ON-FARM RECHARGE METHODS MANUAL

A summary of strategies and challenges

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Funded By:
California Department of Water Resources

August 2023

Sustainable Conservation

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1. Introduction

Under the Sustainable Groundwater Management Act, groundwater sustainability agencies (GSAs) have been charged with developing and implementing groundwater sustainability plans (GSPs) that guide how to meet their subbasin's sustainability goals. On-farm recharge is one of several key tools identified in GSPs to improve groundwater sustainability by applying excess surface water on farm fields to recharge aquifers. Successful GSP implementation will depend on the leadership of GSAs and the participation of numerous growers to use peak flows for aquifer recharge in wet years.

This document gathers observed results and lessons learned from over a decade of Sustainable Conservation working directly with growers and irrigation districts to implement on-farm recharge. There are a limited number of scientific research studies documenting the potential and challenges of on-farm recharge. This report summarizes what is known from in-field practice while more extensive scientific studies can be completed. Its purpose is to provide practical information about on-farm recharge from growers to growers. The intended audience is growers interested in on-farm recharge, as well as technical assistance providers such as resource conservation districts, crop advisors, and non-profit organizations.

2. Why conduct on-farm recharge?

There are numerous potential benefits associated with on-farm recharge:

Improve Groundwater Sustainability
Extra surface water creates opportunities for recharging the root zone and the local groundwater basin, which can raise water levels and reduce pumping costs. If correctly done, on-farm recharge can also help protect or improve the quality of local drinking water supplies in communities that are dependent on groundwater.

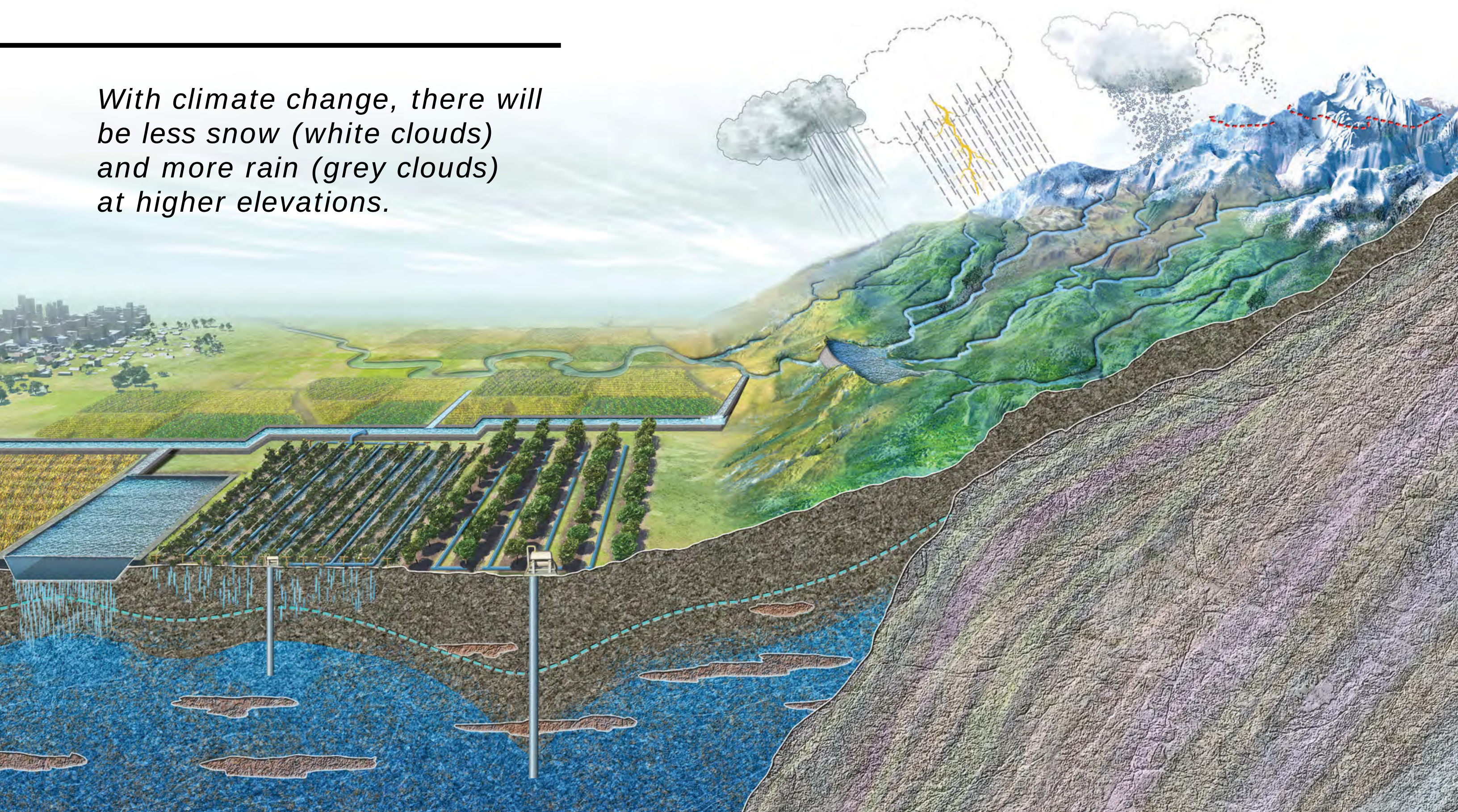
Reduce Flood Risk
The planned diversion of stormwater onto fields can reduce flood risk in nearby areas. If recharge is planned on a large scale, there may be opportunities to reduce flood risk at a regional level.

Support Groundwater-Dependent Habitat
On-farm recharge in specific locations can help to support ecosystems that rely on groundwater.

Sustain a Farming Economy and Preserve Working Lands
Recharging groundwater during wet periods can help the farming community adapt to a changing climate that includes the increasing frequency and severity of floods and drought.

It is important to note that on-farm recharge alone will not address all groundwater overdraft challenges facing many California basins and subbasins.

In many areas, pumping curtailment and land repurposing will be needed to achieve sustainable groundwater management and secure the future of farming and the communities they support.



With climate change, there will be less snow (white clouds) and more rain (grey clouds) at higher elevations.

3. Preparing for On-Farm Recharge

Evaluate Local / Regional Recharge Opportunities

Groundwater sustainability agencies are composed of one or more local public agencies (e.g., irrigation districts, county governments) that are responsible for water supply, water management, or land use decisions within a groundwater basin. GSAs develop and implement groundwater sustainability plans to manage groundwater in a basin, using either a single GSP or multiple, coordinated GSPs.

The Sustainable Groundwater Management Act requires GSAs to consider the interests of all beneficial uses and users of groundwater and to encourage the active involvement of diverse social, cultural, and economic segments of the population within the groundwater basin prior to and during the development and implementation of the GSP.

The GSAs set the stage for local and regional recharge projects and programs through development of projects and management actions in their GSP(s). Landowner participation in these efforts may be self-directed engagement with their GSA or water provider, participation in agency-led public meetings or committees, or submitting formal letters of interest.

Please see next page for potential questions for growers to ask their irrigation district or GSA to explore on-farm recharge.

Does the district or GSA have (or intend to have) a recharge program?	
YES	**NO**
• How does a grower participate in the program? • What are the conditions to participate? • What incentives, funding, credits, or other assistance are available to support growers participating in on-farm recharge? • How does the program plan to measure recharge at the farm level and at a district/subbasin scale? • Is the program willing to invest in more infrastructure to support on-farm recharge?	• What would it take to start an on-farm recharge program? • How can growers support on-farm recharge programs?

Does the district or GSA have water rights to provide water for recharge?	
YES	**NO**
• What is the predicted volume, timing, and place of use for recharge water available in wet years? • Does the district manage water under local threat of flood conditions? • Are there any water quality issues (site- specific or regional) that growers need to be aware of before implementing on-farm recharge?	• Does the district or GSA plan to pursue new or modified water rights or assist growers with this process?

Water Rights

In any recharge project or program, the first order of business is to understand water rights.

For **growers within water districts**, the easiest path forward is to work within the local district's existing water rights and authorities to divert surface water for recharge purposes. Existing water rights may need to be modified for purpose or place of use to accommodate district- or GSA-scale recharge programs. New temporary or permanent water rights may be needed for diversions outside of the irrigation season (i.e., winter) to maximize use of high flows for groundwater recharge.

A streamlined water rights process is available for GSAs or local agencies pursuing permanent and temporary water rights for diverting high flows for recharge. The process can be accessed here: Groundwater Recharge Streamlined Processing

Growers not served by a water district and fully dependent on groundwater may be able to work with a local district or other existing water right holder to deliver water outside of the district for either direct or in lieu recharge depending on the existing water right conditions (which sets the timing and location of where they can send water). Growers outside of districts could also, on their own or working with other growers or their local agency (e.g., the county), apply for temporary or permanent water rights.

Site Suitability

Conveyance and Infrastructure

Adequate surface water conveyance to the parcel or field is critical to on-farm recharge.

Typical turnouts and pipeline capacity range from 3 to 15 cubic feet per second (cfs) or more. As flood flows may be short in duration and rich in suspended sediments, properties with flood irrigation infrastructure (versus micro and drip irrigation) are ideal for on-farm recharge. The rate of flow, size of field, and soil infiltration rate will help determine the size of sections to be targeted for recharge because it may not always be possible or practical to flood the entire field at the same time.

If a field is not currently served by surface water, additional investment in permanent or temporary infrastructure would be required, some of which may be subsidized by local, state, or federal funding (see section on Financial Aspects of Recharge).

