INTRODUCTION TO GROUNDWATER RECHARGE

California Almonds
Almond Board of California

Sustainable Conservation

TABLE OF CONTENTS

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Key Terms

- **Recharge methods:** Different techniques employed for conducting and enhancing recharge
- **Recharge duration:** Amount of time for each water application and dry down period based on volume applied and seasonal timing
- **Infiltration:** Downward entry of surface water into the soil
- **Percolation:** Movement of water through the soil by gravity and capillary forces
- **Groundwater recharge:** The practice of applying excess surface water for recharge during acceptable periods is a key method of addressing overdraft.
- **Groundwater banking:** Groundwater banks consist of water that is "banked," often during wet or above normal water years, but also when excess water is available from reservoirs. The water to be banked is provided by the entity that will receive the water in times of need.

Abbreviation Key

ABC – Almond Board of California

DWR – California Department of Water Resources

Flood-MAR – Flood Managed Aquifer Recharge

GRAT – Groundwater Recharge Assessment Tool

GSA – Groundwater Sustainability Agencies

GSP – Groundwater Sustainability Plans

Districts – Irrigation and other water districts

NRCS – Natural Resources Conservation Service

OFR – On-farm recharge

SAGBI – Soil Agricultural Groundwater Banking Index

SGMA – Sustainable Groundwater Management Act

WAFR – Water Available for Recharge

INTRODUCTION

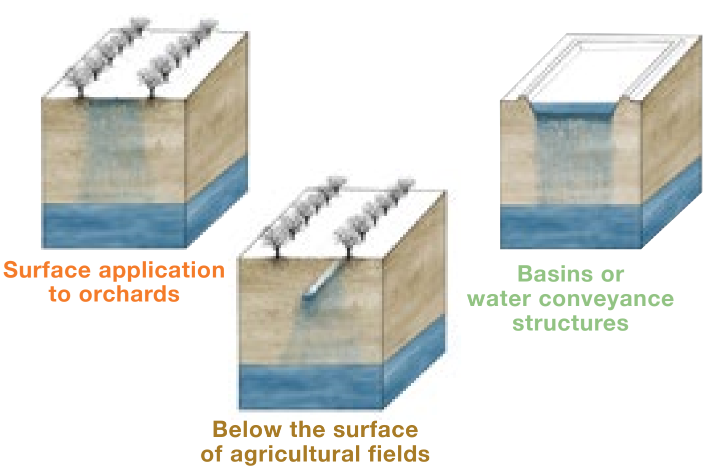
The Central Valley is one of the most productive agricultural regions in the United States. Growers and communities, however, are faced with a future of declining groundwater quality, quantity, and availability during drought, due to overdraft. In areas where soil conditions are suitable and excess water is available, ground water recharge represents one of the most cost-effective methods to increase storage, thereby ensuring water supply and improving water quality. Through this guide, California almond growers can begin evaluating their options for addressing local sub-basin overdraft through recharge, helping secure reliable, sufficient, and drought resilient groundwater supplies.

DETERMINING WHETHER RECHARGE IS AN OPTION

Key questions to ask when considering whether your orchard is suitable for groundwater recharge:

1. Do I have access to surface water for recharge?
2. Is my orchard soil suitable for recharge?
3. What recharge methods are available?
4. What orchard management changes are necessary to perform recharge?

