effective scarcity of groundwater so they would have no motive to create or participate in a market. Fundamentally, an allocation and market rely on rights that are well enough defined that potential traders know what they can legally trade (buy or sell) and not be at risk for the time and expense of legal challenge. Therefore, an allocation must by its nature be built on top of the underlying water rights of the participants.

Trading Structure. Trading structures are the ways in which buyers and sellers of water connect with one another and execute a transaction. It is one component of a groundwater market institution, but it does not constitute the entire market (this is a common source of confusion). A trading structure can be thought of as the "marketplace" where buyers and sellers go to gather information and conduct trading business. Structures range from informal, such as bilateral negotiations, to water brokers and more formal exchanges, such as electronic clearinghouses. The selection of the trading structure affects the cost to participate in the market and how participants gather information about the market. For example, an electronic clearinghouse can automatically match buyers and sellers, whereas informal bilateral trades require individuals to locate, negotiate, and execute trades with one another. The search and transaction costs for the different types of trading structures can vary in important ways. This, in turn, affects access to the market, which emphasizes the importance of developing a trading structure concurrent with other market elements.

Market Rules. Market rules are restrictions on groundwater trade quantities, timing, or location that are derived from groundwater allocation decisions, Subbasin hydrology, GSP sustainability criteria, and other legal, social, or political concerns. For example, a trading rule might limit the quantity of groundwater traded out of an area within the Subbasin (or impose trading ratios) with sustainability concerns (e.g., falling groundwater levels). Another trading rule might define the volume of an allocation that can be carried over across years to limit market "speculators" and encourage greater trading in the market. Regardless of trading structure, the market rules should be clear and specific so that participants can determine whether the trade would be approved or denied before the transfer application is submitted. Clear and specific criteria for approval improve the quality of transfer applications and also expedite the review process, with defensible reasons for the application decision. Market rules are important for ensuring that the market does not negatively affect third parties, but market rules also may "thin" the market, making fewer parties eligible to trade with one another. Rules should be developed to balance market participation and prevent unintended outcomes of the market.

Monitoring and Enforcement. The three primary methods of measuring groundwater use include using crop coefficients and irrigated area, satellite remote sensing, and well metering. The monitoring methods are not necessarily mutually exclusive, and multiple methods may be implemented within the same market. The core requirement is that the market participants understand and accept the monitoring method so that they know what quantities are being bought and sold in the market. Enforcement follows from monitoring and is typically the responsibility of the market administrator, which would be the GSA. **Appendix 8f** includes a summary of a generalized groundwater credit accounting framework that describes an application of a monitoring/tracking approach for the Subbasin.

Market Administration. The role of a market administrator is to incorporate rules and regulations, as well as relevant updates, into how parties are matched; to match parties based on eligibility to trade and on price point; and to finalize the transaction through contracting, recording, and exchanging monies. Market administrators can be any number of entities, public or private, but would typically involve the GSA (or GSAs) for some components of administration. Many administrators are private, for-profit organizations, as are Mammoth Water, Waterfind, and Western Water Market. The selection of a market administrator typically considers how certain private data, such as price information, are handled, whether there is a real or perceived conflict of interest or bias in the market structure, the cost structure, and other basic qualifying criteria (e.g., experience, domain expertise).

Market Reporting. Market reporting includes tracking the characteristics of trading activity, including the quantity of water traded, parties and wells involved in the trade, and the timing and duration of the trade. These characteristics must be known for proper completion of each transaction and must be provide to the GSA Collaborative for inclusion in the Annual Report and the 5-year update of the GSP. Permanent transfers may require additional reporting, such as recording the deed transfer at the county clerk's office. It is important to note that market reporting can be handled within the market trading structure. For example, electronic clearinghouse smart markets automatically match buyers and sellers, approve trades, and report specified market outcomes.

SUMMARY

This appendix provided a general overview of a groundwater market institution. The Solano GSAs may consider a groundwater market to support GSP implementation in the future. The components of a groundwater market described here provide an initial summary of the requirements for setting up a functioning groundwater market that provides benefits to Subbasin participants. If initiated, market development would involve the GSAs, technical experts, and a substantial stakeholder and public outreach effort in the Subbasin. Future funding opportunities to support groundwater market development include potential state grants, US Bureau of Reclamation Water Smart grants, and local funding through GSA fees. A groundwater market is one way to increase flexibility and reduce costs associated with any future demand management (or other limits on groundwater pumping in specific areas) in the Subbasin. The concepts described in this appendix would need to be more fully developed under a future study for a potential Solano Subbasin groundwater market.

Potential next steps would be completed under GSP implementation, concurrent with the development of planned projects and management actions, and would include:

- Develop a planning study to evaluate the willingness and ability to pay for groundwater in the Solano Subbasin. The study would serve dual purposes of: (i) evaluating potential trading outcomes under a market and impacts to third-parties and (ii) establishing willingness to pay for additional water supply, which would support planned project feasibility studies.
- Pursue potential funding options and partners for a groundwater marketing study, which may include USBR WaterSmart grants (which require a cost-share) or other funding opportunities with partners. The study would expand on the groundwater market components and define specific options for the Solano Subbasin.
- Preliminary groundwater market study design could be targeted to individual market components, each of which are related to other aspects of the GSP. For example, a planning study of potential groundwater allocation concepts could be developed as one component of groundwater market design. However, it is also related to Subbasin funding and financing mechanisms (cost allocation) as well as implementation of other recharge projects (if any benefits are associated with recharge projects). Developing targeted studies (rather than a full groundwater market design) may be a cost-effective way to introduce and explore concepts without committing to a full groundwater market.

APPENDIX 8e

Solano Agricultural Scenario Planning System

The Solano Agricultural Scenario Planning System (SASPS) is a web-based application that GSAs and other local agencies can use to design voluntary programs to engage agricultural producers in on-farm sustainable groundwater management projects. Developed by TFT, with support from the USDA Natural Resources Conservation Service (NRCS) and in collaboration with the Dixon and Solano RCDs, SASPS is customized for the Solano Subbasin.

GSAs that need to engage the agricultural community in on-farm sustainable groundwater management projects can use SASPS to view key agricultural metrics in their area of interest, design custom programs to meet their management objectives or budget targets, and identify optimal areas for efficient recruitment of landowners. Practices covered by the tool focus on distributed recharge including managed aquifer recharge (MAR) and cover crops plus demand reduction via irrigation efficiency upgrades. GSAs can identify specific agricultural fields where these practices are feasible, view the site-specific economic cost burden to farmers implementing these practices (over 10 years), and see the impact across a suite of water resource metrics, including farm-level changes in the annual volume of: (i) groundwater or surface water use, (ii) infiltrated water, and (iii) runoff. GSAs can use this data to develop programs that contribute to sustainable groundwater management.

To develop SASPS, TFT classified all farm fields across the Solano Subbasin by agricultural type, and irrigation system, and other physical characteristics (including soils, subsurface texture, and topography). A field-scale feasibility assessment was completed to determine which, if any, of these on-farm practices can be implemented on each field, either alone or in combination in the Subbasin. Environmental and economic modeling were completed for all potential on-farm "projects" and for multiple program design scenarios, which can be evaluated against comparable current condition scenarios.

SASPS allows users to design a custom program, by:

1. Selecting a service area such as a GSA boundary, other entity boundary, area of potential interest, etc.,
2. Defining an environmental water resource target,
3. Setting a budget constraint, and/or,
4. Specifying the expected level of recruitment.

A User Guide for SASPS is under development. The full data sets and methodologies that underly SASPS are described in the final grant report for NRCS Conservation Innovation Grant 69-3A75-17-287, completed in 2020.

This program contributes to the Solano Subbasin sustainability by providing GSAs and their partners with a tool to design outreach, technical assistance, and incentive programs to address localized groundwater supply or demand issues. Programs can also be designed to improve surface water flows (through reduced irrigation demand) and improve surface water quality through reduced sediment and nutrient loading in agricultural return flows.

Metrics for Evaluation

SASPS is an optional tool that GSAs can maintain and use on an as-needed basis to address program development needs in response to potential changes in Subbasin conditions. Potential metrics for evaluation of the Grower Outreach and Engagement Program are summarized below:

Metric	Question
Agency adoption:	How many agencies have adopted SASPS to design sustainable groundwater management programs?
Program design:	How many spatially explicit water conservation programs have been developed using SASPS?
Grower adoption:	How many farmers have adopted practices recommended by SASPS?

Expected Benefits

At the landscape-level, SASPS provides an understanding of the potential changes in groundwater and surface water supplies and demands that are achievable within a specific area of interest through changes in agricultural management and on-farm improvements. SASPS also provides the likely economic cost of achieving specific volumes of groundwater supply and demand modifications over time in specific areas through distributed changes to agricultural management.