A Note on Flood Emergencies

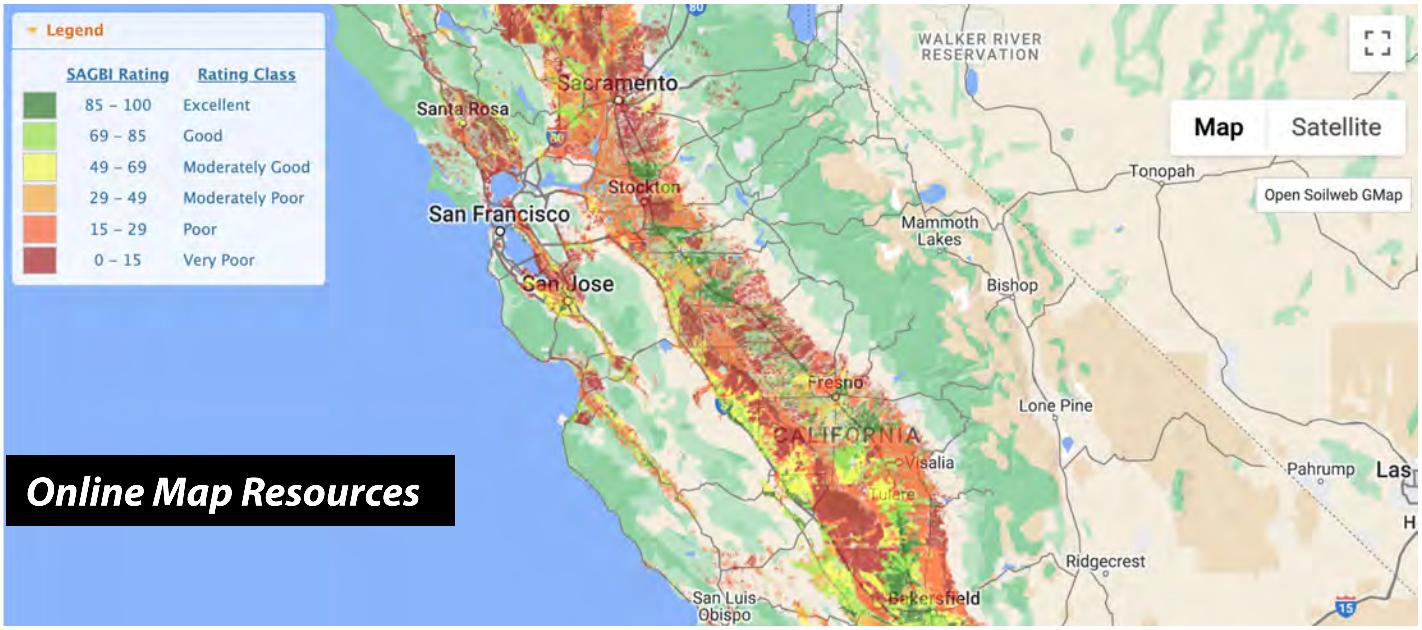
Local and state leadership recognize the need to simplify water rights permitting for using high flows to maximize recharge during threat of flood conditions. In March 2023, the governor issued the first executive order that clarified how floodwater resulting from 2023 winter storms could be diverted for recharge outside of the water rights process. The executive order required that flood conditions are declared by a local flood management agency and other conditions for recharge are met to reduce project impacts on groundwater quality and local ecosystems.

This executive order represented a shift in how floodwater is managed for groundwater recharge in California. Subsequently in July 2023, Senate Bill 122 was approved by the governor and codified language similar to the executive order for using flood flows for groundwater recharge under local threat of flood conditions.

Soil and Geologic Suitability
Understanding the underlying hydrogeology below the root zone is key in order to anticipate the flow and ultimate effect of recharge on local groundwater conditions. The movement of water through soils is complex and highly localized. Recharged water will generally find preferential pathways to the aquifer instead of infiltrating uniformly across the field. Sites with sandy streaks or coarse soils tend to be the best suited for on-farm recharge because of high water infiltration rates. High infiltration rates are most desirable for a recharge field as soil does not remain saturated for long and field inundation is less likely to cause harm to permanent crops.

Understanding Hydrogeology
The vadose zone is the unsaturated layer of soil between the root zone and the water table. It is an important factor controlling water movement from the land surface to the aquifer and strongly affects the rate of infiltration. Sandy loam, loamy sand, and sand textures are generally preferred for planned recharge activities because of potential for higher infiltration and percolation rates as compared to heavier silt and clay soil types.

There are numerous clay and silt layers that affect the speed and flow direction of groundwater. Most notably, the Central Valley contains a layer of Corcoran Clay, which is a remnant of an ancient lakebed that is 4,000 square miles and covers most of the lower San Joaquin Valley (see figure below). This largely impermeable layer ranges from 50 to 120 feet thick and ranges from 50 to 800 feet beneath the ground surface. When planning recharge in areas over Corcoran Clay, it is important to understand that recharged water will only affect the aquifer above the clay layer. In other words, wells that pull from below the clay layer will not be using water from on-farm recharge that may be occurring directly above the layer.



The University of California, Davis [Soil Agricultural Groundwater Banking Index] is a suitability index for groundwater recharge on agricultural land. The Soil Agricultural Groundwater Banking Index (SAGBI) score is based on five major factors that are critical to successful recharge on crop land: deep percolation (up to 6 feet deep), root zone residence time, topography, chemical limitations, and soil surface conditions. SAGBI classifies soils into six major categories based on suitability for recharge, ranging from excellent to very poor ratings.

Note that the SAGBI classifications are useful at a regional scale but may not reflect on-the ground knowledge of site conditions nor reflect recent land management practices that could have an influence on percolation potential. For example, recently levelled fields that have been ripped may be more suitable for recharge than is reflected in the SAGBI rankings.

Land IQ, a California-based company that specializes in earth sciences, developed an online tool that provides growers with another look at site recharge suitability by evaluating SAGBI along with the depth to groundwater

Airborne Electromagnetic (AEM) and Towed Transient Electromagnetic (tTEM) Surveys

The California Department of Water Resources (DWR) is currently conducting statewide airborne electromagnetic (AEM) surveys (Airborne Electromagnetic Surveys) to improve the understanding of groundwater aquifer structures. During an AEM survey, a helicopter tows electronic equipment that sends signals into the ground. A receiver mounted on the helicopter measures the electromagnetic response of the subsurface materials, providing a visual representation of soil composition to bedrock and the depth to groundwater. The resulting information will provide a standardized, statewide dataset that improves the understanding of large-scale aquifer structures and helps identify areas ideally suited for groundwater recharge. In tandem with this effort, other entities, such as universities, are conducting towed transient electromagnetic (tTEM) surveys that give a higher resolution to the AEM data for specific areas of interest.

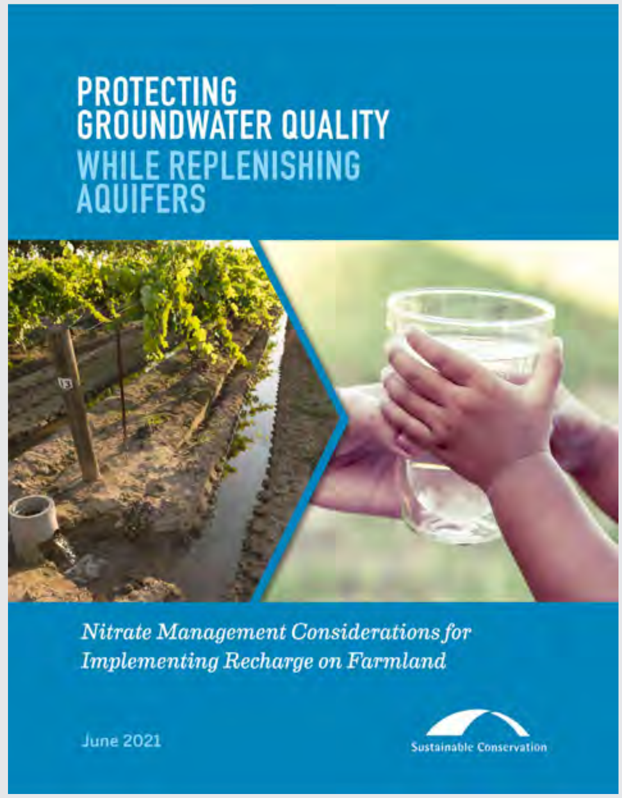
and depth to the Corcoran Clay layer. If water has a difficult time moving into the soil or runs into a hardpan layer as it percolates, then those sites will be of limited use for replenishing groundwater.

Water Quality

An important consideration when selecting a field for on-farm recharge is the potential impact on groundwater quality. When planned and managed correctly, recharge can potentially improve groundwater quality by diluting contaminated groundwater.

Ideally, a recharge practitioner can apply clean surface water onto a field or recharge basin that does not contain substantial legacy nutrients or other hazardous contaminants that can be leached into groundwater. Additionally, recharging on active farmland requires carefully managing applications of nutrients, pesticides, and other agrochemical inputs to avoid leaching of contaminants to the shared groundwater supply. At a minimum, the grower should follow all manufacturer recommendations for agrochemical application restrictions and recommendations, particularly the required wait periods before applying water to fields.

One technique to protect water quality and reduce the overall rates of nitrates and other constituents leaching into an aquifer is to focus on-farm recharge to a limited number of sites that use appropriate agrochemical management and multiple applications of sufficient amounts of water, rather than recharging large areas or rotating on-farm recharge fields annually.



For further detail about how on-farm recharge can be used to effectively protect or improve groundwater quality, see Sustainable Conservation's Water Quality Guidance.

4. Recharge On Perennial Crops

Fields where perennial crops are grown may be suitable for on-farm recharge, especially those that are dormant in winter. The tolerance to on-farm recharge conditions will vary by crop type, variety, rootstock, soil type, timing of water application, and a wide array of environmental conditions. Deciduous tree and vine crops are generally more tolerant of root zone saturation from dormancy up to bud-break. Once out of dormancy, these crops are sensitive to long-term root zone saturation. There is ongoing research to better understand maximum thresholds of different crops' tolerance to inundation and root zone saturation during on-farm recharge activities.

As a general rule, growers should consider on-farm recharge timing in relation to crop cultural development and stages of growth so as to avoid plant health problems. Grower's knowledge of soil infiltration rates should help with planning on-farm recharge applications, along with knowing the timing of tree and vine development and growth stages, such as flower or fruit initiation, that may be more sensitive to saturated soils. Some growers have successfully conducted recharge after dormancy, typically on sandier soils. A grower's knowledge should serve as the main guide to determine when, how much, and how long on-farm recharge can be conducted on a specific field. Each crop and soil type will have different factors that require a tailored recharge application method and close field monitoring.

Practitioners of on-farm recharge generally use methods similar to flood irrigation. Water application methods specific to on-farm recharge include focusing water on sandy fields with high percolation rates and limiting the length of time that orchards and vines are saturated. (See Section 7 for methods to prepare fields and manage water during on-farm recharge.)

Grapevines

Grapevines are considered to be generally tolerant of on-farm recharge during the dormant season up to the time of buds setting. They do not have a high nitrogen demand, so the risk of leaching during recharge is minimized.

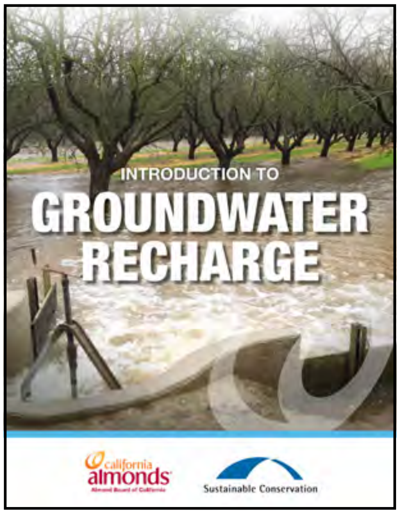
Although more research is needed, pioneering growers have experimented with on-farm recharge on grapevines beyond the dormant season as shown in the photo above. Growers that were interviewed applied water during the dormant season and into May, which is past bud-break. In some cases, recharge in their vineyards occurred into July. Recharge has also been done in the fall after harvest when surplus water was available. Growers often targeted on-farm recharge to fields with mature or older vines, and for wine and raisin grape varietals intended for contracts or commodity markets. Soil types varied from heavier silty loams to very sandy soils.

While successful, the primary concern of the growers is the additional steps needed to manage increased risks of powdery mildew resulting from higher humidity levels that can occur during on-farm recharge. Because of concerns about nutrient leaching and plant stress in the spring, some growers suggested conducting on-farm recharge only during the dormant season.