RECHARGE METHODS COVERED IN THIS GUIDE



BACKGROUND AND PURPOSE

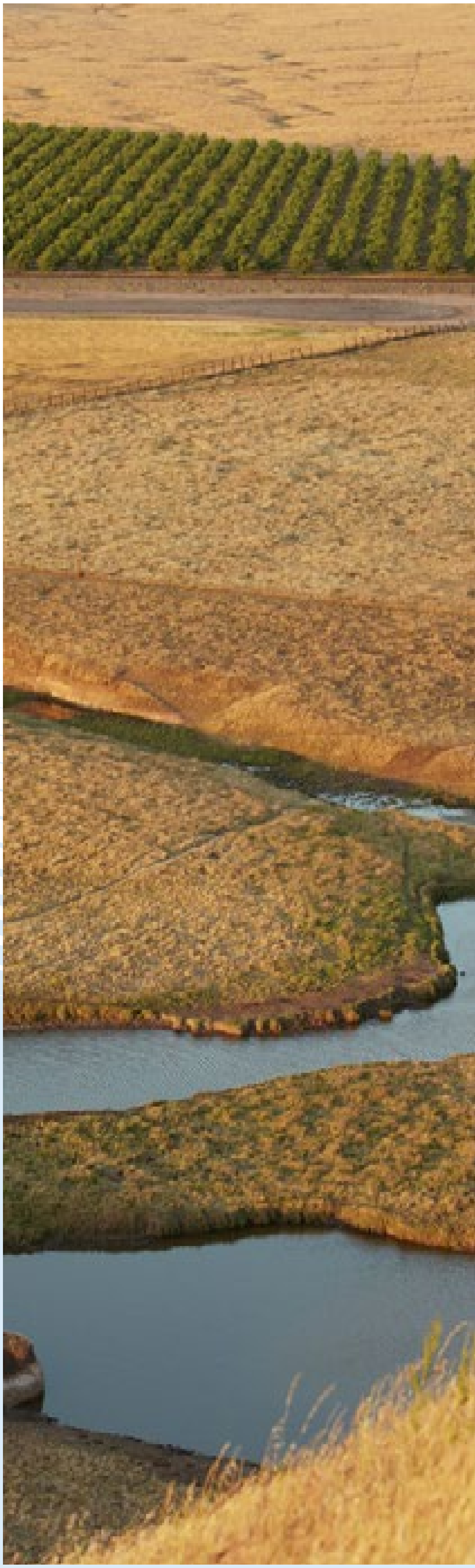
Sustainable groundwater supplies are critically important to the future of growing almonds in California. Under the Sustainable Groundwater Management Act (SGMA), Groundwater Sustainability Agencies (GSA) in high and medium priority basins are charged with addressing overdraft and bringing groundwater basins into balance through management within 20 years of adopting their Groundwater Sustainability Plan (GSP). Without new supply-side mitigation such as groundwater recharge, SGMA implementation is projected to lead to demand-side fallowing of between 750,000 and 1 million acres of irrigated cropland, including almond orchards.[1, 2]