At the agricultural field or farm level, SASPS provides estimated economic costs and groundwater benefits of specific management changes, which informs prioritization and decision-making for the funding, incentivization, outreach, and technical assistance aimed at promoting these practices. Finally, SASPS also provides an estimation of the ancillary benefits of implementing these practices on individual fields or groups of fields, including reduced sediment and nutrient pollution runoff, flood reduction, etc.

Through its ability to identify feasible, prioritized, and optimized farm management changes given user-defined goals and constraints, SASPS can reduce the cost of maintaining groundwater sustainability. SASPS can identify the most cost-effective sites for specific changes to agricultural management, which can inform strategies for outreach, technical assistance, funding, and incentivization of sustainable agriculture.

Timetable for Implementation

Field-scale data analyses generated in the development of the SASPS tool were applied to two PMAs in the Solano Subbasin GSP: the Westside Streams PMA and Rain-MAR PMA. To remain current, the field classification that drives the analyses of SASPS should be updated for the Subbasin at approximately 3-year intervals.

Cost Factors

SASPS may be maintained and supported by GSAs on an as-needed basis to address changing needs in the Subbasin. Estimated costs for maintenance and support of the SASPS tool are as follows:

- *Application maintenance and updates*. The SASPS tool has already been developed for and applied in the Solano Subbasin, dramatically reducing costs going forward. The tool will likely require maintenance costs of approximately $25,000 per year to remain current and functional. As noted above, upgrades, including a reclassification of field-input data will be required every 3 years at an approximate cost of $75,000.
- *User support*. Planning staff at GSAs and partner agencies will need periodic training and technical support at an approximate bi-annual cost of $20,000.
- *Grower outreach*. When a GSA develops a program, partner agencies such as the Dixon RCD and Solano RCD would be the logical conduit to assist with grower outreach and engagement. These costs would be determined on a case-by-case depending on the size and scale of the program.

Sources of funding for the Grower Outreach and Engagement Program may include:

- *GSA fees*. SASPS is designed to optimize GSA investments in sustainable groundwater management practices. GSA fees may be warranted to maintain the tool for use in program development.
- *Public agency grants* may be available to develop specific programs that address groundwater issues in the Subbasin. Application maintenance fees, user support costs, and grower outreach costs may be recoverable from grants for program development and implementation.

The water budget for the Solano Subbasin is relatively balanced over the baseline period of analysis, and projects and programs are focused on localized areas of interest. Use of the SASPS tool by GSAs will likely vary based on the level of perceived future need.

APPENDIX 8f

Generalized Groundwater Credit Accounting Framework

THE FRESHWATER TRUST

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Crediting Framework for Managed Aquifer Recharge Projects

Considerations & Strategies for Incentivizing Stormwater Recharge Projects as Part of a Conceptual Market-based System

September 29, 2021

EXECUTIVE SUMMARY

Across California Groundwater Sustainability Agencies (GSAs) are developing management plans to satisfy the requirements of the Sustainable Groundwater Management Act of 2014 (SGMA). This statute requires that GSAs create Groundwater Sustainability Plans (GSPs) to document current conditions and define a path to groundwater sustainability. In most situations unsustainable groundwater use can only be redressed through a combination of demand curtailment and supply augmentation. Thus, many GSPs are likely to contain strategies to promote Managed Aquifer Recharge (MAR), a term that broadly describes actions designed to promote groundwater recharge, as a means of making progress towards sustainability by augmenting the groundwater supply.

However, groundwater management is an inherently local affair and the specific sustainability strategies, including MAR, will often need to be customized to the local setting and conditions. In some basins, GSAs and their partners may want to incentivize the implementation of specific forms of MAR such as stormwater retention or intentional flooding of agricultural fields. Beyond supply augmentation actions, GSAs could even create incentives for demand-side improvements, such as irrigation efficiency upgrades and certain forms of cover cropping. Both supply- and demand-side distributed land management actions, especially MAR projects, are often discussed in the context of market-based systems. Such systems can be used to incent groundwater-beneficial activities. Yet, like the management actions, the market-based systems are very diverse and need to be tailored to suit the individual context. The purpose of this document is to discuss the considerations for designing market-based systems to incentivize infrastructure-independent, distributed land management practices that generate groundwater recharge benefits.

Market-based Strategies

At a conceptual level, there are two general categories of market-based approaches that could apply to groundwater management: (i) groundwater trading, or (ii) an incentive-based system.

The first approach, a **Groundwater Trading Institution**, establishes property rights in groundwater and some market to facilitate the transaction of those groundwater rights. As noted in the Solano GSP, Appendix 8c ("Groundwater Trading System"), a groundwater trading market is an economic institution that can simultaneously create incentives to recharge and manage demand. Importantly, a groundwater trading institution requires the creation of a subbasin-wide cap on groundwater extraction that is then divided between users as *groundwater allocations.* These allocations constitute defined rights to groundwater that can then be used, bought, sold, or saved as part of the market institution. Through this market, incentives like tradable credits can be awarded for MAR activities or other desirable actions.

Even in the absence of groundwater allocations and a groundwater market institution, strategies exist that can drive desirable actions. **Market-based Incentives** generally refer to any approach that awards a benefit for implementing projects like MAR. These incentives can be financial, taking the form of direct payments or a rebate against some future financial obligations. These incentives could also be non-financial and instead operate by lessening some obligations imposed by the applicable GSP. Likewise, the GSA could establish a system to provide credit that would count against potential future extraction limits or even function within a future groundwater trading institution—essentially a prospective groundwater banking strategy. There are a variety of potential incentives, the available options depend on the specific circumstances in a basin. Notably, market-based incentives be employed as a standalone strategy that does not require the creation of allocations, or as part of a larger groundwater trading institution.

General Considerations for Market-based Approaches

Regardless of whether a groundwater trading institution, an incentive-based approach, or some combination of the two is pursued, there are a number of generally applicable considerations. Specifically, every market-based approach must adhere to the following basic principles:

Conforms to GSP – The market-based system must be consistent with the applicable GSP and should contribute to the sustainability goals. For instance, the MAR projects should occur in the recharge areas identified by the GSP, monitoring should document how the projects support replenishment, and the program should align with the GSP's findings, objectives, and sustainability criteria.

Results in Additive Benefits for Basin – All projects within a market-based program should generate measurable progress towards addressing undesirable results, reduce the cost of achieving sustainability, or secure long-term and demonstrable groundwater improvements.

Avoids Detrimental Effects – Market-based activities should never be detrimental to the GSP's sustainability criteria, lead to undesirable results, or cause unacceptable impacts to third parties.

Complies with Applicable Laws & Regulations – Both the market-based programs and individual MAR projects must adhere to all applicable local, state, and federal legal and regulatory requirements. It may be necessary to secure legal counsel to advise on a market-based program.

Establishes Framework to Govern the Program – Market-based environmental programs commonly adopt a "Trading Framework" or other guidance to compile the necessary programmatic rules and protocols to govern the program. In the SGMA context, this framework may be established independent of the GSP, incorporated into the GSP directly, or some combination of the two.

Program-Specific Considerations for Incentivizing MAR

Beyond the general considerations relevant for all market-based programs, several issues will differ for specific programs and the MAR actions employed within them. Although there may be additional considerations for a given scenario, the practice-specific considerations generally include the following:

Program Area – All market-based programs will require a defined program area that identifies the geographic boundary where MAR actions can occur. The service area should be based on the GSP, though it may require additional study to ensure that all MAR activities occur in a hydrologically connected area to guarantee that recharge benefits accrue to the same groundwater basin.

Quantifying Recharge Benefits – To award incentives in exchange for MAR projects, the results of individual projects must be quantified to demonstrate that groundwater benefits exceed what would have occurred without the project. To accomplish this, market-based programs will require a system for documenting pre-project baseline conditions, monitoring the results, and measuring benefits at a project (i.e., field) scale. GSPs establish historic groundwater conditions using hydrogeologic models, which may be informative for documenting baseline conditions. SGMA also requires the establishment of monitoring programs that could help support market-based efforts. However, the incremental effect of individual MAR projects generally will not be detectable at a subbasin-wide scale. Therefore, site-specific data may also be needed to document conditions prior to the implementation of a MAR project, which may help to incentivize the expansion of monitoring networks by requiring active monitoring of private wells as a precondition to market participation.