Almonds

On-farm recharge in almond orchards has been evaluated by a number of growers and researchers. There is growing consensus that recharge can be conducted on almond orchards during the dormant season when trees have lowered metabolic rates and can tolerate soil saturation. Because of the trend toward more frequent but smaller application of nutrients, on-farm recharge should be avoided during the growing season to limit the risk of leaching these nutrients into the groundwater. Growers interested in on-farm recharge should preserve flood irrigation infrastructure for orchards converted to micro irrigation.

The Almond Board of California published an in-depth Introduction to Groundwater Recharge that reviews in detail some of the considerations specific to conducting recharge on almond fields.



Pistachios

Pistachios are grown on heavier clay or saline soils, which are considered less suitable for other more sensitive tree crops, like almonds. Heavier clay soils have a lower infiltration rate and are less suitable for on-farm recharge. Newly planted pistachio orchards are typically on drip or micro sprinkler irrigation; but older orchards with existing flood irrigation valves could consider on-farm recharge, especially if the rows were recently ripped prior to planting or have sandy streaks that improve infiltration. Pistachios appear to be more sensitive to water when temperatures rise in the spring, and caution needs to be exercised during the growing season.

More research is needed about the tolerance of pistachios for planned recharge events. Natural flooding events suggest that pistachios may have a relatively high tolerance for recharge when carefully managed.

Walnuts

Walnut orchards have a longer dormancy period than almonds, so the prime on-farm recharge opportunity for walnuts is generally from November to early May, depending on the timing of the bud break. Some walnut varieties can be more sensitive to excess water in the root zone than others. Caution is advised to consider current rootstock conditions and susceptibility to root rot diseases such as phytophthora spp.

Alfalfa

Alfalfa is a perennial legume primarily grown for feeding livestock or used as a cover crop and soil conditioner. Alfalfa is harvested March through October, and a typical alfalfa season in the Central Valley can yield seven to eight cuts of hay per year. On-farm recharge can be applied during the plant's semi-dormancy season from October through February. Additionally, there could be recharge opportunities during the growing season, which would require careful timing of water applications to avoid delays in harvest time because of soil and plant moisture. Additionally, the duration of water application must be short enough to avoid plant development problems.

5. Recharge On Annual Crops and Other Land Uses

Fallow Fields

Fallow fields are readily adapted for on-farm recharge, especially if they are equipped with flood irrigation valves and water conveyance. Growers can consider fallowing fields in the time between retiring and replanting an orchard, which also reduces overall water demand and reduces risk for certain soil diseases to persist to the new tree crop (i.e., replant disease). Fallow fields can be inundated at any time of the year.

Annual Crops

On-farm recharge can be conducted on annual crop fields during periods when a crop is not being cultivated, such as after harvest. It should be noted that recharge on annual crop fields may erode beddings intended for the following season. In that case, additional water control structures, like berms, may also need to be constructed.

When recharge occurs on fields normally planted with row crops, recharge events need to be carefully managed with agricultural practices.

In some instances, a crop buyout or temporary/seasonal land fallowing program may incentivize on-farm recharge in fields that are grown in annual crops.

18-acre on-farm recharge basin in Madera County

Basins

Growers may want to devote portions of their fields to recharge basins for various reasons, such as reducing their overall irrigated acreage under groundwater allocations, converting sandy areas that may be difficult to grow crops, and building overall groundwater resilience.

Basins also have the added benefit of having little to no water quality concerns and being able to accept water any time of year, especially during snowmelt, when many crops are in full swing and cannot accept additional water. Various types of funds exist for growers to create basins on their property (see Section 8, Financial Aspects of On-Farm Recharge).

Alternative Recharge Locations

Growers may want to consider focusing recharge on portions of their land that are not currently in agricultural production, such as unlined ditches and ephemeral streams. These areas have the added advantage of being able to accept water at any time of year, and they do not pose any water quality risk or conflict with agricultural practices.

Photos courtesy of Donny Hicks.

Two adjacent orchards, with bare ground (left) and with winter cover crops (right), after receiving 0.75 inch of rain in January 2023. Water was drained within hours in the orchard with a cover crop compared to days in the bare-ground orchard.

Cover Crops

The interactions between on-farm practices such as recharge and cover cropping are a growing area of research. Growers report improved infiltration in fields established with cover crops because of the greater number of roots in the soil, which reduces surface sealing, improves soil structure, and can increase soil organic matter. Fields with cover crops also show improved water use; some growers have been able to delay the first irrigation or irrigate less frequently in the summer months as these cover crops improve soil health and increase capture and retention of precipitation and applied water.

Non-legume winter cover crops can be used to scavenge excess nitrate-nitrogen in the upper soil horizons between cash crop rotations, which may provide a valuable service in reducing nutrient leaching below the root zone, especially prior to on-farm recharge But if recharge water is ponding on active cover crops for an extended period of time, the cover crop may not thrive or survive past the inundation period. This may or may not be acceptable to the grower, depending on the grower's objectives with the cover crop.

Additionally, because the nutrient scavenging potential is correlated with cover crop biomass, ponding on an active cover crop could still lead to leaching of nutrients. More research is needed to understand the timing considerations of recharge on cover crops and its effect on nutrient leaching.

6. Other Types of Recharge

Unsaturated Zone Wells

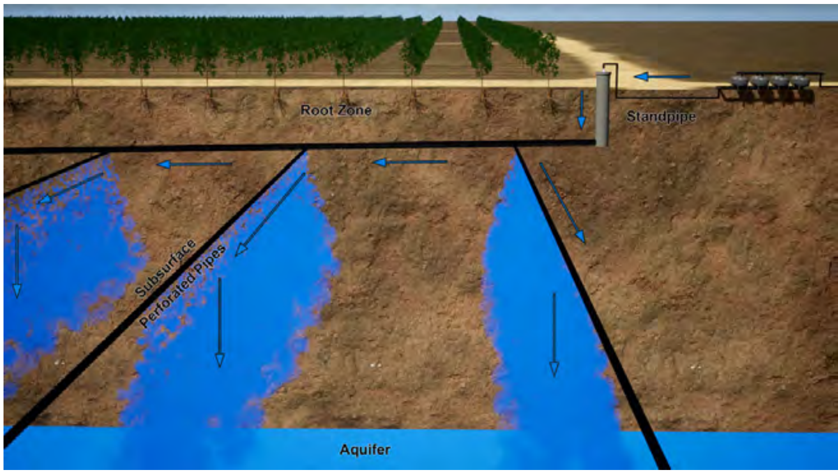
Unsaturated zone wells are gravity-fed excavated pits or shallow wells lined with perforated casing and backfilled with gravel or stone. Unsaturated zone wells penetrate layers of clay soils that have poor infiltration rates, allowing for rapid infiltration of recharged water into more permeable soils deeper underground. They could potentially be used to bypass contaminants that would otherwise be leached from the upper soil layer during an inundation event. But extra care should be taken to avoid unintentional contamination of the underlying aquifer by providing clean source water.

Photo by R. M. Gailey, Consulting Hydrogeologist PC.

Reverse Tile Drains

Subsurface groundwater recharge using tile drains was introduced to the San Joaquin Valley in 2017. Conventional tile drain systems are installed to drain water out of the soil in fields with a high water table, which can create anoxic conditions for crops (e.g., areas in the Sacramento Valley and Tulare basin). The adaptation of “reverse tile drains” instead applies excess water below the root zone into areas with over-drafted aquifers for the express purpose of recharge.

A key benefit of the reverse tile drain system is that it does not saturate roots, allowing water application during the growing season. It also separates field management needs, such as nutrient or pest management, from the availability of water and timing of recharge.



Schematic courtesy of LIDCO, Inc.

The cost of installation can be a drawback, as these systems require significantly higher capital expenses compared to other forms of on-farm recharge.

Growers who are interested in a reverse tile drain system will need to install tile drains and pipelines prior to planting a field. This system should be considered when planting a new orchard or replacing an existing oneto consider only if planting a new orchard or replacing an existing one.

7. Practical Methods to Prepare Fields and Manage Water During On-Farm Recharge

Flood Irrigation Infrastructure

Fields with existing flood irrigation infrastructure are most suited to on-farm recharge. Drip and sprinkler systems are not generally recommended for on-farm recharge because of the typically slow rate of water application, which may not exceed evapotranspiration. For fields without flood irrigation, the grower will need to install temporary or permanent flood conveyance infrastructure, such as the following:

- **Pumps**
- **Flow Meters** at turnouts, or some other system to measure amounts of water applied
- **Conveyance** to move water to various parts of the field, such as pipes

Fields that are set up with flood and drip irrigation may be best suited to adapt to the increasing frequency and intensity of droughts and floods. The grower can use drip irrigation during dry periods, and flood irrigation for on-farm recharge in wet periods.

See CASE STUDIES in the Appendix at the end of this document for specific examples of how different growers prepare for and apply recharge water on their fields.

Preparing Fields for On-Farm Recharge

Berms installed within furrows help to slow horizontal movement of recharge water and enhance infiltration and percolation. Berms constructed at intervals within furrows also prevent ponding of water at the end of the field.

Trees planted on berms are ideally suited to on-farm recharge because the berms help keep parts of the root system above water ponding levels.

One method to increase the rate of infiltration is discing. Tilling the soil between rows can break up crusting that seals soils, allowing for increased infiltration of recharge water. Tilling has to be done carefully in order to avoid damage of roots and field equipment. Gypsum can also be applied prior to recharge events to prevent soil crusting and maintain higher infiltration rates.

As stated before, planting cover crops may improve water infiltration into the soil. Cover crops can also prevent the soil surface from sealing and improve water storage capacity. Growers that recharge on fields with cover crops report faster infiltration and less ponding of water.

Recharge basins need to be designed correctly to be safe and effective. Growers can reference general guidance on how to build a basin from the Natural Resources Conservation Service's Conservation Practice Standard 815 Groundwater Recharge Basin or Trench. Additionally, growers interested in ecologically beneficial recharge basins can reference the Environmental Defense Fund's Building Multibenefit Recharge Basins brochure.

Managing Water During Recharge on Perennial Crops

Alternate row irrigation is the wetting of alternate rows while leaving adjacent rows dry, which prevents roots from being completely submerged during recharge. Lowered oxygen levels sometimes associated with soil saturation can also be avoided with this method. Alternate row irrigation is a conservative approach for most crops, and the standard approach for more sensitive crops.

Surge irrigation is the intermittent application of water used to improve distribution uniformity along a furrow. It works on the principle that dry soil infiltrates water faster than wet soil. Surge irrigation can be used to increase infiltration of on-farm recharge water in a field while limiting ponding.

Duration of water application is important. Growers reported applying water for five to seven days followed by a rest period for infiltration and percolation beyond the root zone. Growers with very sandy soils or sandy streaks in heavier soils reported being able to apply recharge water continuously during the dormant period because water was fully infiltrated before reaching the end of the field.

Irrigation water temperature is also important when considering the duration of soil saturation. Growers reported that trees are more tolerant to saturation in winter when average temperatures are lower than in spring. Soil oxygen levels that are important for root respiration also vary with temperature and soil biotic activity. Research is needed to better understand the dynamics of temperature, oxygen levels, and their influence on tree health during recharge.

Maintenance and Monitoring

Areas around flood irrigation valves will need to be monitored for erosion. Berms will need to be monitored and repaired to ensure uniform distribution of water.