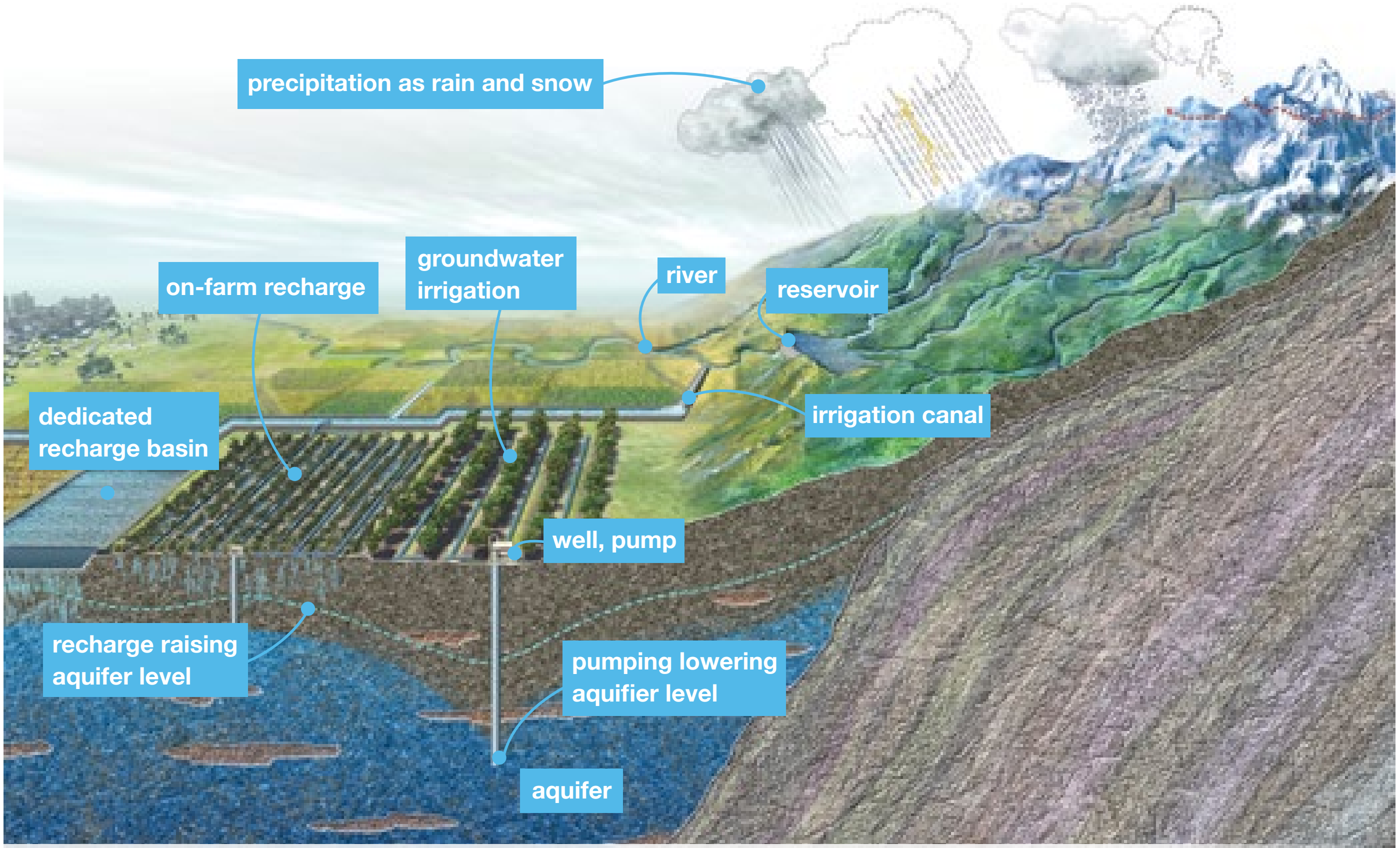
Maintaining agricultural water supplies and addressing overdraft in California's highly variable Mediterranean climate requires maximizing capture and use of the atmospheric rivers that deliver most of the state's water supply during short periods of extreme rain, at times exceeding surface reservoir capacities. Using groundwater recharge to direct excess flows underground has been shown to be more economical than other storage methods,[3] thereby mitigating overdraft, replenishing aquifers for water supplies and supporting SGMA implementation. Other benefits of recharge include decreased pumping costs, flushing salts from the root zone, and mitigating subsidence. Maximizing recharge, however, is limited by multiple challenges: identifying and conveying surface water supplies to recharge locations, economic costs, soil and crop limitations, aquifer characteristics, and regulatory hurdles such as securing water rights, permitting projects, and water quality regulations.

This guide will help California almond growers evaluate their options for conducting groundwater recharge, by describing the factors to consider and the primary recharge methods available. The information provided in this guide is based on a combination of current scientific knowledge and growers' experiences. Groundwater recharge, including on-farm recharge (OFR) in almond orchards, is still in a learning phase. Nevertheless, it is a pro-active method that growers can adopt, helping aquifer levels stabilize or even begin to recover, supporting the long-term viability of almond farming in the Central Valley of California.

Research funded by the Almond Board of California (ABC) has focused on establishing the safety and efficiency of conducting OFR during the dormant season, which provides a better safety margin for plant health, and reduced environmental impacts. However, there are a range of recharge methods available that take advantage of floods and water available at other times of the year when reservoirs can make releases. Additional methods covered in this guide are sub-surface application using tile drains and dedicated recharge basins.

With each recharge method, there are management considerations growers should consider, which when combined with estimated frequency of available recharge water, can inform the analysis of the costs and benefits of different recharge options.[4] Ultimately a combination of methods may be the best local solution for groundwater basins that rely on recharge to reach sustainability. All methods require coordination beyond individual farms to secure recharge water, get credit for water applied, and ensure grower actions are accounted for in ongoing efforts to address SGMA requirements.