Program Administration – A program administrator is needed to oversee the operation of the market-based program. This responsibility could be taken on by the GSA(s) or delegated, in whole or part, to some third party. The specific responsibilities of the administrator will include implementing and enforcing rules and policies, accepting and monitoring MAR projects, tracking the results, and meeting GSP and SGMA reporting rules. Key considerations for the Program Administrator include:

- *Program Eligibility*. The Program Administrator would ensure eligibility by reviewing project information, such as the recharge suitability, water rights, regulatory compliance, land use history, irrigation infrastructure, and monitoring systems, among other pertinent information.
- *MAR Practice Standards.* MAR projects need to be designed and implemented consistent with practice standards to help ensure they produce the intended benefits. There are a variety of potential sources of practice standards. The applicable standards should be identified during program design and each project should be reviewed for consistency with the standards.
- *Tracking & Reporting Outcomes.* It is necessary to document that practices were implemented properly and generated the anticipated benefits. Programmatic approaches to reporting are recommended but the specific tracking and reporting protocol will be determined in program design and implemented by the administrator.
- *Verification*. It is crucial to verify that a practice was designed, implemented, and performing in accordance with the standards. Programs may require third-party site inspections, or perform random audits, or some combination of these, to provide independent verification. Once verified, the administrator issues the incentive to the participant.

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INTRODUCTION

In response to years of drought, California adopted the Sustainable Groundwater Management Act of 2014 (SGMA).[1] This law seeks to achieve long-term sustainability by empowering Groundwater Sustainability Agencies (GSAs) to determine the locally appropriate course of action. However, only two overarching approaches to managing groundwater overdraft exist: curtail demand or augment supply.[2] Curtailing extractions is difficult and may not be sufficient to achieve sustainability in many regions without causing significant economic and social impacts to those entities most reliant upon groundwater resources. Augmenting supply, on the other hand, is often more socially preferable but is only viable when water is available for augmentation and other localized conditions exist. Thus, for many basins, a combination of the two approaches will likely be necessary—extraction limits[3] will be needed to curb overdraft and stabilize groundwater levels to the extent that recharge activities have not mitigated the issues. As a result, there is considerable interest in options to increase groundwater supplies through Managed Aquifer Recharge (MAR)[4]—actions designed to promote groundwater recharge.

MAR, as well as water use efficiency and other demand-side improvements, are often discussed in the context of a market-based system that would create incentives for recharge activities. There are various conceptual market-based approaches. The most common concept, "Groundwater Trading,"[5] involves (1) assigning extraction allocations or some defined right to a set amount of groundwater to individual groundwater users, and (2) creating a market institution for the users to buy and sell unused allocations. A groundwater trading system could encourage recharge by providing credit for recharge activities, credit that could then be used or transacted in the marketplace.

Another complementary market-based approach involves creating a recharge incentive program. Such a program would encourage individuals to implement recharge actions by offering incentives (financial, managerial, or as some form of credit). These incentives could be based on the activities implemented or the volume of water recharged by those activities. An incentive program could be an independent approach, or it could be part of a larger groundwater trading market—the necessary considerations are largely identical for both approaches. Notably, an incentive-based approach, especially one that is based on financial incentives, would not necessarily require the establishment of allocations or other property

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*The information contained in this report is for information purposes only, it is not legal advice and should not be interpreted as such. A California attorney should be consulted on all issues with potential legal implications.

[1] The three bills that form SGMA are A.B. 1739, 2013–14 Leg., Reg. Sess. (2014), 2014 Cal. Stat. Ch. 347; S.B. 1168, 2013–14 Leg., Reg. Sess. (2014), 2014 Cal. Stat. 346; and S.B. 1319, 2013–14 Leg., Reg. Sess. (2014), 2014 Stat. Ch. 348.

[2] NELL NYLEN GREEN, ET AL., CENTER FOR LAW, ENERGY & THE ENVT, TRADING SUSTAINABLY: CRITICAL CONSIDERATIONS FOR GROUNDWATER MARKETS UNDER THE SUSTAINABLE GROUNDWATER MANAGEMENT ACT (2017), law.berkeley.edu/trading-sustainably.

[3] Agencies may seek to curtail extractions by assigning individual allocations or through other means. For instance, alternative sources of irrigation water could be provided, such as recycled water, for use in lieu of groundwater extraction.

[4] Recharge is even identified as one of the priorities in the CALIFORNIA WATER RESILIENCE PORTFOLIO (2020), waterresilience.ca.gov/wp-content/uploads/2020/01/California-Water-Resilience-Portfolio-2019-Final2.pdf.

[5] The term "Groundwater Trading" is often used interchangeably with "Groundwater Banking." In this context groundwater trading will refer to the market-based system for generating, quantifying, crediting, and transacting groundwater benefits. Groundwater banking, on the other hand, will exclusively refer to augmenting and holding groundwater supplies for future use, essentially using aquifers as a savings bank for future extractions. Banking is one type of recharge incentive approach.

rights to groundwater, thereby avoiding a major hurdle to market-based approaches in the SGMA context. However, this strategy requires securing the incentives (financial or otherwise).

Many MAR strategies exist that could then be pursued as part of a market-based program. Historically, direct recharge has occurred using recharge basins—large holding ponds designed to percolate water into the ground. This method has some notable limitations, such as the expense of building the infrastructure and the limited geographic benefit. Alternatively, distributed recharge activities can be used to increase infiltration across a comparatively large area. This distributed approach tends to focus on either passive recharge through altered farm management that minimizes precipitation runoff to increase infiltration into the soil, or active recharge that involves applying additional surface water on agricultural fields.[6] Generally, the passive approaches are more widely viable but have less potential recharge benefits. Conversely, active recharge tactics are often more effective but are less widely feasible because they require excess surface water be available to inundate seasonally fallowed fields (i.e., winter recharge) or fields planted with crops that tolerate saturated conditions.[7]

TERMINOLOGY

As each situation is different and each program unique, an array of potential market-based strategies exist that could be used to increase recharge to support groundwater sustainability. The specifics of each program will be defined by the relevant GSA(s). However, two general categories of conceptual approaches exist:

Groundwater Trading: A full market system that assigns individual groundwater rights, treating them as an asset that can be bought and sold.

Incentive-based System: A strategy for encouraging private entities to take certain voluntary actions by offering incentives, financial or otherwise.

The purpose of this document is to discuss how certain infrastructure-independent land management actions could be incorporated into groundwater trading programs. Distributed Best Management Practices (BMPs) represent a promising source of groundwater benefits and, as such, may represent valuable components of groundwater trading programs. Yet, every groundwater trading program will be unique, using different strategies to address the numerous competing considerations that factor into a market-based program.[8] In light of these inevitable differences, this document does not provide concrete, inflexible guidance. Instead, this document aims to identify the component parts of trading and incentive programs that may need to be individually addressed. The goal of this analysis is to identify and highlight the unique considerations and factors specific to distributed BMPs, as well as to offer some insight into the potential mechanisms to account for the differing characteristics of these actions, thereby assisting program developers in expanding the scope of future trading markets.

[6] This active recharge is often called "Flood MAR". CAL. DEPT. OF WATER RESOURCES, FLOOD-MAR: USING FLOOD WATER FOR MANAGED AQUIFER RECHARGE TO SUPPORT SUSTAINABLE WATER (June 2018), https://water.ca.gov/Programs/All-Programs/Flood-MAR.

[7] Studies indicate that field inundation activities hold great potential as one tool to augment groundwater supplies. W. BAGNASCO, ET AL., MULTI-BENEFIT APPROACHES TO SUSTAINABLE GROUNDWATER MANAGEMENT, BREN SCHOOL OF ENVTL. SCIENCE, U.C. SANTA BARBARA (Apr. 2018), www.bren.ucsb.edu/research/2018Group_Projects/documents/BasinBenefits_FinalReportforEDF_redacted.pdf; H.E. Dahlke, T.N. Kocis, A. Brown, *Recharging California's Groundwater: Crop Suitability & Surface Water Availability for Agricultural Groundwater Banking*, AM. GEOPHYSICAL UNION (Dec. 2016).

[8] A. Ayres, et al., Public Policy Institute of Cal., Improving California's Water Market: How Water Trading & Banking Can Support Groundwater Management (Sept. 2021), www.ppic.org/publication/improving-californias-water-market/ (discussing various strategies and considerations related to groundwater markets in California).

CALIFORNIA LEGAL & REGULATORY CONTEXT

The legal and regulatory context that applies to groundwater in California is both fairly new and the result of over a century of legal developments. On one hand, the Sustainable Groundwater Management Act of 2014 marks the creation of the first statewide regulatory structure for groundwater in California. On the other hand, groundwater rights concepts have been developed and refined since the early twentieth century. A thorough analysis of the history and intricacies of this legal and regulatory context if beyond the scope of this discussion, but a brief summary is included as it provides valuable context.