Conservative Approach to On-Farm Recharge

Growers using a conservative approach to recharge avoid any ponding of water in the field. Water applied would generally be fully infiltrated before flow reaches the end of the row.

Active Approach to On-Farm Recharge

Growers using a more active approach to recharge would apply enough water to pond up to berm level. They should be careful to avoid water saturation near the rootstock and the scion union of grafted trees. Growers believe that saturating the graft union increases the risk of introducing pathogens into the trunk.

8. Financial Aspects of On-Farm Recharge

Cost

The cost of installing the infrastructure needed for moving water onto the field will depend on the location of the field relative to the water source and any existing infrastructure. If permanent irrigation infrastructure is not available nor desired, temporary structures may be required to pump and spread the required volume of water needed for recharge. Temporary structures can be installed at relatively lower cost than permanent pipelines.

At least one person is needed to activate and monitor recharge activities on the ground. When enrolled in an incentive program, growers may be expected to record data, such as pumping start/stop dates and times, flow capacity of the pump, date-stamped photos of the recharge events, and other observations such as depth and duration of ponding.

The cost of water for on-farm recharge varies considerably, depending on the availability of surface water supplies and district incentive programs. Water for recharge can sometimes be available at a highly discounted rate or even free, depending on a district's desire to engage growers in recharge (see Incentives section below). In some cases, the district can help the grower with the electricity costs of running pumps. Even when growers pay the full cost for recharge water, the expense can be offset if a district offers a credit on water bills or an increased allocation for groundwater pumping.

The following cost estimates are based on an economic model that was used to evaluate on-farm recharge on a 160-acre field in the Kings River Basin. For more details, including the model assumptions, consult M. Cubed's original March 2016 report, "Analyzing Cost Effectiveness for Kings Basin Flood Flow Recovery".

Typical Costs Associated With On-Farm Recharge on a 160-Acre Field

DESCRIPTION	LABOR
Infrastructure	
Surface pipe	$35,000
4 Lift pumps (one pump per 40 acres)	$24,000
Fuel for 4 pumps	$32,500
Labor	
Build temporary berms (and repair as needed)	$2,400
Annual ripping or gypsum application	$12,800 ($80/acre)
Irrigator labor (1 hour per acre, 3 recharge cycles per flood year)	$7,200 ($15/hour)
Annualized (over 20 years)	
Cost/AF in a single flood year	$34/AF recharged
Cost/AF, Adjusted for flood frequency (38%)	$89/AF recharged

Source: Analyzing Cost Effectiveness for Kings Basin Flood Flow Recovery (M. Cubed, March 2016)

Incentives

Locally Led On-Farm Recharge Incentive Programs

Many irrigation districts have on-farm recharge incentive programs for their growers, ranging from a robust groundwater crediting program to offering discounted or free water, as mentioned above. Sustainable Conservation has produced a summary of district recharge programs led by irrigation districts in the Central Valley.

Natural Resources Conservation Service Financial Assistance

In 2023, the Natural Resources Conservation Service piloted a recharge program in a few areas of the Central Valley that helped growers offset infrastructure and management costs associated with recharge. In addition to receiving financial assistance for constructing a recharge basin or applying on-farm recharge water to cropland, growers could simultaneously apply for other Environmental Quality Initiative Program (EQIP) practices that help offset costs with upgrading infrastructure and water conveyance. Once the pilot phase is complete, it is expected EQIP will be widely available for growers interested in recharge.

Statewide Programs

Current efforts to pay growers to temporarily fallow or permanently repurpose previously irrigated fields may offer attractive economic benefits to growers while also providing suitable recharge areas. Programs such as the LandFLEX program and the Multibenefit Land Repurposing Program are some examples of how the state is attempting to aid growers with transitioning to less intensively irrigated acreage. Growers interested in providing on-farm habitat (for example, wildlife-friendly recharge basins) may also be able to access other types of funding dedicated to conservation efforts.

A Note on Measuring and Reporting
If a grower is engaged in an on-farm recharge program with incentives, it is important to be able to measure the amount of water applied during recharge events. Some irrigation districts already have meters in place at turnouts. Sometimes bills from irrigation districts can help to determine how much water was applied to individual or small clusters of fields. Additionally, the design capacity of a turnout, along with the duration of the recharge event, can help to estimate the amount of water applied.

9. Information and Guidance

Introduction to Groundwater Recharge Almond Board of California

This guide is targeted to California almond growers to help evaluate their options for conducting groundwater recharge by describing factors to consider and primary recharge methods available. The information provided in this guide is based on a combination of current scientific knowledge and growers' experiences.

Flood-MAR Hub

Flood-MAR Network
The Flood-MAR Hub is a one-stop shop for all things related to Flood Managed Aquifer Recharge (Flood-MAR). This site showcases on-the-ground recharge projects, research, guidance, tools and more. The reader can also join the Flood-MAR network list-serve to keep updated on statewide efforts to increase the pace and scale of groundwater recharge in California.

Groundwater Exchange

California Data Library
The Groundwater Exchange is a central, collaborative, and publicly accessible online resource center connecting water managers, water users, and community members with tools and resources to support the design and implementation of effective Groundwater Sustainability Plans under California's Sustainable Groundwater Management Act.

10. Acknowledgements

Sustainable Conservation would like to thank the following people and agencies for providing valuable information that helps to inform the content in this document. The views expressed in this document are those of the authors and do not necessarily represent the views of the individuals and organizations listed below.

Al Costa, grower

Arlen Thomas, grower

Christine and Erich Gemperle, growers

Daniel deGraaf, deGraaf Engineering, Inc.

Dina Nolan, Madera Irrigation District

Don Cameron, grower

Eric Harcksen, grower

Eric Spycher, grower

Jennifer Spaletta, North San Joaquin Water Conservation District

Jesse Roseman, Almond Board of California

Karun Samran, grower

Ladi Asgill, former Sustainable Conservation agronomist

Russel and Matt Efird, growers

Wendy Rash, Natural Resources Conservation Service, USDA

Wes Miller, Turlock Irrigation District

This report was prepared by Sustainable Conservation through funding provided by the California Department of Water Resources.

11. Appendix: Case Studies

Growers new to recharge in 2022-23

Christine and Erich Gemperle, Almonds, Stanislaus County

Eric Harcksen, Almonds, Merced County

Eric Spycher, Almonds, Merced County

Karun Samran, Almonds, Madera County

Growers piloting recharge since 2016

Al Costa, Wine Grapes, San Joaquin County

Arlan Thomas, Almonds, Madera County

Russel and Matt Efird, Raisin Grapes, Fresno County

Don Cameron, Almonds, Fresno County

Don Cameron, Wine Grapes, Fresno County

Don Cameron, Basin Recharge System, Fresno County

On-farm Recharge Pilot
Projects Case Study

Grower: Christine and Erich Gemperle

Crop: Almonds

Location: Ceres, Stanislaus County

Site Conditions

- Acreage = 36.5 acres for recharge in a 40-acre field
- Crop type = Almonds
- 20 acres, crop age = 5 years
- 20 acres, crop age = 21 years
- Land IQ rating = Moderately good
- Soil Agricultural Groundwater Banking Index rating = Excellent

Water Supply

- Gravity flow water was supplied free of charge from Turlock Irrigation District (TID) as part of their flood risk reduction efforts. TID notifies grower when water is available for delivery.

Soil Health

- Cover cropping for 10 years, mix of clover and broadleaf mustards.

On-Farm Recharge Logistics

Labor needed:

- One person to monitor recharge events day and night. No tractor work was involved.
- 4 days at 18 hours per day = 72 hours
- $20/hour labor = $1,440

Field infrastructure:

- Fields are set up with 1 turnout per 5 acres for gravity flood irrigation.
- TID installed Rubicon Flume meters to measure water use

Field preparation and management:

- Very little preparation was needed because the farm maintained the flood irrigation system even after converting to dripline and micro sprinkler irrigation.
- Gate valves require lubrication.

Recharge Events

Total applied water:

Water applied January 12-15, 2023.

- 27.5 acre-feet over 36.5 acres, about 0.8 foot per acre

Water applied February 1, 2023.

- 16.5 acre-feet over 36.5 acres, about 0.5 foot per acre

Total water recharged:

- 43.9 acre-feet over 36.5 acres, about 1.2 foot per acre

For more information, contact: Rogell Rogers, Agronomist, Sustainable Conservation, at rrogers@suscon.org or 209-576-7729 x346.

On-farm Recharge Pilot Projects
Case Study

Grower: Eric Harcksen

Crop: Almonds

Location: Ballico, Merced County

Site Conditions

- Acreage = 18 acres for recharge (control field 20 acres)
- Crop type = Almonds
- Crop age = Mixture of 21 years and 28 years
- Land IQ rating = Good
- Soil Agricultural Groundwater Banking Index rating = Good

Water Supply

- Water was supplied free of charge from Turlock Irrigation District (TID) as part of their flood risk reduction efforts. TID notifies grower when water is available for delivery.
- TID covered the electrical cost of $66.20 for pumping.

Soil Health

- Cover cropping mix of clover and broadleaf mustards.
- Shredded tree clippings spread across topsoil in the fall.

On-Farm Recharge Logistics

Labor needed:

- One person to monitor recharge events.
- 5 days at 12 hours/day = 60 hours
- $20/hour labor = $1,200

Field infrastructure:

- Water was pumped into the grower's existing underground flood system, which has valve gates every other tree row in the field.
- TID installed Rubicon Flume meters to measure water use.

Field preparation and management:

- Every 4 tree lines use 8- to 10-inch-high berms to enclose or hold water until water rose 6–8 inches.
- After water rose 6–8 inches, the valve was shut off and the next valve turned on to allow water to flow into the next set of four tree lines.

Recharge Events

Total applied water:

- Five applications were made during December 2022.
- 21.08 acre-feet over 18 acres, about 1.17 feet per acre

Total water recharged:

- 20.95 acre-feet over 18 acres, about 1.16 feet per acre (1.27 feet per acre with rain)

For more information, contact: Rogell Rogers, Agronomist, Sustainable Conservation, at rrogers@suscon.org or 209-576-7729 x346.

On-farm Recharge Pilot Projects
Case Study

Grower: Eric Spycher

Crop: Almonds

Location: Bellico, Merced County

Site Conditions


- Acreage = 13 acres for on-farm recharge
- Crop type = Almonds
- Crop age = 7 years
- Land IQ rating = Excellent
- Soil Agricultural Groundwater Banking Index rating = Excellent

Water Supply

- Water was supplied free of charge from Turlock Irrigation District (TID) as part of their flood risk reduction efforts. TID notifies grower when water is available for delivery.

Soil Health

- Soil was amended with a cover crop and composting during the first three years of growth.

On-Farm Recharge Logistics

Labor needed:

- Three people to monitor recharge events (10 hours each person per day for 2 days = 60 hours) plus 1 person for 10 hours tractor work.
- $20/hour for 70 hours = $1,400

Field infrastructure:

- The original gravity flood system was divided into one underground water valve for every 8 plant lines.
- TID installed Rubicon Flume meters to measure water use.