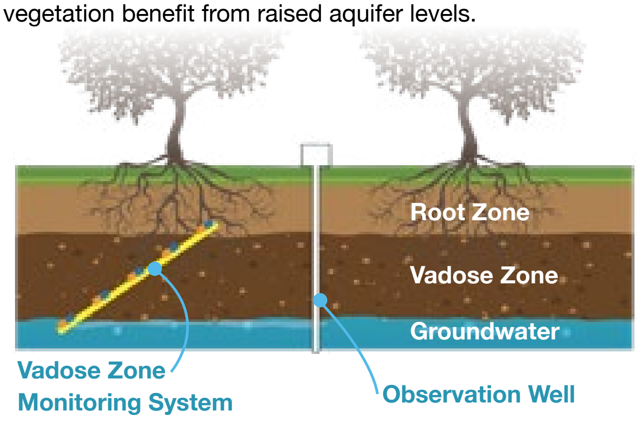
Overview of Groundwater Recharge in Agricultural Land. Illustration from Sayo-Art LLC, by Sustainable Conservation

HOW GROUNDWATER RECHARGE WORKS

Groundwater recharge occurs when water infiltrates into the ground and replenishes underground aquifers. Some recharge happens naturally from rainfall and as leakage from rivers. In agriculture, additional recharge occurs through irrigation of crops and water conveyance in unlined canals. Intentional or managed aquifer recharge is performed by managing the rate and placement of water to maximize recharge, based on knowledge of infiltration rates and environmental limitations. In-lieu recharge provides surplus surface water to historical groundwater users, thereby leaving groundwater in storage for later use.

The vadose zone — which extends from the soil's surface to the groundwater table or saturated zone — controls water movement and affects recharge rates. Sandy loam, loamy sand, and sandy soil textures are generally preferred for recharge due to higher infiltration rates compared to silt and clay. Unique layers in the subsurface such as heavier soils and clay layers (e.g., Corcoran clay) affect the time and place where the recharge water will arrive at the groundwater table. Recharge can also be directed underneath heavier surface soils to more permeable subsurface layers. Due to this variability in subsurface soil and sediment texture, it is important to understand the hydrologic characterization of soils and depth to groundwater before initiating recharge.

Recharge can be a part of multi-benefit projects, that through surface water application increase aquifer health, thereby improving drinking water supplies. Migratory birds can also use fields flooded for recharge, while groundwater dependent ecosystems such as wetlands and stream vegetation benefit from raised aquifer levels.



ABC ENGAGEMENT AND RESEARCH

Following the driest four consecutive years of statewide precipitation in the historical record (2012-2015), and the associated passage of SGMA, ABC began funding groundwater recharge research. Researchers Helen Dahlke, Ken Shackel, and Astrid Volder of the University of California (UC), Davis, along with Roger Duncan and David Doll of UC Cooperative Extension, and Peter Nico of Lawrence Berkeley National Lab analyzed the impacts of OFR on almond orchard health and the movement of water beneath the soil subsurface.

During the 2015-2016 winter, OFR experiments were initiated on two almond orchards located in the San Joaquin Valley near Modesto and Delhi. In 2016-2017, a third field in the Sacramento Valley in Orland, which had heavier soil, was added to the study. The field study measured the amount of water applied and infiltrated at all three sites. In Modesto and Delhi, researchers looked at the effect of recharge on the tree root system, in addition to orchard health and yield.

In multiple flood irrigation events in December and January, the Modesto and Delhi sites received a total of 24 inches of winter water runoff captured for groundwater recharge. At the Modesto site, where the orchard was flooded weekly for four consecutive weeks, the loamy soils remained saturated for up to 48 hours after each water application. In contrast, the much sandier soils at the Delhi site returned to pre-flooding conditions within 12 hours of each water application.

At the Orland site, seven recharge events were conducted but only 4.8 inches of water could be effectively applied. This was due to particularly rainy and wet conditions that year, along with low soil hydraulic conductivity and soil infiltration capacity, keeping soil water content near field capacity.

Results showed that more than 90% of the water applied to Delhi's sandy soil and greater than 80% of the water applied to Modesto's sandy loam soil percolated past the root zone, with no measured adverse effects on tree water status, canopy development, and yield. Groundwater recharge did not negatively affect new root production and tended to extend root lifespan.[5] Based on these results, researchers concluded that applying additional water during dormancy is not likely to have negative impacts on almond orchards in moderately-to-well-drained soils.