The Sustainable Groundwater Management Act of 2014

To briefly recap, SGMA requires that all high- and medium-priority basins have Groundwater Sustainability Plans (GSPs) in place by 2022 at the latest. GSAs must determine the basin-wide rates of groundwater recharge and extraction to create the GSP's sustainable water budget. Additionally, the GSPs must include measurable objectives and interim milestones that will lead to sustainability within 20 years.[9] SGMA provides GSAs with much discretion and flexibility in defining and pursuing sustainability in each basin.

Despite this discretion, SGMA's implementing regulations establish some minimum requirements for GSPs. Beyond the general administrative requirements, GSPs must document the basin's characteristics and conditions, and then define the sustainability criteria in terms of specific, measurable objectives and interim milestones.[10] To evidence progress towards sustainability, each GSP is required to establish a monitoring network sufficient to demonstrate short-term, long-term, and seasonal trends in the basin conditions, as well as provide information on groundwater extraction across the basin.[11] This monitoring network will also help to support project and management actions—the specific efforts that constitute the GSP's core strategy for attaining sustainability.[12] GSAs must have a 'data management system' to store the monitoring data and any other information relevant to the GSP.[13] This system will help satisfy the requirement to annually report basin-wide groundwater extractions and elevations.[14]

As this brief overview illustrates, groundwater monitoring and modeling efforts are mandatory components of all GSPs in addition to being required for developing portions of the GSPs and for tracking the outcomes of GSP implementation. A reliable, accurate in-situ monitoring network is crucial to characterize current conditions, define sustainability metrics, and substantiate the changing basin conditions. Groundwater elevation modeling is similarly necessary to help understand the basin settings, develop sustainability criteria, and inform management actions.

Importantly, this monitoring and modeling system would support a market-based MAR system, at least in part, by providing a means of documenting baseline conditions as well as potentially the actions and outcomes. Moreover, the confluence of the required groundwater monitoring network, data

[9] CAL. WATER CODE §§ 10727, 10727.2.
[10] CAL. CODE REGS. tit 23, §§ 354.12, 354.22 –.30.
[11] CAL. CODE REGS. tit 23, §§ 354.32 –.40, 356.2.
[12] CAL. CODE REGS. tit 23, §§ 354.42 –.44.
[13] CAL. CODE REGS. tit 23, § 352.6.
[14] CAL. WATER CODE § 10728.

management system, and elevation modeling potentially create an opportunity for GSAs to take the first step towards a full groundwater trading program by creating a centralized and accessible platform that could track groundwater use in near real-time and model the implications of that use. Once established, this type of platform could be refined and expanded as a market institution for groundwater trading.

State Groundwater Doctrines

Under California law there are several distinct types of groundwater as well as several types of groundwater rights.[15] Concerning types of groundwater, *native groundwater* is the most common and widespread form. Native groundwater is the water that naturally percolates from surface water sources (e.g., rivers, wetlands, precipitation, etc.). Native groundwater also includes migration from adjacent subbasins as well as local surface water where the beneficial use has resulted in percolation of excess water. Another form of groundwater is *developed water*, groundwater that would not have infiltrated into the basin without active human intervention (i.e., active recharge), which generally includes imported water that is transported from another basin for beneficial use or recharge.[16] *Salvaged water* is a form of water that would have been wasted if not for human intervention, such as stormwater that is prevented from running off a property.[17] The determination of the type of groundwater is a fact-specific inquiry, but these classifications have important implications for water rights and management. The main import for the SGMA context is that the non-native groundwater is essentially treated as new water and the entity that developed or salvaged it has the paramount right. Conversely, native groundwater is subject to the general, largely correlative, groundwater rights doctrines.

California groundwater rights are largely based on state common law and can be divided into three categories: overlying rights, appropriative rights, and prescriptive rights. The foundation of these rights rests on the seminal 1903 State Supreme Court decision *Katz v. Walkinshaw,*[18] which established the Correlative Rights Doctrine that vests property owners with an *overlying right* to as much groundwater as they can extract for use on their property. This right is both correlative and usufructuary—all landowners overlying a basin have equal rights to the groundwater they can use. There also exists a category of *appropriative rights* to groundwater, which constitute the right to extract surplus groundwater—water not required to satisfy the superior overlying rights—and move it off the overlying property for use elsewhere.[19] Unlike overlying rights, appropriative rights are subject to a system of priority between users (the 'first in time, first in right doctrine'). *Prescriptive rights* are the least common form of groundwater right and only arise in instances where the other groundwater rights have been infringed for an extended period of time due to overuse of the resource.[20] This system remains in effect as neither recent judicial opinions nor SGMA have fundamental altered groundwater rights. Thus, in most cases groundwater rights are correlative and do not bestow an individual property right.

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[15] E. Garner, et al., *The Sustainable Groundwater Management Act and the Common Law of Groundwater Rights—Finding a Consistent Path Forward for Groundwater Allocation*, 38 UCLA J. OF ENVTL. LAW 163 (2020).
[16] City of Los Angeles. v. City of San Fernando, 537 P.2d 1250, 1295 (Cal.1975).
[17] City of Santa Maria v. Adam, 149 Cal. Rptr. 3d 491 (Ct. App. 2012).
[18] 74 P. 766 (Cal. 1903); City of Barstow v. Mojave Water Agency. 5 P.3d 853 (Cal. 2000).
[19] City of Pasadena v. City of Alhambra, 207 P.2d 17 (Cal. 1949).
[20] This is essentially the concept of adverse possession applied to groundwater. *Santa Maria*, 149 Cal. Rptr. 3d 491.

CONCEPTUAL MARKET-BASED STRATEGIES

To develop an accounting framework for specific MAR actions or categories of such actions, it is first necessary to understand the larger context in which such actions will be taken. A variety of potential market-based approaches exist that can involve any number of transactional or incentivized strategies. Accordingly, the context will be specific to the GSP and basin. Despite the range of potential formulations, two general approaches to market-based systems for groundwater sustainability are most likely: a groundwater trading market and/or an incentive-based recharge program. A programmatic strategy for encouraging MAR can occur as part of either of these approaches.

Groundwater Trading Market

A groundwater trading system represents a market institution that simultaneously creates incentives for recharge and curtails demand, in part through fostering more efficient resource use.[21] In order to establish a trading system, a number of enabling conditions must first be satisfied.[22] At a minimum, true groundwater trading requires creating individual property rights capable of being traded. The common, though not exclusive, approach is to define a basin-wide groundwater extraction cap then divide that cap among users in the form of groundwater allocations—individual rights to a volume of groundwater in a set period. The allocations are a defined asset that can then be used, bought, sold, or saved.[23] Of course a basin-wide extraction limit and the associated individual allocations can be developed and implemented to reduce demand without an accompanying trading system. The market institution facilitates the transaction of allocations, which provides the increased operational flexibility needed to mitigate the individual hardships that may result from extraction limits.

Beyond defining allocations, establishing a trading market will require crafting rules to govern the marketplace's operation.[24] These protocols should address any unique considerations for the basin to prevent undesirable outcomes, provide predictability to participants, and maximize beneficial results.[25] An accounting system will also be needed to record transactions, track individuals' extractions against their allocations, and facilitate oversight and enforcement. SGMA does not define the means of exchanging extraction allocations; GSAs have broad latitude in designing the trading program and the

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[21] A.B. Ayres, K.C. Meng & A.J. Plantinga, Do Environmental Markets Improve on Open Access? Evidence from California Groundwater Rights, Working Paper, Natl. Bureau of Econ Research (2019, rev. 2021), www.nber.org/papers/w26268.

[22] S. Heard S, M. Fienup & E. Remson, *The First SGMA Groundwater Market is Trading: The Importance of Good Design and the Risks of Getting it Wrong*, CAL. AGRIC. (2021), https://doi.org/10.3733/ca.2021a0010; A. Ayres, et al., Public Policy Institute of Cal., Improving California's Water Market: How Water Trading & Banking Can Support Groundwater Management (2021).

[23] C. BABBITT, ET AL., ENVTL. DEFENSE FUND & NEW CURRENT WATER & LAND, GROUNDWATER PUMPING ALLOCATIONS UNDER CALIFORNIA'S SUSTAINABLE GROUNDWATER MANAGEMENT ACT: CONSIDERATIONS FOR GROUNDWATER SUSTAINABILITY AGENCIES (2018), www.edf.org/sites/default/files/documents/edf_california_sgma_allocations.pdf.

[24] S.A. Wheeler, K. Schoengold & H. Bjornlund, *Lessons to be Learned from Groundwater Trading in Australia & the U.S.*, in INTEGRATED GROUNDWATER MANAGEMENT: CONCEPTS, APPROACHES & CHALLENGES, 493-517 (Anthony J. Jakeman, et al., eds., 2016), https://link.springer.com/chapter/10.1007/978-3-319-23576-9_20#citeas.