Field preparation and management:

- Berms were installed to a height of 1.5 feet to flood 4 plant lines at one time.
- After reaching a head height of 7-8 inches, the berms were breached to direct water to move to the next set of 4 plant lines.
- 5-6 hours after the water was shut off, the water had completely infiltrated into the soil.

Recharge Events

Total applied water:

Water applied December 14-15, 2022.

- 16 acre-feet over 13 acres, about 1.2 feet per acre

Total water recharged:

- 15.99 acre-feet over 13 acres, about 1.2 feet per acre

For more information, contact: Rogell Rogers, Agronomist, Sustainable Conservation, at rrogers@suscon.org or 209-576-7729 x346.

Sustainable Conservation

On-farm Recharge Pilot Projects Case Study

Grower: Karun Samran

Crop: Almonds

Location: Chowchilla, Madera County

Site Conditions

- Acreage = 5 fields (total 165 acres)
- Crop type = Almonds
- Fields 1 and 2 = 12 years old
- Fields 3, 4, and 5 = 6 years old
- Land IQ rating = Moderately good
- Soil Agricultural Groundwater Banking Index rating = Good to moderately good

Water Supply

- Chowchilla Water District (CWD) provided water at $10 per acre foot.
- CWD notified grower when water was available for recharge.

Soil Health

- Spread compost on berms post-harvest, 3 tons per acre.
- Applied shredded pruning brush in between plant lines.
- Cover cropping mix of clover and broadleaf mustards grown winter through spring.

On-Farm Recharge Logistics

Labor needed:

- One person to monitor recharge events.

Field infrastructure:

- The original gravity flood irrigation infrastructure was still intact, so no prep work was required.
- CWD metered turnouts.

Field preparation and management:

- Flood 10 rows at a time using one underground water valve.
- Upon filling the rows with 3-4 inches of water, shut off the valve and rotate to the next 10 plant rows.
- Repeated this process until the entire field has been flooded.

Recharge Events

Total applied water:

Water applied at various times from 1/13/2023 through 2/6/2013.

- 175 acre-feet over 165 acres, about1.1 feet per acre

Total water recharged:

- 172.6 acre-feet over 165 acres, about 1 foot per acre

For more information, contact: Rogell Rogers, Agronomist, Sustainable Conservation, at rrogers@suscon.org or 209-576-7729 x346.

Sustainable Conservation

On-farm Recharge Pilot Projects Case Study

Grower: Al Costa

Crop: Wine Grapes

Location: Acampo, San Joaquin County

Project Description

Al Costa is a wine grape grower in the San Joaquin County who has participated in on-farm recharge since 2018. His 13.7-acre recharge site is very sandy, allowing the application of large volumes of water without harm to his crops (see tables below for details). The grower also has the benefit of working with an irrigation district that is very supportive of recharge efforts.

The on-farm recharge effort at the vineyard is a prime example of what can be achieved when different entities, such as farm communities, local irrigation districts, and groundwater sustainability agencies, collaborate with the common goal of replenishing groundwater.

The accomplishments of the grower and the recharge benefits observed at his farm are an important reminder that grower participation is critical to achieving Sustainable Groundwater Management Act goals. Incentivized on-farm recharge programs encourage grower participation, because many growers need financial support to cover the cost of infrastructure and electricity required to conduct on-farm recharge. Growers would like to see an expansion of similar programs in the San Joaquin and Sacramento valleys.

Field Description

Category	Details
Acres	• 13.7 acres (recharge site) • 9.1 acres (control site)
Type of crop	Zinfandel grapes
Age of crop	Planted in 1992
Average root depth	6–7 feet
Irrigation infrastructure	Irrigation is applied using a single dripline tape per plant row.
Soil amendment	Periodically, based on need, the grower applies gypsum at a rate of approximately 20 pounds per acre.

Hydrogeology

Category	Details
Soil texture	• Sandy. • Mr. Costa notes it was extremely hard to get irrigation water across the field. Grape vines tended to be less developed at the end of furrows because of low soil moisture retention in sandy soil texture. There are some extremely sandy streaks in the recharge and control sites.
Land IQ rating	Moderately good
Soil Agricultural Groundwater Banking Index rating	Good to excellent
Restrictive layers	None
Depth to groundwater	75–80 feet

On-Farm Recharge Logistics

Category	**Details**
Source of water	Water for groundwater recharge was provided by North San Joaquin Water Conservation District (NSJWCD).
Maximum diversion rate	10 cubic feet per second
Method of diversion	Water was pumped from the Mokelumne River into an underground conveyance pipe that leads to the vineyard.
Cost of water	• NSJWCD did not charge the grower for the recharge water. • NSJWCD paid for the electricity to pump the water from the Mokelumne River and for the infrastructure to convey the water to the vineyard recharge pilot site. • The grower provided the labor and equipment to prepare the site and manage the applied water.
Field preparation and management during recharge	• A 6-inch berm was installed at the outer perimeter of the recharge field site, and an inflatable gated pipeline was placed on the west side of the field for flooding each row. • Water was conveyed through an underground pipe for approximately 1,500 feet before entering a flood-pipe riser at the head of the multiple rows on the field's west side where the inflatable, gated flood pipe was connected. • The water that was pumped into the rows rapidly infiltrated before reaching the end of the field, which was approximately 1,000 feet from west to east.
Nutrient management	Fertilizer was not applied during the dormancy period from late November to early April.
Average inundation height	The maximum depth of water in the field was 3–4 inches.
Duration of inundation	The infiltration rate was excellent. The water could be turned on continuously for 24 hours without overflooding the field.
Time to dry down	It took 1 day to dry down soil was required after turning off applied water.

Recharge Events

Year 2018

Dates of recharge	Duration (days)	Field size (acres)	Water applied (total acre-feet)	Water applied (feet per acre)	ETc (feet)	Net water recharged (total acre-feet	Net water recharged (feet per acre)
Oct. 5–Nov. 5	32	13.7	237	17.30	0.26	232.73	16.99

Table notes: Dates of recharge, field size, and water applied sourced from the grower. Crop evapotranspiration (ETc) value sourced from California Irrigation Management Information System station #71C.
Net water recharged = water applied – (1.2 x ETc x acres).

Year 2019

Dates of recharge	Duration (days)	Field size (acres)	Water applied (total acre-feet)	Water applied (feet per acre)	ETc (feet)	Net water recharged (total acre-feet	Net water recharged (feet per acre)
Oct.4–Oct. 17	14	23	125.87	5.47	0.07	123.94	5.39
Oct. 21–Oct. 27	7	23	53.76	2.34	0.04	52.66	2.29
Nov. 16–Nov. 30	15	23	115.76	5.03	0.03	114.93	5.00
Rain							0.20
Total	36		295.39	12.84	0.14	291.53	12.88

Table notes: Dates of recharge, field size, and water applied sourced from the grower. ETc value sourced from California Irrigation Management Information System station #71C.
Net water recharged = water applied – (1.2 x ETc x acres).

Year 2022

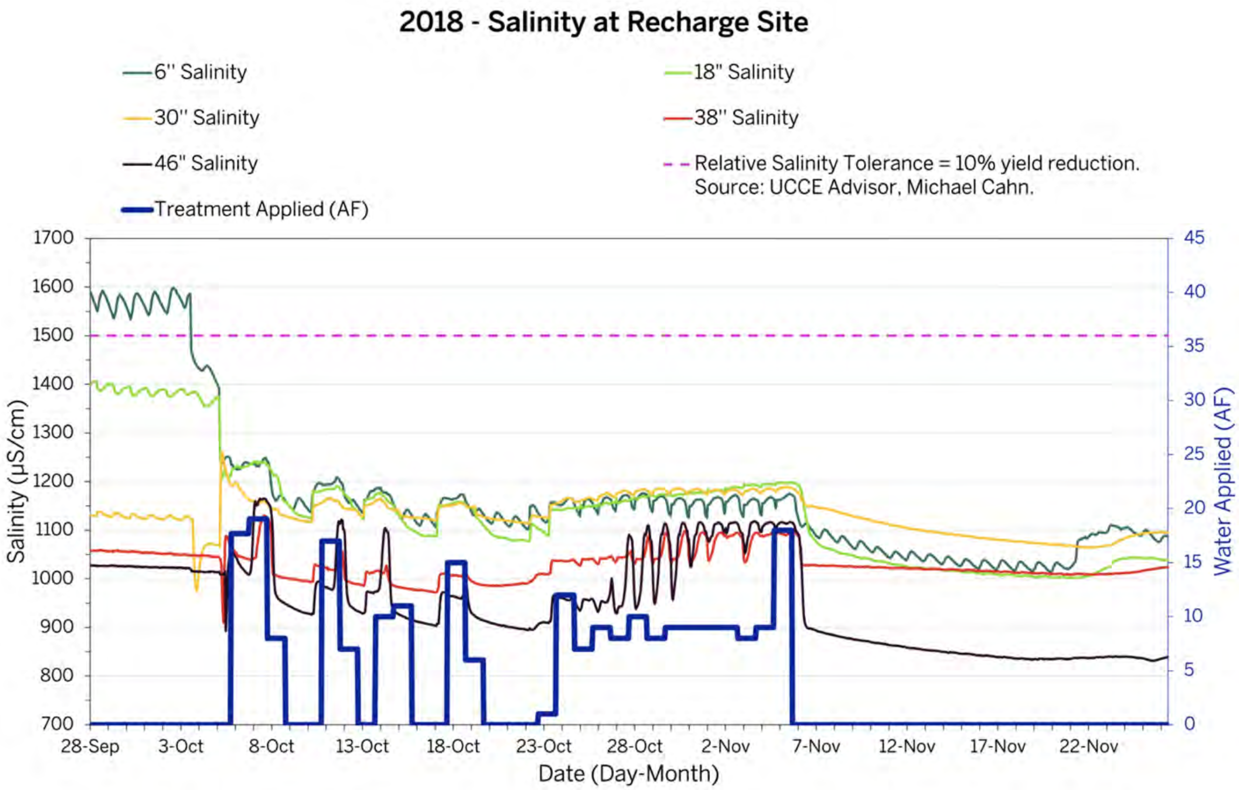
Dates of recharge	Duration (days)	Field size (acres)	Water applied (total acre-feet)	Water applied (feet per acre)	Etc (feet)	Net water recharged (total acre-feet	Net water recharged (feet per acre)
Dec. 9–Dec. 31	23	23	223.47	9.72	0.01	223.15	9.70
Rain							0.49
Total							10.19