While research has shown that recharge can be done under these conditions in almond orchards, management changes (e.g., fertilizer and disease management) may be necessary to implement OFR safely and effectively.

Similar research on crop health has not been done for the other two recharge methods covered in this report but given the separation between the recharge area (underground or in a separate basin) and the orchard, there are not the same potential tree health concerns.

IS RECHARGE A GOOD FIT FOR MY OPERATION?

Though recharge programs are in the early stages of development, almond producers can participate and contribute to the protection and restoration of sustainable groundwater supplies and address overdraft. To determine whether a recharge project is a potential fit for a given operation and if so which method, growers should begin by answering the four questions outlined here. Producers can ensure recharge programs are in place at their local GSA and water agencies and directly participate through On-Farm Recharge, subsurface recharge systems or basins. As growers evaluate their property's potential as a recharge site, they must engage with their local Groundwater Sustainabilty Agency (GSA) and District, to coordinate and support efforts to maximize recharge. These agencies can further help growers determine whether and what type of recharge project makes sense on a specific property.

A strong recharge program includes a combination of practices, ranging from dedicated basins to OFR to more innovative practices that are locally developed. Soil types and water availability are key characteristics to consider, both to maximize the volume recharged and protect or even improve water quality. Different recharge methods will also have different considerations for what management changes will be required.

Although there are many examples to follow, there are many hurdles to overcome to maximize recharge, including policy challenges. Solutions will include streamlining the permitting of recharge projects where necessary and securing of water rights. GSAs will also need to develop incentives for recharge at the local level.

The role of scientific research and on the ground partnerships with growers is critical for improving understanding of how to perform recharge cost-effectively and sustainably, while at the same time maintaining crop health and productivity. Best practices continue to evolve on how to use recharge while maintaining or even enhancing water quality. While California is facing serious water challenges, recharge is an effective tool that can help improve the future of the state's water resources.

Do I have access to surface water for recharge?

To implement recharge, growers need to secure surface water by working with local government agencies, who are responsible for securing water rights, developing accounting methods for future groundwater withdrawal, and designing incentives to encourage grower participation. Surface water for recharge can come from multiple sources such as flood releases in heavy rain years, reoperation of upstream reservoirs, and water purchased for banking and storage.

The primary agencies growers need to work with are:

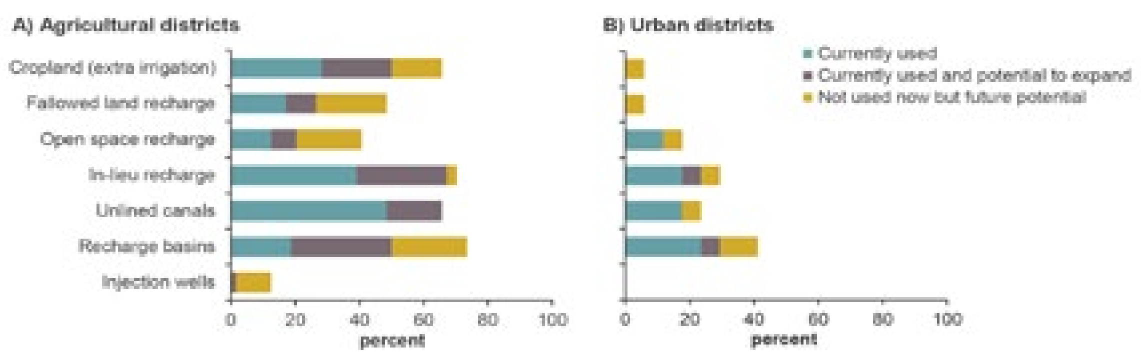
- Groundwater Sustainability Agencies (GSAs) sustainably manage groundwater at a local level. GSAs develop and implement Groundwater Sustainability Plans (GSPs) to manage groundwater in a basin, using either a single plan or multiple, coordinated plans within each sub-basin. The SGMA Data Viewer provides maps to determine the GSA covering an orchard and the relevant GSP.[6]
- Irrigation and other water districts (Districts) support GSP implementation by finding surplus water, developing necessary infrastructure and conveyance, and strategically distributing water for recharge programs.