[25] NELL NYLEN GREEN, ET AL., CENTER FOR LAW, ENERGY & THE ENVT, TRADING SUSTAINABLY: CRITICAL CONSIDERATIONS FOR GROUNDWATER MARKETS UNDER THE SUSTAINABLE GROUNDWATER MANAGEMENT ACT (2017), law.berkeley.edu/trading-sustainably.

oversight system. However, history has shown that a successful trading system requires clear protocols, quality standards, data collection methods, and transaction accounting.[26]

As illustrated by the pilot programs in California, a groundwater trading market is most efficient and effective when developed as part of an integrated, web-based system.[27] This is because an integrated, accessible system can maximize market efficiencies and help to decrease the transactional costs in a system with distributed actions and participants.[28] Such a trading market also likely needs to be compatible with the required data management system and, even if not ultimately mandated, such an integrated approach could generate both management and market efficiencies. Accordingly, a web-based system capable of hosting near real-time data from a variety of sources could offer the most utility to GSAs, especially if the system iteratively generates models and other outputs based on that data to support compliance reporting, management actions, and trading market operation.[29] Integration of this sort may not be required by law but linking the various considerations that relate to and underpin a trading market would greatly enhance market function and outcomes.

Incentive-based System

A strictly incentive-based recharge strategy provides a means to augment groundwater supply, it does not require allocations to manage demand. Such a strategy exclusively creates positive incentives to encourage voluntary MAR actions by private entities. The incentives can be financial or, depending on the groundwater sustainability requirements that apply to landowners, incentives may be linked to certain land management requirements—non-financial incentives depend on the specific context of a basin and sustainability plan.[30] In contrast to a groundwater trading system, an incentive-based approach has fewer preconditions (e.g., extraction cap and groundwater allocations are not required) and has less potential to negatively impact third-parties. As a result, such a strategy likely faces less stakeholder opposition and generally would be easier to implement.[31] However, where a groundwater trading market by its very nature creates the motivations to drive participation, an incentive-based approach requires the GSA or its partners to create and maintain the incentive structure. This could require potentially substantial ongoing investments for financial incentives. Conversely, non-financial

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[26] A. Johnson, et al., *Groundwater Measurement & Trading: California Pilots Groundwater Measurement and Trading Program with IoT Sensors and Blockchain*, THE WATER REPORT (Feb 15, 2019). *See also* D.E. Garrick, N. Hernàndez-Mora & E. O'Donnell, *Water Markets in Federal Countries: Comparing Coordination Institutions in Australia, Spain and the Western USA*, 18 REG'L ENVTL. CHANGE 1593 (2018) (comparative analysis of water markets and associated institutions in Australia, Spain and the US).

[27] Envtl. Defense Fund, Rosedale–Rio Bravo Water Accounting & Trading Platform: A Pilot Project Advancing Sustainable Groundwater (2020), www.edf.org/waterplatformstory; S. Heard S, M. Fienup & E. Remson, *The First SGMA Groundwater Market is Trading: The Importance of Good Design and the Risks of Getting it Wrong*, CAL. AGRIC. (2021).

[28] For instance, the 'smart market' design used in a Nebraska groundwater trading program "provide[d] a centralized hub for trading activity," which minimized transaction costs. R.K. Young, Smart Markets for Groundwater Trading in Western Nebraska: The Twin Platte (Oct. 2016), https://static1.squarespace.com/static/56d1e36d59827e6585c0b336/t/5805463315d5dbb1ab599f36/1476740670534/Nebraska-Smart-Markets-Young.pdf.

[29] The lack of data and incomplete information represent a major source of market inefficiencies. Davíd Pilz, et al., FINAL REPORT ON POLITICAL ECONOMY OF WATER MARKETS, Part II (Nov. 2016), www.ampinsights.com/political-economy-of-water-markets

[30] It is difficult to predict the specific circumstances and thus the specific potential incentives. The main point is that many of the potential burdens imposed on individual landowners as a result of groundwater sustainability efforts could be leveraged to create incentives to drive individuals to implement MAR.

[31] Even if the monitoring and verification framework for incentives is identical to the structure required for a full trading marketplace, the incentive approach will be easier to implement because it does not require allocations or extraction limits.

incentives such as prospective credits in a future groundwater trading market or reduced land management obligations do not require notable financial commitments but do require that GSAs make durable commitments to prospective participants despite the potential uncertainty of future groundwater policies.

A variety of potential incentives exists. Financial compensation is a very likely approach. Many GSAs are funding their sustainability efforts through property-based fees, groundwater extraction fees, or a combination of the two.[32] Therefore, financial incentives for MAR could be a direct payment from the GSAs—essentially paying for outcomes—or a rebate against participants' future financial obligations. Beyond financial mechanisms, GSAs could create resource incentives based on the prospect of future extraction limits or other impending managerial obligations. For instance, if extraction limits are likely to be imposed for the basin in the future, then a GSA could issue credits to MAR participants that would count against future extraction limits—essentially a prospective groundwater banking strategy. Alternatively, if some other obligation or responsibility is anticipated in the future, then the incentive could be a commitment to delay or lessen the obligation that will otherwise apply to the MAR participant. These are only general examples of the potential options, the incentives that could be utilized in practice will be driven by the specific funding and management strategies employed in that basin based on how those strategies can be leveraged to motivate actions by specific stakeholders.

GENERAL CONSIDERATIONS FOR MARKET-BASED APPROACHES

There are some issues and requirements that will exist regardless of the type of market-based strategy that is employed. These general considerations should be taken into account throughout the stages of planning and implementing a market-based program to ensure the ultimate program supports sustainability and avoids counterproductive outcomes.

Conforms to the Groundwater Sustainability Plan

Every GSA will have to either create a GSP or cooperate with neighboring GSAs to adopt a single GSP for the entire basin.[33] Any market-based program will operate within the context of the GSP and serve as a strategy for promoting progress toward achieving sustainability as defined by the GSP. Due to the primacy of GSPs as the means of managing groundwater resources, any market-based program will need to be consistent with all aspects of the applicable GSP. Furthermore, as the main regulatory driver, the GSP may need to touch on any market-based policies, such as trading rules or protocols, either directly or by reference.[34]

[32] T. MORAN & D. WENDELL, THE SUSTAINABLE GROUNDWATER MANAGEMENT ACT OF 2014: CHALLENGES AND OPPORTUNITIES FOR IMPLEMENTATION 12-13 (2015), waterinthewest.stanford.edu/sites/default/files/WitW_SGMA_Report_08242015_0.pdf. *See also* J.S. Acos, M. Carlson & M. Hildebrand, Panel Presentation at American Groundwater Trust Conference: Funding Options for Groundwater Sustainability Agencies (2019), https://mavensnotebook.com/2019/04/16/panel-presentation-funding-options-for-groundwater-sustainability-agencies/.

[33] CAL. WATER CODE § 10727 et seq. This is true despite many basins being based on geopolitical boundaries rather than hydrogeology, which has occasionally created a disconnect between the basin's management and characteristics.

[34] By comparison, in Clean Water Act trading the regulatory driver is the individual discharge permit, so trading frameworks are often developed independently then incorporated into permits by reference. *See,* Or. Dep't of Envtl. Quality, NPDES Permit, 100985 (2011); City of Medford, Water Reclamation Facility Thermal Credit Trading Program (2011).

Other aspects of GSPs required by SGMA will need to be considered, as certain components of GSPs may help to support and inform any market-based program. For instance, SGMA requires basin-wide groundwater monitoring.[35] Any market-based recharge approach will need to be consistent with this monitoring regime and may even benefit from it. SGMA also directs GSAs to identify existing and potential recharge areas and detail how those areas contribute to basin replenishment.[36] The areas identified should constitute the priority geographies where recharge activities may be eligible to generate credits or other incentives. Lastly, any market-based strategy may not conflict with the findings, objectives, and mandates of the applicable GSP, otherwise those actions would undermine the system they aim to improve. As these examples demonstrate, MAR activities will need to align with, or at least not contravene, the other terms of the GSP.