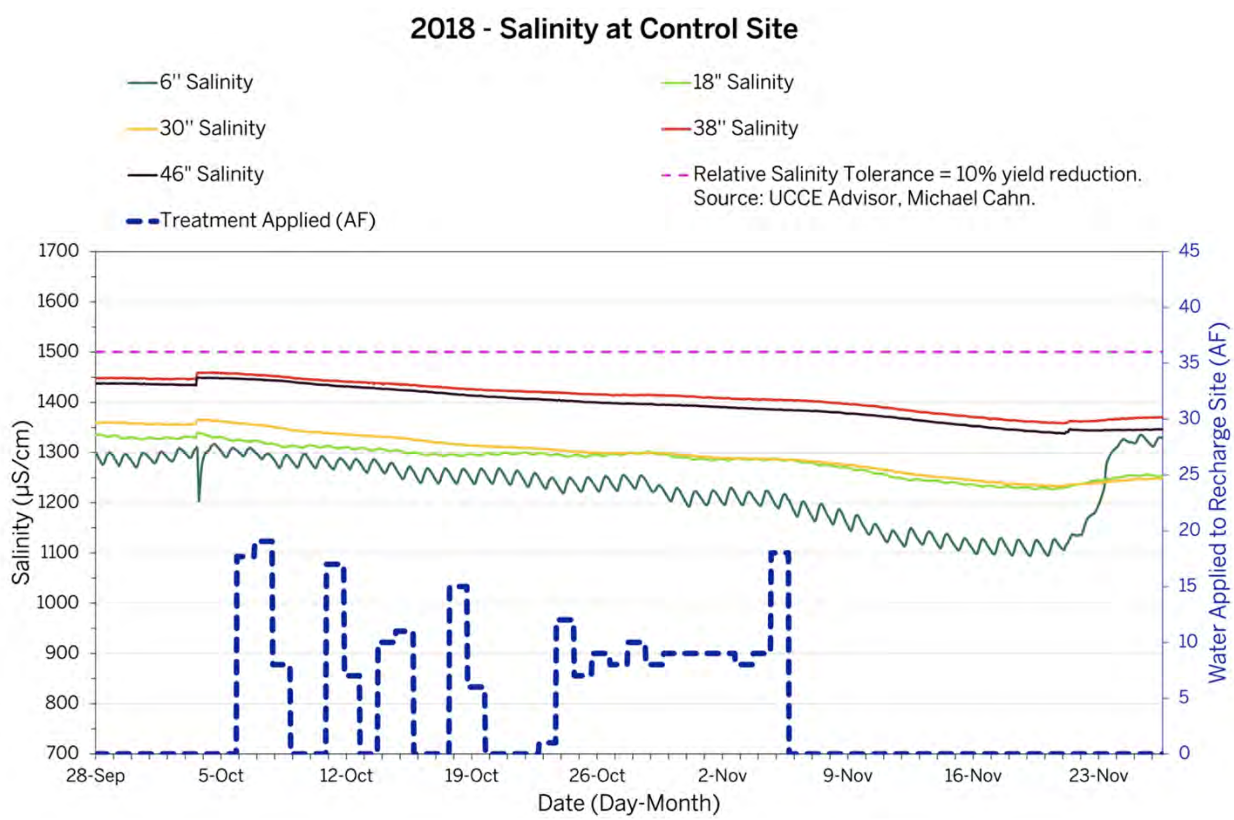
Table notes: Dates of recharge, field size, and water applied sourced from the grower. ETc value sourced from California Irrigation Management Information System station #71C.

Net water recharged = water applied – (1.2 x ETc x acres).

Changes in Field Conditions

Category	2018	2019
Diseases and weeds	The grower did not notice any increase in disease activity over the standard practice of routine powdery mildew and bunch rot prevention sprays that were also used on the control plot.	The grower did not notice any increase in disease activity of powdery mildew and bunch rot in the grapevines.
Yields	The recharged field yielded 2.29 tons per acre. The control field produced no significant difference in yield compared to the recharged field. Year 2018 was an off-year of production. In normal years, production is twice the tonnage per acre.	Not known.
Salinity	In the charts below, see an example of salinity dilution occurring during the application of recharge water within the first 46 inches of soil. Many growers refer to this as an immediate benefit from on-farm recharge to their crop growth and development. Growers throughout the Central Valley have commented on the excess salt buildup in the soil because of drought in California which has been compounded by drip irrigation in reducing yields and quality of crops.	Soil salinity levels were ideal, between 800–1,143 microSiemens per centimeter (µS/cm) in the first 46 inches of soil. These levels were well below the grapevine's tolerance level of 1,500 µS/cm.
Changes to field practices	The grower did not notice any increase in disease activity over the standard practice of routine powdery mildew and bunch rot prevention sprays that were also used on the control plot.	The grower did not notice any increase in disease activity of powdery mildew and bunch rot in the grapevines.


2018 - Salinity at Recharge Site
6" Salinity
18" Salinity
30" Salinity
38" Salinity
46" Salinity
Relative Salinity Tolerance = 10% yield reduction. Source: UCCE Advisor, Michael Cahn.
Treatment Applied (AF)
Salinity (µS/cm)
Water Applied (AF)
Date (Day-Month)
28-Sep
3-Oct
8-Oct
13-Oct
18-Oct
23-Oct
28-Oct
2-Nov
7-Nov
12-Nov
17-Nov
22-Nov


2018 - Salinity at Control Site
6" Salinity
18" Salinity
30" Salinity
38" Salinity
46" Salinity
Relative Salinity Tolerance = 10% yield reduction. Source: UCCE Advisor, Michael Cahn.
Treatment Applied (AF)
Salinity (µS/cm)
Water Applied to Recharge Site (AF)
Date (Day-Month)
28-Sep
5-Oct
12-Oct
19-Oct
26-Oct
2-Nov
9-Nov
16-Nov
23-Nov

Grower’s Experience

Category	Details
Grower observations	Mr. Costa believes his field could receive a lot more water if it is available and if he has continued access to local incentive assistance funding to help offset electrical bills for pumping.
Grower motivations	• Mr. Costa wants to recharge for replenishing overdrafted aquifers in order to meet Sustainable Groundwater Management Act goals. Also, he wants to help ensure the production of agriculture for future generations. • Mr. Costa thinks the immediate benefit of on-farm recharge is reduction in soil salinity, which promotes a healthier plant.

Groundwater Fate

The farm is located near the Mokelumne River, prompting interest in determining if recharged water flowed toward or away from the river. The North San Joaquin Water Conservation District funded a groundwater fate engineering study to understand where recharged water was going. According to their data, all monitoring wells confirmed increases in groundwater levels following the 2018 and 2019 recharge events. In both years, the most significant changes in water levels occurred at wells farther from the river relative to the recharge field indicating that the bulk of the recharge water was moving away from the river. This farm is somewhat unique because the soil is so sandy, but these results counter the commonly held belief that applying water on farms near rivers or streams does not contribute to aquifer recharge.

Position of monitoring well relative to recharge field	Approximate distance to the Mokelumne River	Increase in water levels from 2018 recharge (approximately 3 months after recharge commenced)	Increase in water levels from 2019 recharge (approximately 4 months after recharge commenced)
North of recharge field, away from river	2,600 feet	9.6 feet	1.5 feet
North of recharge field, away from river	2,550 feet	4.8 feet	5.3 feet
West of recharge field, parallel to river	2,160 feet	5.4 feet	4.9 feet
Recharge field	1,750 feet	4.0 feet	4.0 feet
South of recharge field, next to river	500 feet	0.8 feet	0.4 feet

LEFT Photograph: On-farm recharge in mid-January 2022. The water head height is 3–5 inches.

RIGHT Photograph: Jose Luis, the field manager, is standing on the west side of the Costa vineyard where the recharge water is pumped into the field from about 1,500 feet of underground pipe using a lay-flat perforated temporary conveyance pipe, which is connected to risers at the head of the plant line. The field manager handles all of the logistics for successful on-farm recharge without unintended consequences. This picture was taken on January 25, 2023, about two weeks following a flood overflow breach from the Mokelumne River after on-farm recharge efforts in December 2022.

The Mokelumne River is the water supply for the Costa vineyard. But as of early January 2023, all on-farm recharge efforts ceased because of river overflow and flood conditions in Acampo, CA.

For more information: contact Rogell Rogers, Agronomist, Sustainable Conservation, at rrogers@suscon.org or 209-576-7729 x346.

Grower: Arlan Thomas

Crop: Almonds

Location: Chowchilla, Madera County

Project Description

Arlan Thomas is an organic almond grower who was motivated to replenish the overdrafted aquifer below his farm to save his well from drying up and to prevent land subsidence. The organic farm used vegetative cover crops in alternate rows to help increase the water infiltration rate on the orchard floor. This farm has desirable Soil Agricultural Groundwater Banking Index (SAGBI) and Land IQ ratings that prioritized the site for on-farm recharge.

Mr. Thomas was willing to apply higher rates as one of the initial on-farm recharge pilot sites in the San Joaquin Valley because the almond trees were very old and the risk was lower as he planned to remove the almond trees in the near future. Yields were already low as a result of crop age.

This farm was the subject of an in-depth study, *On-Farm Flood Capture and Recharge at an Organic Almond Orchard, Recharge Rates and Soil Profile Responses* by Phil Bachand & Associates, Davis, California, and Tetra Tech, Rancho Cordova, California (April 2017). The information in this case study is largely based on the Bachand/Tetra Tech report, which focuses on salinity, soil moisture, and other aspects of the effects of on-farm recharge on tree crops.

Field Description

Category	Details
Acres	• 13.5 acres high recharge (targeted 2 feet of water per recharge event). • 13.75 acres medium recharge (targeted 1 foot of water per recharge event). • 26.25 acres control (no on-farm recharge).
Type of crop	Organic almonds since 2014.
Age of crop	• Planted 1976 (40 years old at time of recharge). • Well past prime (usually 25–30 years old).
Average rood depth	4–5 feet.
Irrigation infrastructure	Flood infrastructure using district turnouts.
Soil amendment	• Mr. Thomas relied on cow manure compost inputs every other row at 5 tons per acre to fertilize the almond trees (equivalent to 225 pounds per acre of nitrogen). • Mr. Thomas grew cover crops on the plant rows where manure was not applied. He mowed the cover crop to a height of 2 inches and spread the plant residues on the topsoil in the late fall.

Hydrogeology

Category	Details
Soil texture	Loamy sand.
Land IQ rating	• Moderately good. • The grower's field observation experience leads him to think infiltration is very high.
SAGBI rating	Good to excellent.
Restrictive layers	Corcoran clay layer about 180 feet below ground surface
Depth to groundwater	160–170 feet

On-Farm Recharge Logistics

Category	Details
Source of water	Chowchilla Water District (CWD).
Maximum diversion rate	3–6 cubic feet per second.
Method of diversion	CWD canal turnout with gravity flow to the field.
Cost of water	CWD delivered surface water at $118 per acre-foot to customers who were able and willing to participate in on-farm recharge.
Field preparation and management during recharge	• Before recharging, the grower mowed the cover crop to approximately 4–5 inches. • Trees are planted on raised plant lines, so no further preparation was needed to manage water in the field.
Nutrient management	No additional fertilizer inputs were made in-season besides the manure compost prior to the dormant season.
Average inundation height	3–4 inches.
Duration of inundation	• The fields were inundated for two days, then rotated back through the field for additional water applications. • Actual infiltration of water applied was within 24 hours.
Time to dry down	3–4 days.