Results in Additive Benefits for Basin

For MAR projects to be included in a market-based program, the specific practice must not be detrimental to the overall groundwater sustainability effort or individual stakeholders, nor create or significantly worsen an undesirable effect. Generally, a market-based program should achieve sustained progress towards addressing undesirable results, reduce the cost of achieving sustainability, and secure long-term and demonstrable groundwater improvements. To accomplish these aims, individual activities should be consistent with the applicable GSP and any other rules, not result in localized impairments to groundwater, and be designed to advance the GSP in order to achieve and maintain sustainability.[37] The approval of individual MAR practices or classes of MAR practices serves as an initial check against undesirable outcomes, ongoing verification and adaptive management will further prevent adverse results. The GSP can also provide guidance on targeting MAR activities, as appropriate, to achieve specific benefits for groundwater-dependent ecosystems (GDEs) or communities (i.e., aquifers used as drinking water supply).

Avoids Detrimental Effects

Another significant concern is the prevention of negative impacts to third parties. Equity for all stakeholders constitutes a paramount concern for both distributed BMPs and direct recharge activities. Creating objective criteria for using pre-implementation site-assessment data and post-implementation monitoring data to make determinations about injury to others will provide clarity and predictability to a trading program. Depending on the circumstances, this system may entail specific considerations for MAR practices to make sure that they do not generate negative impacts to neighboring landowners or stakeholders. For MAR activities, examples of localized negative impacts that should be avoided include groundwater mounding that can contribute to over-saturation or flooding, pollutant transport to groundwater used for drinking water, and impacts to downstream water users. Having defined metric criteria and mechanisms to judge external impacts will safeguard against injury to specific individuals as

[35] CAL. WATER CODE §§ 10727.2, 10727.4, 10727.6.
[36] CAL. WATER CODE §§ 10727.2, 10727.4.
[37] The Water Quality Trading rules adopted by Oregon contain overarching purposes, policies, and objectives that may be informative when considering the general goals of a trading program. OR. ADMIN. R. 340-039-0001 & -0003.

well as general injury to the groundwater resources.[38] The need for eligibility criteria is discussed below; these would be designed, in part, to prevent MAR from being implemented in locations that may result in injury. When a site is deemed eligible under a program, project monitoring and evaluation will provide further safeguards. Given the overarching purpose of a market-based system—to effectively improve groundwater sustainability outcomes—it is paramount that the strategies developed avoid adverse outcomes, and that such outcomes are quickly identify and remedied.[39]

Complies with Applicable Laws & Regulations

Despite being seemingly obvious, it nevertheless warrants mentioning that all market-based systems must comply with all applicable local, state, and federal legal requirements. Both a market-based program itself as well as the individual MAR actions must abide any relevant laws and regulations. Identifying and detailing each potential source of legal requirements is beyond the scope of this analysis, professional legal counsel should be secured to advise GSAs on all SGMA compliance actions, including the potential creation of a market-based program.

Nevertheless, a few topics related to MAR justify mentioning to ensure they receive proper consideration in any market-based system. The first such issues concerns water rights, specifically the rights associated with surface water used for MAR. California has a robust system of doctrines that govern the timing, quantity, location, and use of surface water—obtaining surface water for infiltration purposes may require securing a new water right or altering an existing water right.[40] Further, the California Environmental Quality Act and similar other environmental regulatory programs should be evaluated to ensure no unintentional illegality occurs.[41] Another concern relates to the source of funding. There are a host of restrictions on California agencies' ability to raise and spend public funds[42]; care must be taken to avoid running afoul of such restrictions when funding a market-based system. Locally, there may be restrictions on the use of private property (e.g., zoning ordinances) that have implications for MAR projects. These examples only serve to illustrate the scope of potential regulatory concerns, but there are numerous other issues that may be pertinent in a specific basin or context.

Establishes Framework to Govern the Program

To function properly, a market-based MAR program requires rules and protocols. Any type of market-based approach requires rules to establish the administrative apparatus, define the processes and procedures, and constrain participant conduct. In other environmental markets, a "Trading Framework"

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[38] Both of these determinations are important due to the usufructuary nature of the overlying groundwater rights identified in *Katz* as well as the application of the public trust to groundwater resources. Joseph L. Sax, *We Don't Do Groundwater: A Morsel of California Legal History*, 6 U. DENV. WATER L.REV. 269, 274 (2003).

[39] Transparency, which is a core component of SGMA, can help to improve more rapid identification of undesirable outcomes by improving the public's knowledge of the issues. CAL. WATER CODE §§ 10728.8, 10729, 10730.

[40] ASS'N OF CAL. WATER AGENCIES, A TECHNICAL FRAMEWORK FOR INCREASING GROUNDWATER REPLENISHMENT (Nov. 2019), www.acwa.com/resources/groundwater-replenishment-framework/; State Water Res. Control Bd., Fact Sheet: Flood Control, Groundwater Recharge, and Water Rights (2019); State Water Res. Control Bd., Permits for Recharge (last visited July 2021), www.waterboards.ca.gov/waterrights/water_issues/programs/applications/groundwater_recharge/.

[41] CAL. PUB. RES. CODE § 21000 et seq.; CAL. CODE REGS. tit 23, § 15000 et seq.; Secondary Source

[42] CAL. CONST. art XIII; LEAGUE OF CAL. CITIES, PROPOSITION 218 IMPLEMENTATION GUIDE (2007), www.cacities.org/UploadedFiles/LeagueInternet/c2/c2f1ce7c-2b14-45fe-9aaa-d3dd2e0ffecc.pdf.

is commonly adopted to compile all of the necessary programmatic characteristics and rules in a single binding document.[43] In the SGMA context, the necessary framework may be established independent of the GSP, incorporated into the GSP directly, or some combination of the two.[44] As mentioned in the section on groundwater trading, the frameworks necessary for such a program are more complicated than those needed for an incentivized approach. In any event, all market-based programs require rules and directives to govern the program and all activities undertaken as part of the program. The individual program specifics will differ based on the unique local circumstances.

The framework for a program will have a number of generally applicable rules and directives. It will also likely include some protocols that apply to specific circumstances or practices. For instance, the procedures for participating in a market-based program and the rules governing the program administration are likely to be generally applicable. In contrast, it may be necessary to adopt additional, unique protocols for various MAR actions to account for the practice-specific considerations. The classification of considerations as either generally applicable or fact-specific will depend on the circumstances. The classifications may not be consistent between different programs; even within one program there may be various exceptions or qualifications.

PRACTICE-SPECIFIC CONSIDERATIONS FOR INCENTIVIZING MAR

Beyond the general considerations that are relevant in virtually all circumstances, there are a number of other issues and concerns that may differ for specific MAR actions.[45] Whereas the general considerations largely relate to the programmatic structures, the following represent the major subjects that could require practice-specific strategies or rules, though depending on the circumstances it may be possible to craft generally applicable policies for some of these considerations.

Program Area

All market-based programs require a defined program area, sometimes referred to as a 'service area.' This area determines the geographic boundary of the market-based program; only entities and practices located within the area are eligible to participate. This area could encompass an entire basin or only a discrete portion of it. Determining the service area may require the completion of studies and modeling to sufficiently understand the aquifer dynamics and hydrogeology.[46] The groundwater dynamics will

[43] NAT'L NETWORK ON WATER QUALITY TRADING, BUILDING A WQT PROGRAM: OPTIONS & CONSIDERATIONS (2015), www.wri.org/research/building-water-quality-trading-program-options-and-considerations (discussing water quality trading approaches).

[44] For example, the Fox Canyon Water Market Pilot, a local groundwater trading program, used a set of project rules and regulations adopted independently of the larger groundwater management plan. Fox Canyon Groundwater Management Agency, Water Market Pilot Project Rules & Regulations (2017); Fox Canyon Groundwater Management Agency, Groundwater Management Plan, 2007 Update (May 2007), http://fcgma.org/public-documents/plans/20-public-documents/plans/95-groundwater-management-plan.

[45] For a discussion of specific considerations for agricultural MAR, *see* WATERHOUSE, ET AL., SUSTAINABLE CONSERVATION, MANAGEMENT CONSIDERATIONS FOR PROTECTING GROUNDWATER QUALITY UNDER AGRICULTURAL MANAGED AQUIFER RECHARGE (2021), https://suscon.org/wp-content/uploads/2021/06/Management-Considerations-for-Protecting-Groundwater-Quality-Under-AgMAR.pdf.

[46] Regardless of any trading activities most, if not all, of this modeling is already required by the SGMA rules and informed by DWR's Best Management Practices. CAL. CODE REGS. tit 23, §§ 352.4, 354.28; Cal. Dep't of Water Res., Best Management Practices & Guidance Documents (last visited July 2021), https://water.ca.gov/Programs/Groundwater-Management/SGMA-Groundwater-Management/Best-Management-Practices-and-Guidance-Documents.

directly inform the scope of a service area, even for specific activities. This is because all MAR activities must occur in a hydrologically connected area such that the additional recharge accrues to the same groundwater basin.[47] The nature of recharge from specific MAR actions may differ, which could impact the extent of an appropriate service area.