Recharge Events

High Recharge Site

Dates of recharge (2016)	Duration (days)	Field size (acres)	Water applied (total acre-feet)	Water applied (feet per acre)	ETc (feet)	Net water recharge (total acre-feet	Net water recharge (feet per acre)
June 4–June 13	10	13.5	92.9	6.88	1.76	64.39	4.77
June 28–July 3	6	13.5	92.9	6.88	1.76	64.39	4.77
July 20–July 26	7	13.5	92.9	6.88	1.76	64.39	4.77

Table notes: Dates of recharge, field size, and water applied sourced from grower. Crop evapotranspiration (ETc) value sourced from California Irrigation Management Information System station #71C.
Net water recharged = water applied – (1.2 x ETc x acres).

Medium Recharge Site

Dates of Recharge (2016)	Duration (days)	Field size (acres)	Water applied (total acre-feet)	Water applied (feet per acre)	ETc (feet)	Net water recharge (total acre-feet	Net water recharge (feet per acre)
June 1–June4	4	13.75	42.25	3.07	1.76	13.21	0.96
June 25–June28	4	13.75	42.25	3.07	1.76	13.21	0.96
July 18–July 20	4	13.75	42.25	3.07	1.76	13.21	0.96

Table notes: Dates of recharge, field size, and water applied sourced from the grower. ETc value sourced from California Irrigation Management Information System station #71C.
Net water recharged = water applied – (1.2 x ETc x acres).

Control Site (Irrigation)

Dates of Recharge (2016)	Duration (days)	Field size (acres)	Water applied (total acre-feet)	Water applied (feet per acre)	ETc (feet)	Net water recharge (total acre-feet	Net water recharge (feet per acre)
May 13–June 16	4	26.25	43.19	1.65	1.75	-11.94	-0.45
June 23–June 25	3	26.25	43.19	1.65	1.75	-11.94	-0.45
July 18	1	26.25	43.19	1.65	1.75	-11.94	-0.45

Table notes: Dates of recharge, field size and water applied sourced from the grower. ETc value sourced from California Irrigation Management Information System station #71C.
Net water recharged = water applied – (1.2 x ETc x acres).

Changes in Field Conditions

Category	Details
Diseases and weeds	No evidence of disease was found.
Yields	Yields were approximately 1,500–1,600 pounds per acre in 2010. Six years later, yield was down to a low of 400–600 pounds per acre in 2016. The grower expected the decline in yield because the crop was 40 years old at the time of this recharge event and well past its prime growing years.
Salinity	For information on salinity dilution impacts resulting from recharge, see the Bachand report.
Changes to field practices	None.

The following information on tree fall is sourced directly from the Bachand report, Table 5: Tree Fall Observations, June 22, 2016.

Treatment	Number of Trees down	Area (acres)	Number of Trees down per acre
Control	5	26.25	0.2
Medium	5	13.75	0.4
High	8	13.5	0.6
Total	18	53.5	0.3

Note: According to the grower, the number of trees felled is normal for this orchard. Differences between treatments are within the range of variability that he has observed in the past, with trees less healthy on the west side (high treatment) than on the east side (control treatment) of the orchard.

Grower's Experience

Category	Details
Grower observations	The grower was surprised at how easy it was to apply a large amount of water to recharge. He would not be surprised if 10–15 feet of water can be recharged on the same field.
Grower motivations	Mr. Thomas wants to promote the future of recharge collaboration for the benefit of the farm community. He thinks that all growers should get involved in on-farm recharge for the benefit of the community.
Monitoring systems	For information on various monitoring methods to measure effects of recharge, see the Bachand report.

For more information: contact Rogell Rogers, Agronomist, Sustainable Conservation, at rrogers@suscon.org or 209-576-7729 x346.

Sustainable Conservation

On-farm Recharge Pilot Projects
Case Study

Grower: Russel and Matt Efird

Crop: Raisin grapes

Location: Fresno County

Project Description

Russel and Matt Efird grow raisins, almonds, walnuts, pistachios, and canning peaches in Fresno County, California. Groundwater levels on their farm have decreased 50 feet from 1992 through 2022. On-farm recharge can help to reverse groundwater overdrafting and cease land subsidence occurring in the subbasin.

This farm can be a good measure of raisin grape tolerance to recharge timing and how much flood water can be applied without increased fungal disease, such as bunch rot, compared to the growers' standard practice. One of the most commonly asked questions about on-farm recharge is, "How much water can be applied and when should recharge be ceased to protect crop health?" Research continues to determine basic recharge guidelines on the timing of and how much recharge water is optimum for a given crop and soil type.

Field Description

Category	Details
Acres (recharge site)	12 acres
Acres (control site)	13 acres
Type of crop	Fiesta raisin grapes
Age of crop	Planted in 1993 (25 years old at time of recharge)
Average root depth	7–8 feet
Irrigation infrastructure	• The vineyard was irrigated by flood valves, double drip lines, and micro sprinklers. • Drip or micro sprinklers were the standard irrigation during the irrigation season. • The flood system was used to conduct on-farm recharge.
Soil amendment	Dairy compost was incorporated into every other row (6 tons/acre) in the late fall after the growing season.

Hydrogeology

Category	Details
Soil texture	Sandy Loam
Land IQ rating	Moderately Good to Excellent
Soil Agricultural Groundwater Banking Index rating	Good
Restrictive layers	• Both the recharge field and the control field were deeply ripped prior to planting in 1993. • Every other row was chiseled (14–16 inches depth) in 2014 for one row and in 2016 for the other row.
Depth to groundwater	• 1992: 100 feet • 2009: 120 feet • 2018: 142 feet • 2022: 150 feet

On-Farm Recharge Logistics

Category	Details
Source of water	Kings River water was delivered from Consolidated Irrigation District (CID) canal system.
Maximum diversion rate	Turnouts have a capacity of 1,012 cubic feet per second.
Method of diversion	Gravity-fed district water canal turnout at the farm.
Cost of water	The CID charges growers an annual $50 per acre surface water delivery fee. No additional fee was charged to growers who elected to divert water for on-farm recharge during this time.
Field preparation and management during recharge	The field was already set up for flood irrigation. The only preparation needed was placement of some strategic berms.
Nutrient management	The Efirds applied recharge water only on rows where the manure compost was not applied in order to avoid nutrient leaching.
Average inundation height	5 inches
Duration of inundation	Less than four hours

Category	Details
Time to dry down	After turning the water off, the field required a dry time of one day to be able to walk on firm ground without muddy conditions. In order to minimize soil compaction, tractor work started 10 to 14 days after shutting off water.

Recharge Events

Recharge Site

Dates of recharge (2018)	Duration (days)	Field size (acres)	Water applied (total acre-feet)	Water applied (feet per acre)	ETc (feet)	Net water recharged (total acre-feet	Net water recharged (feet per acre)
April 28–May 5	6	12	25.84	2.15	0.12	24.11	2.01
May 6–May 9	4	12	25.84	2.15	0.12	24.11	2.01

Table notes: Dates of recharge, field size, and water applied sourced from the grower. Crop evapotranspiration (ETc) value sourced from California Irrigation Management Information System station #71C.
Net water recharged = water applied – (1.2 x ETc x acres).

Control Site (Irrigation Only)

Dates of recharge (2018)	Duration (days)	Field size (acres)	Water applied (total acre-feet)	Water applied (feet per acre)	ETc (feet)	Net water recharged (total acre-feet	Net water recharged (feet per acre)
May 4–May 5	2	13	5.19	0.40	0.02	4.88	0.38

Table notes: Dates of recharge, field size and water applied sourced from the grower. Crop evapotranspiration (ETc) value sourced from California Irrigation Management Information System station #71C.
Net water recharged = water applied – (1.2 x ETc x acres).

Changes in Field Conditions

Category	Details
Diseases and weeds	• Some limited bunch rot in the control field and the treated field was seen by the growers. Powdery mildew and bunch rot are typical occurrences of leaf, stem, and fruit disease. Aerial fungicide applications are routinely included in cultural practices, according to the growers, who also notes that it is typical to see bunch rot in areas closer to irrigation valves. Although the Efirds were concerned about promoting powdery mildew under flood conditions, they could not confirm additional mildew resulted from recharging. • The growers think they needed more weed control spray across the treated field and the untreated field. They said they cannot determine if the need was because of the flooding, which would take several replications of recharge at this farm site.
Yields	Both the recharge field and the control field yielded 3.29 tons of raisin grapes per acre.
Salinity	Salinity levels in the recharge area and the control area were generally lower than the soil salinity threshold level (1,500 miliSeimens per centimeter or mS/cm) that can cause growth reduction and yield problems. The salinity levels were monitored from 2 inches to 46 inches of soil depth.
Changes to field practices	The Efirds noted that they needed one more fungicide application and one extra herbicide application before harvest, and more labor hours were required. But they also said that this should be expected when extra water is applied to fields.

Growers' Experience

Category	Details
Grower observations	• In the future, the growers are reluctant to put on extra water after March and would instead focus on recharging when vines are dormant. This is due to potential disease issues that could adversely affect yield and quality. • The Efirds saw that the Fiesta raisin variety has heavier foliage than others, which could potentially make it more susceptible to Bunch Rot because of higher canopy humidity. However, the growers also noted that the raisins were rained on multiple times close to harvest, which may have also contributed to Bunch Rot. • The Efirds think that many growers will focus on the benefits of using surface water for on-farm recharge in order to help reduce the build-up of salts in the field and groundwater.
Grower motivations	• The growers believe that recharge is beneficial for replenishing groundwater but want to see more support from state and federal agencies for individual growers doing on-farm recharge. • On-farm recharge can help replenish several wells on their property that are used for pumping groundwater.

For more information: contact Rogell Rogers, Agronomist, Sustainable Conservation, at rrogers@suscon.org or 209-576-7729 x346.

On-farm Recharge Pilot
Projects Case Study

Grower: Don Cameron, Terranova Ranch

Crop: Almonds

Location: Helm, Fresno County

Project Description

This case study site is a great example of how on-farm recharge on young almond trees during the first years of production on suitable soils can be implemented without affecting yield and crop health. Don Cameron, general manager of Terranova Ranches Inc., had a goal in 2011 to determine how much water can be applied as on-farm recharge without crop damage or yield losses. He decided to start on very small plots of transitional fallow land. In 2017, the ranch expanded recharge efforts to a young almond orchard. Recharge occurred in this orchard for more than two weeks in spring 2017. The almond trees have been growing vigorously since then without any adverse effects on production yields. In 2023, the ranch reported the 10-year-old almond orchard as being a superior producer in yield and quality, averaging more than 2,000 pounds per acre.

Field Description

Category	Details
Acres	76
Type of crop	Almonds (25% Monterey scion, 25% Woody colony scion, 50% Nonpareil scion on the Rootstock Nemaguard).
Age of crop	Planted 2013 (4 years old at time of recharge in 2017).
Average root depth	3–4 feet deep.
Irrigation infrastructure	• Drip irrigation system and original flood irrigation infrastructure was in place. • On-farm recharge water was pumped from district canals, using flow metered pipe, into the field.
Soil amendment	Pre-season poultry compost was applied in the fall and incorporated into the soil in years not receiving floodwater.

Hydrogeology

Category	Details
Soil texture	• Loamy sand on field. • Infiltration rate is about 2.5–3 inches per day.
Land IQ rating	Moderately poor (north field is sandier).
SAGBI rating	Moderately poor.
Restrictive layers	N/A.
Depth to groundwater	230–250 feet below ground surface.

On-Farm Recharge Logistics

Category	Details
Source of water	Liberty Mill Race Ditch Company.
Maximum diversion rate	4–5 cubic feet per second.
Method of diversion	Pumped from Kings River North Fork into Terranova's on-farm canal ditch.
Cost of water	$4 per acre-foot for flood water.
Field preparation and management during recharge	Place berms intermittently in the field every 5–10 rows until entire length of row is inundated up to 12 inches at the end of row, then breach the berm to allow the flood flow to the next 5–10 rows.
Nutrient management	• In order to avoid aggressive spring fertilizer application being delayed by flood conditions, the grower used a fall liquid application of UN 32 at 80–85 pounds per acre of nitrogen through the drip irrigation system at the end of year 2, prior to tree dormancy. • The grower followed his normal nitrogen management plan by applying sequential applications of 30–35 pounds of nitrogen per acre via drip tape from March through June.
Average inundation height	12 inches of water depth.
Duration of inundation	The field was inundated for approximately 1–2 weeks.
Time to dry down	3–4 days after turning off water.

Recharge Events

Dates of recharge (2017)	Duration (days)	Field size (acres)	Water applied (total acre-feet)	Water applied (feet per acre)	ETc (feet)	Net water recharged (total acre-feet	Net water recharged (feet per acre)
April 2–April 15	15	76	52.96	0.70	0.09	44.75	0.59
May 28–June 17	21	76	98.78	1.30	0.21	79.63	1.05
Total			**151.74**	**2.00**	**0.30**	**124.38**	**1.64**

Table notes: Dates of recharge, field size, and water applied sourced from grower. Crop evapotranspiration (ETc) value sourced from California Irrigation Management Information System station #71C.
Net water recharged = water applied – (1.2 x ETc x acres).

Changes in Field Conditions

Category	Details
Diseases and weeds	No abnormal disease occurrence was noticed by the grower during or after on-farm recharge.
Yields	Almond yields for the recharge field were 2,296 pounds per acre of almond nuts compared to 2,094 pounds per acre of almond nuts for a control plot.
Salinity	No data
Changes to field practices	None.

Grower's Experience

Category	Details
Grower observations	• Mr. Cameron notes that it is important for growers who are planning to plant a new almond orchard to select rootstocks and scions that have low susceptibility to fungal diseases such as *phytophthora* ssp. • Mr. Cameron believes that the oxygen content in saturated soils is related to the water temperature. The warmer the water, the less oxygen that is contained, and the sooner there may be problems with ponding water in fields. He stopped recharging when the water and air temperature became too hot (90 degrees) for the trees and vines to survive. • Being able to move water through the soil quickly is an advantage. Mr. Cameron believes that not all soils are capable of recharging groundwater, and that growers should stick to the lighter, sandier soils.
Grower motivations	• Mr. Cameron is interested in replenishing overdrafted aquifers under his land in compliance with the Sustainable Groundwater Management Act. Also, he wants to prove that on-farm recharge is more cost-effective than irrigation district recharge basin efforts and that collective grower-led on-farm recharge can be more effective at achieving aquifer recharge. • Mr. Cameron believes that it is important to document practical lessons learned to complement scientific research. He encourages more growers to participate in the Kings River basin groundwater recharge efforts to improve the knowledge of field characteristics for recharge suitability.

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On-farm Recharge Pilot
Projects Case Study

Grower: Don Cameron, Terranova Ranch

Crop: Wine Grapes

Location: Helm, Fresno County

Project Description

This case study site provided the opportunity to test on-farm recharge on wine grapes planted in moderately poor soil and subsurface conditions as rated by Soil agricultural Groundwater Banking Index (SAGBI) and the Land IQ soil suitability index. It also demonstrated the feasibility of applying recharge water during the wine grapes growing season, thereby increasing the total possible volume of annual on-farm recharge when excess surface water is not available until springtime, as occurred in 2017 and 2023.

The farm began experimenting with on-farm recharge in 2011. This was one of the pioneering recharge test plots to begin establishing guidelines for on-farm recharge in the San Joaquin Valley. In 2016, Mr. Cameron added his perennial crops such as almonds, olives, pistachios, grapes, and walnuts to the targeted list of crops for on-farm recharge.

Field Description

Category	Details
Acres	77.5 acres
Type of crop	Ruby red wine grapes.
Age of crop	Planted in 1998.
Average root depth	6–7 feet.
Irrigation infrastructure	• Flood with single check at end of plant row and intermittent berms between plant lines as needed. • Flow meters at turnouts.
Soil amendment	Periodic gypsum applications and light soil tillage done based on need.

Hydrogeology

Category	Details
Soil texture	Sandy-silt loam.
Land IQ rating	• Moderately poor. • Grower did not agree with the rating. He believes the soil has a higher rating because of long-term application of soil amendments which will increase infiltration over time.
SAGBI rating	Moderately poor.
Restrictive layers	N/A
Depth to groundwater	Unknown.

On-Farm Recharge Logistics

Category	Details
Source of water	Liberty Mill Race Ditch Company
Maximum diversion rate	4–5 cubic feet per second.
Method of diversion	Pumped into the Terranova canal ditch from the 4-gate turnout at the Kings River North Fork.
Cost of water	$4 per acre-foot of surface water.
Field preparation and management during recharge	Berm the field every 10 rows at a time until the entire field is inundated 8–12 inches. This resulted in an enclosure that was about 100 feet wide and 0.25 mile long.
Nutrient management	The grower applies nitrogen (UN 32) in the fall prior to dormancy to promote higher nitrogen carryover into the spring. This enables him to avoid the need for initial fertilizer applications (or allow for lower inputs) in anticipation of potential recharge opportunities that typically occur in the spring in the Tulare Basin.
Average inundation height	6–8 inches.
Duration of inundation	Duration of flood condition was approximately 1 week.
Time to dry down	7–10 days

Recharge Events

Dates of recharge (2017)	Duration (days)	Field size (acres)	Water applied (total acre-feet)	Water applied (feet per acre)	ETc (feet)	Net water recharged (total acre-feet	Net water recharged (feet per acre)
March 30–April 8	10	77.5	92.4	1.19	0.05	87.75	1.13

Table notes: Dates of recharge, field size, and water applied sourced from grower. Crop evapotranspiration (ETc) value sourced from California Irrigation Management Information System station #71C.
Net water recharged = water applied -)1.2 x ETc x acres).

Changes in Field Conditions

Category	Details
Diseases and weeds	The grower made an aerial fungicide prevention application on the grapes because of his concerns of contracting bunch rot from the extra moisture. The grower was also concerned about latent Fusarium root rot because of the flooded conditions. After the fungicide application, no disease was seen.
Yields	10.31 tons per acre.
Salinity	The grower said the on-farm recharge helps dilute the salinity in the soil profile. The plants appear to respond with vigorous growth during the spring
Changes to field practices	The grower delayed in-season applications of fertilizer because of on-farm recharge or intentional flooded conditions. Some fertilizer was applied just prior to dormancy in anticipation of springtime recharge and to avoid the need for an aggressive fertilizer program during the growing season while conducting recharge events.

Grower's Experience

Category	Details
Grower observations	• The grower believes that the oxygen content in saturated soils is related to the water temperature. The warmer the water, the less oxygen that is contained, and the sooner there may be problems with ponding water in fields. He stopped recharging when the water and air temperature became too hot (90 degrees) for the trees and vines to survive. • Being able to move water through the soil quickly is an advantage. Mr. Cameron believes that not all soils are capable of recharging groundwater, and that growers should restrict on-farm recharge to the lighter, sandier soils.
Grower motivations	• Mr. Cameron is interested in replenishing overdrafted aquifers under his land in compliance with Sustainable Groundwater Management Act. He also wants to prove that on-farm recharge is more cost-effective than irrigation district recharge basin efforts and that on-farm recharge can be more effective at achieving aquifer recharge. • Mr. Cameron believes that it is important to document practical lessons learned to complement scientific research. He encourages more growers to participate in the Kings River basin groundwater recharge efforts in order to improve the knowledge of field characteristics for recharge suitability.

Year 2023 On-Farm Recharge Photographs

Above photo note: Mr. Cameron started recharging this field in late-March 2023 and has included it in his goal to recharge 30,000 acre-feet at Terranova Ranch. Ruby red wine grapes seen here on April 21, 2023.

Above photo note: Ruby red wine grapes on-farm recharge in mid-April 2023 with a 3-foot berm on the outer perimeter of the orchard to ensure water stays in the targeted field. The water has a head height of approximately 1 foot.

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On-farm Recharge Pilot Projects Case Study

Grower: Don Cameron, Terranova Ranch

Crop: On-Farm Recharge Basin System

Location: Helm, Fresno County

Project Description

Don Cameron, general manager of Terranova Ranch Inc., has been planning and building an on-farm recharge basin storage system for more than five years. Despite the long planning and construction phase, he is beginning to see promising results because of the massive amounts of rainfall and snowmelt in 2023 that have sparked a flooding emergency in the area.

The system comprises three on-farm recharge basins, each having a capacity of 50–60 acre-feet of water storage. These basins are unlined, which allow them to function as recharge basins while also serving as storage sites from which to convey on-farm recharge water to surrounding fields. He is offering the stored basin water to his farm neighbors at cost. Mr. Cameron spoke of his desire to divert enough water during high rainfall years such as 2023 to recharge Terranova Ranch and neighboring farms in the Kings subbasin. His goal in 2023 is to recharge 30,000 acre-feet, which he thinks he will reach.

The following pictures were taken during a recent tour of Terranova Ranch in April 2023. They document the water infrastructure work involved in the construction of this unique on-farm recharge basin system. Operations require considerable work in the field to strategically coordinate water conveyance across the farm. Staff required training in the coordination of opening and closing valves and gates as water pumps were turned on and off. Mr. Cameron spoke about the many adjustments for labor required for this system, and he stated, “The rewards are worth it.”

Pump used to divert water from the Kings River at peak flow levels. Maximum pump capacity of 12.5 acre-feet per hour (151 cubic feet per second).

Two of three on-farm recharge unlined recharge basins, each with storage capacity of 50–60 acre-feet. Mr. Cameron has observed a significant increase in shorebird activity in and around the recharge basins.

Water in an unlined canal conveyance system with pistachios orchards on either side.

The diversion point of water on the Kings River North Fork canal into the Terranova Ranch.

Four turnout gates on the Kings River diverting water into the Terranova Ranch canal system.

Mr. Cameron, using his computer telemetry to control the height of the turnout flood gates.

Pumping water from internal canal into a pistachio orchard through an intricate conveyance system.

Water metered and pumped from internal canal into a pistachio orchard.

Water is being pumped using diesel power take-off (PTO) motors from the basins into the pistachio orchards and wine-grape vineyards using thousands of feet of pipe across the entire ranch to convey water to different plantings for on-farm recharge.

Long length of pipe used to convey water from internal unlined canal ditches with water pumps into a pistachio orchard.

On-farm recharge in pistachio orchard (April 26, 2023) showing complete spring leaf out and trees already in full bloom.

Recharge on this pistachio orchard is the result of a well-planned and well-constructed farm infrastructure for an on-farm basin storage and water conveyance delivery system.