In addition to the hydrological connection, determining a trading area requires balancing numerous considerations. For example, adopting a larger trading area maximizes the number of potential projects and participants, whereas a smaller area minimizes potential attenuation and uncertainty, considerations particularly important to a trading program. Furthermore, the service area may be limited to the area covered by the GSP because it will likely be defined as part of the GSP. Within the GSP's total area, however, the service area may encompass a single GSA's jurisdiction, the entire basin or subbasin and all of the GSAs within that area, or some other discrete geographic region like a small management area. In any event, the area will necessarily be based on the hydrogeologic characteristics of the region as well as other insights pertinent to the specific program.

Quantifying Recharge Benefits

Quantification of benefits is an important component of a market-based program. In order to award credit or other incentives to private entities in exchange for MAR projects, the quantitative outcome of those projects must be understood. This requires detailing the pre-project site conditions, baseline, and establishing a monitoring network to gather the data that will then inform the necessary calculations.[48] Importantly, the monitoring and quantification requirements need to be considered in light of the associated costs and benefits to strike a balance that is economically feasible and provides sufficient certainty.

Baseline

In order to quantify the benefit of a MAR action, it is first necessary to establish a baseline. At its most basic, baseline refers to the conditions that exist at a given point in time. In the market-based context, the concept of baseline serves to define both current groundwater conditions and current land use practices to create a static point of comparison for evaluating future results. These considerations ensure the asserted benefits of a MAR project are in excess to what would have occurred without the project. Baseline, therefore, helps prevent market-based programs from becoming counterproductive.

Defining current groundwater conditions will occur as part of the planning process as SGMA requires that GSPs detail the status of groundwater across the basin.[49] This process will determine historic groundwater levels as well as other conditions like groundwater demand and hydrogeology.[50] Thus, the

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[47] The Wheeler Water Institute published a report that goes into greater detail about the potential impacts of groundwater trading if the appropriate dimensions are not fully considered. NELL NYLEN GREEN, ET AL., CENTER FOR LAW, ENERGY & THE ENVT, TRADING SUSTAINABLY: CRITICAL CONSIDERATIONS FOR GROUNDWATER MARKETS UNDER THE SUSTAINABLE GROUNDWATER MANAGEMENT ACT (2017), law.berkeley.edu/trading-sustainably.

[48] E. FASSMAN-BECK, ET AL., EVALUATING POTENTIAL METHODS TO QUANTIFY STORMWATER CAPTURE, S. CAL. COASTAL WATER RESEARCH PROJECT TECHNICAL REPORT 1116 (Apr. 2020), www.waterboards.ca.gov/water_issues/programs/stormwater/storms/docs/stormwatercapture_finalcombined.pdf.

[49] CAL. WATER CODE §§ 10727.2(a).

[50] CAL. CODE REGS. tit 23, §§ 354.16, 354.18 (detailing requirement to account for historic conditions).

GSP will likely establish a historic groundwater level baseline, which can then be compared against future, post-implementation conditions to help reveal the extent of benefits from projects.

The current land use practices, on the other hand, will likely not be documented in the GSP at a discrete enough scale to capture the recent use of specific properties. Instead, it may be necessary to document the individual site conditions prior to the implementation of a MAR project. Individual field practices are not likely to significantly alter the basin-scale modeling that was applied in the development of the GSP, however improved understanding of the baseline conditions and the trajectory of improvement resulting from MAR practices should inform updates of the GSP. The conditions that should be documented will differ for different types of projects but should generally document the state of the property, land use practices, cropping patterns, existing infrastructure, localized topography, current water retention and application, and anything else of note. This will create a basis of comparison to demonstrate that the MAR project is a new action, not part of the existing land use. While existing land uses may generate some benefits for groundwater infiltration, these preexisting conditions will likely have been considered in the GSP as part of the basin's baseline.

Monitoring Network

Every GSP requires a groundwater monitoring network that conforms to explicit monitoring protocols and standards.[51] This monitoring network should support MAR projects by informing efforts to document results and calculate benefits while also helping to identify any undesirable groundwater quantity and quality outcomes. A monitoring network that is sufficiently representative of the basin conditions should provide evidence of the benefits of the market-based program and the resulting progress towards sustainability. To support a market-based program, the monitoring network should generate data that reflects the basin-wide conditions as well as data that is accurate and discrete enough to reflect specific, local conditions.

Depending on a basin's situation, the existing monitoring network may supply sufficient information. Conversely, it may be necessary to expand the existing monitoring to capture more accurate and granular localized information that is most directly relevant to a specific MAR project. Market-based programs may offer a means to encourage the expansion of active groundwater monitoring to include private wells, which are not currently required to monitor or report on groundwater use or conditions.[52] This could be accomplished by requiring active monitoring of private wells as a precondition to participating in the market-based program, a strategy that has been employed in at least one existing groundwater trading programs.[53] Another option to expand the monitoring network is by offering incentives or subsidies to landowners. In any event, a reliable and representative monitoring network is needed for the development and implementation of a market-based program, such a program can then be used to expand and refine the monitoring network.

51 CAL. CODE REGS. tit 23, §§ 352.

52 A. ESCRIVA-BOU, ET AL., ACCOUNTING FOR CALIFORNIA'S WATER (July 2016), www.ppic.org/content/pubs/report/R_716EHR.pdf.

53 S. Heard S, M. Fienup & E. Remson, *The First SGMA Groundwater Market is Trading: The Importance of Good Design and the Risks of Getting it Wrong*, Cal. Agric. (2021) (discussing the Fox Canyon Groundwater Market).

Measuring Project Benefits

The calculation of groundwater benefits as part of a market-based recharge program should reflect the modeled or measured augmentation of groundwater supplies, minus any adjustments for environmental considerations or other sources of uncertainty. Quantifying MAR benefits requires a combination of direct measurement and modeling and will be heavily informed by the approaches taken in the GSP—the means of measuring MAR benefits should align with the GSP's approaches.[54]

Calculating MAR benefits begins by documenting the quantity of additional surface water that was applied (e.g., intentionally applied to farmland) or captured (e.g., stormwater prevented from becoming runoff). The net volume recharged can then be estimated by accounting for factors such as the soil profile, evapotranspiration, seasonality, local hydrogeology, surface water return flow, and uncertainty generally. Notably, the temporal differences in the MAR action and the resulting benefits will need to be considered to avoid near-term adverse outcomes. The specific factors that need to be evaluated will differ based on the type of MAR project and the basin. This variability of considerations and the need for GSP implementation tracking under SGMA makes it necessary to thoroughly document the quantification strategy, including all the specific inputs and assumptions. Establishing a clear, comprehensible quantification approach that balances simplicity and accuracy will help to both minimize transaction costs and maximize confidence in the program. Importantly, benefit quantification should always be intentionally conservative to avoid overestimating the results as this could undermine sustainability efforts.[55]

Program Administration

It is necessary to have a program administrator to oversee the operation of the market-based program. This entity will be responsible for implementing and enforcing the rules and policies governing the program, making final determinations about individual MAR projects, and tracking the results in order to include that information with the mandatory SGMA reporting. The program administrator will likely be a GSA, though this responsibility could be delegated to a third-party, especially if there is the perceived potential for conflict-of-interest concerns.[56] Regardless of the chosen administrator, this entity will need to oversee the generally applicable policies as well as the practice-specific policies and considerations. The following subjects are considerations or decisions that will fall within the purview of a program administrator and may be practice-specific to some degree.

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[54] For instance, the hydrogeologic conceptual model required in every GSP will improve the understanding of MAR outcomes. CAL. CODE REGS. tit 23, §§ 354.14, 354.16.

[55] In other market-based contexts, discount factors are used to account for uncertainty and prevent undesirable outcomes. These ratios proportionally discount the quantified benefits such that only a portion of those benefits are then awarded as part of a market-based program. *See, e.g.,* U.S. EPA, WATER QUALITY TRADING TOOLKIT FOR PERMIT WRITERS, EPA 833-R-07-004 (2007, updated 2009) (discussing ratios in water quality trading programs); U.S. FISH & WILDLIFE SERVICE, INTERIM GUIDANCE ON IMPLEMENTING THE ESA COMPENSATORY MITIGATION POLICY (2017) (detailing ratios in endangered species mitigation).

[56] As many of the individuals and entities active in GSAs have vested interests the groundwater, sometimes even being users of groundwater in their own right, it may be necessary or desirable to enlist an objective third-party to help fill this role.

Eligibility

Many trading programs may have an optional or mandatory preapproval system to vet proposals prior to implementation.[57] This preapproval system often constitutes an expedited, preliminary version of the final verification that precedes the issuance of a benefit as part of the market-based program.[58] The purpose is to help ensure that good projects progress and bad projects are culled before getting too far, thereby preserving resources for all involved and avoiding unanticipated results. This initial eligibility determination process also provides assurances to project proponents prior to implementation.

This preliminary eligibility determination process involves an interested participant furnishing the program administrator with sufficient information to make a preliminary determination about the appropriateness and eligibility of the proposal. The eligibility and preapproval strategy will need to consider the specific nature and characteristics of each type of potential recharge action in order to properly account for any unique considerations. For MAR projects, this determination would likely require some combination of information on the site's recharge suitability, regulatory compliance (e.g., CEQA, ILRP, etc.), land use history, conveyance and irrigation infrastructure, and water measurement systems, as well as the landowner's specific intentions, funding mechanisms, and experience with similar undertakings. This information serves to provide an accurate picture of conditions of site and suitability for inclusion in a market-based program.

MAR Practice Standards

To receive credit in a market-based system, a MAR project should be designed and implemented consistent with rigorous practice standards to ensure that the project will produce the intended groundwater benefits. Each project type should have practice standards that define whether a project is designed correctly, and that the appropriate project characteristics have been considered prior to implementation. These standards should include specifications for design, implementation, maintenance, and performance tracking, or some combination thereof based on programmatic needs.[59] The adoption of standards creates a transparent and consistent benchmark for project proponents as well as the program administrators. Therefore, standards serve to provide certainty and predictability to all parties while minimizing risk of project shortcomings by laying out minimum viable project design, implementation, and stewardship practices.

Standards are commonly practice-specific, requiring individual criteria for each type of project. For many best management practices that can generate recharge benefits, these types of standards already exist. For instance, the Natural Resources Conservation Service (NRCS) has a suite of practice standards that

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[57] For example, the Fox Canyon Water Market required the completion of some actions and forms prior to participating in the trading system. *See* Fox Canyon Groundwater Management Agency, Water Market Pilot Program Registration (2017), http://fcgma.org/public-documents/plans/20-public-documents/plans/95-groundwater-management-plan. Interestingly, the Twin Platte groundwater market in Nebraska uses an algorithm to evaluate eligibility. R.K. Young, Smart Markets for Groundwater Trading in Western Nebraska: The Twin Platte (Oct. 2016).

[58] This is because many of the considerations for initial suitability are similar to the considerations for final verification. For a discussion of MAR suitability considerations, see A.T. FISHER, ET AL., REGIONAL MANAGED AQUIFER RECHARGE AND RUNOFF ANALYSES IN THE SANTA CRUZ AND NORTHERN MONTEREY COUNTIES, CALIFORNIA, CAL. COASTAL CONSERVANCY PROJECT No. 13-118 (2018), https://www.rcdsantacruz.org/managed-aquifer-recharge.

[59] NAT'L NETWORK ON WQT, BUILDING A WQT PROGRAM: OPTIONS & CONSIDERATIONS, 104 (2015) (discussing project design standards).

are part of the Field Office Technical Guides, which are often issued for individual states or regions, making the information useful for local activities.[60] NRCS is developing *Interim* Practice Standards (#815 "Groundwater Recharge Basin or Trench" and #817 "On-Farm Recharge") that, once approved, will be available to local field offices to provide technical support on the design and implementation of MAR.[61] The NRCS standards only represent one option; any sufficiently detailed and reliable guideline can be used to inform practice standards. Fortunately, additional sources exist to provide scientifically sound practice standards. [62] Drawing from these types of preexisting sources will help to ensure that the most accurate and sound practice standards are adopted while simultaneously minimizing the resources needed to develop, draft, and vet new standards.

Tracking & Reporting Outcomes

Tracking and reporting project outcomes represents a central component of many market-based programs, groundwater trading or incentive programs are no different.[63] Without post-implementation monitoring and reporting, program administrators cannot ensure approved practices were implemented properly and generating the anticipated benefits. Given that this tracking and reporting will directly relate to the specific practice standards, the reporting requirements will need to account for the distinctions between the various types of projects. Specifically, it will be necessary to detail the following: implementation scope and success; compliance with the applicable quality standards; any remaining maintenance or implementation actions; and any divergence from the initial proposal. In practice, this consideration may prove fairly simple since much of the post-implementation reporting should mirror the pre-implementation eligibility information, highlighting any divergence from the initial proposal.

Although necessary, tracking and reporting have the potential to increase the transaction costs associated with project implementation. This is especially true if reporting is haphazard, lacking an efficient system for collecting and submitting the information. To avoid this issue, it is preferable to design a reporting system that enables participants to capture and report the required information in a programmatic manner. This could entail project-specific templated documents to streamline the overall process. Reporting could also be completed via an online portal, making the process more efficient for all involved parties. This type of templated data collection and programmatic management system would streamline the entire process, making participation easier for interested parties and simplifying

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[60] These NRCS guides are the primary scientific references for technical information about the conservation of natural resources. There are even California-specific resources. Natural Resources Conservation Service, *California NRCS Technical Resources* (2018), www.nrcs.usda.gov/wps/portal/nrcs/main/ca/technical/.

[61] Natural Resources Conservation Service, *Field Office Technical Guide* (Sept. 2018). NRCS' Interim Standards MAR are currently in draft form and have not received final approval.

[62] To provide one example of many, in the Laguna de Santa Rosa water quality trading program, the local Program Manual was the initial source of most quality standards. SONOMA COUNTY WATER AGENCY, STREAM MAINTENANCE PROGRAM MANUAL (Jan. 2009); Cal. Reg'l Water Quality Control Bd., N. Coast Region, Res. R1-2018-0025: Approving Trading Framework for the Laguna de Santa Rosa (2018), www.waterboards.ca.gov/northcoast/water_issues/programs/nutrient_offset_program/.

[63] The Fox Canyon program, for example, allows the administrator to determine when and what information participants will be required to provide. Fox Canyon Groundwater Management Agency, Rules & Regulations: Water Market Pilot (2017), http://fcgma.org/public-documents/plans/20-public-documents/plans/95-groundwater-management-plan.

management for the market administrators. Maximizing the ease of participation will help bolster the overall market-based approach, minimizing transaction costs and making participation more attractive.

Benefit Verification & Issuance of Incentives

The last step in a market-based program is commonly verification of benefits and the issuance of the resulting incentive. This stage serves to ensure that the approved practice was implemented and is performing as reported before the program administrator completes all necessary administrative reviews and issues the incentives. Although a different context, the *Draft Regional Recommendations for the Pacific Northwest on Water Quality Trading* provides a clear explanation of how verification currently occurs in water quality markets:

> *Verification is the process of confirming that a credit-generating BMP has been implemented properly, that credits have been quantified accurately at the site, and that the BMP is continuing to function over time. ... Verification is not the confirmation that a trading plan is achieving its overall goals but is a confirmation that the BMPs installed at credit-generating sites are designed, implemented, and performing in accord with relevant quality standards.*[64]

Numerous strategies exist for carrying out verification. Some programs require third-party site inspections; others involve qualifying project developers to implement proposals; still others only reserve the option to inspect a site if deemed necessary or as part of a random audit. These options are not mutually exclusive and may be combined in a number of ways as deemed appropriate for the circumstances. It may even be possible to remotely verify project implementation and function, which could help streamline the overall market operation and avoid increased transaction costs, making a groundwater market that much more attractive to potential participants.

Regardless of the approach utilized in a specific circumstance, this process should independently confirm and document practice implementation and function to justify the subsequent issuance of the incentive. To build trust in the overall market-based approach, and therefore spur increased participation, the verification should rely on transparent standards and processes, both for the verification itself as well as the underlying practice standards and quantification methodologies. This will help to curtail any skepticism and improve confidence in the overall market-based program. The verification of the benefits concludes with the market administrator issuing the incentive to the participant. The specific of the issuance will depend on the incentive. For instance, a groundwater trading incentive would likely be issued within the larger trading marketplace, whereas a direct financial incentive may be as simple as issuing payment to the participating landowner. In any event, the issuance of the incentive marks the successful completion of the verification and thus the entire MAR project.

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[64] WILLAMETTE P'SHIP & THE FRESHWATER TRUST, DRAFT REGIONAL RECOMMENDATIONS FOR THE PACIFIC NORTHWEST ON WATER QUALITY TRADING, at 134 (2014). *See also* H. WATERHOUSE, ET AL., SUSTAINABLE CONSERVATION, MANAGEMENT CONSIDERATIONS FOR PROTECTING GROUNDWATER QUALITY UNDER AGRICULTURAL MANAGED AQUIFER RECHARGE (2021) (discussing importance of verification).