Many Districts have existing, well-established groundwater replenishment projects using large recharge basins, while others use unlined canals and ditches. Of submitted GSPs to date, the largest single method proposed for reaching sustainability is capture of unrealized recharge potential.[7] To design new recharge programs, Districts are applying decision support tools like the Groundwater Recharge Assessment Tool (GRAT) to guide planning and implementation, using information such as crop and soil suitability and available conveyance infrastructure.[8] Overall, Districts have a strong interest in identifying opportunities to expand recharge.[9]

In addition to GSA-specific incentives, the Natural Resources Conservation Service (NRCS)[10] has now identified groundwater sustainability as a resource concern and has an incentive practice for groundwater recharge.[11]

One advantage of OFR is that it can rely on existing irrigation distribution networks – often idle in the winter when floodwater is available – connected to large areas of productive agricultural lands. New conveyance infrastructure, however, may also be needed to route surface water supplies more broadly. Coordinating groups such as the Water Blueprint for the San Joaquin Valley[12] are collaboratively developing these necessary programs.

The California Department of Water Resources (DWR) recognizes the potential for groundwater recharge on agricultural lands to address overdraft and support long-term water supply reliability. Therefore DWR has assembled the Flood Managed Aquifer Recharge (Flood-MAR)[13] program and network to coordinate research and state-level action. Flood-MAR is tasked with supporting local communities and decision-makers as they integrate groundwater recharge and flood management to promote long-term sustainability and resiliency of basins. The DWR Reservoir Reoperation and Water Available for Recharge (WAFR) reports also provide information on how additional surface water could be provided for recharge.[14]



PPIC. Ag Water Districts see significant potential for expansion in the recharge methods covered in this guide.

Is my orchard soil suitable for recharge?

Sandy soils and sandy streaks can make it difficult to irrigate a field with flood systems but are preferred for OFR, where rapid water infiltration is desirable These types of soils rarely become saturated and are thus less likely to cause harm to crops.

The University of California, Davis, Soil Agricultural Groundwater Banking Index (SAGBI) is a suitability index for groundwater recharge on agricultural land. The SAGBI score is based on five major factors that are critical to successful recharge:

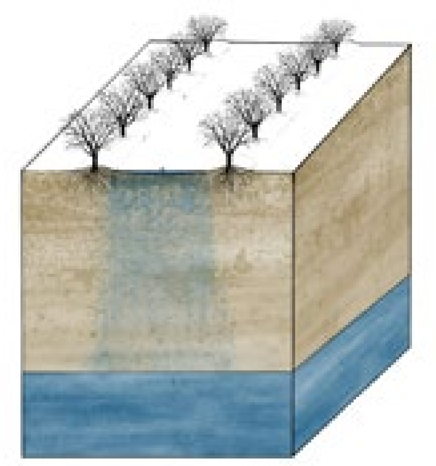
- Deep percolation
- Root zone residence time
- Topography
- Chemical limitations
- Soil surface condition

Partnering with Land IQ, a Sacramento-based agricultural and environmental scientific research and consulting firm, ABC developed an online tool that provides almond growers with an initial look at site recharge suitability for OFR.[15] Assessing field recharge suitability includes evaluating the SAGBI soil infiltration rates, depth to groundwater, and potential geologic impediments like Corcoran clay. If water has a difficult time moving into the soil or if it runs into a hardpan layer as it percolates, then those sites will be classified as limited for replenishing groundwater using OFR. Specific site conditions may still be appropriate for the other two methods covered in the guide.

What recharge methods are available?

SURFACE APPLICATION TO ORCHARDS

On-farm recharge (OFR) is the application of surface water above crop demand in agricultural fields such as almond orchards using existing or supplemental irrigation infrastructure, for the purpose of recharging the aquifer. One major advantage of OFR is that per acre-foot recharged, it can provide a less expensive, more distributed method than construction of new large dedicated recharge basins.[4, 16] While it can raise concerns around impacts to crop health and yield due to saturated soils in the root zone and excess humidity, recharge method, design, and operation can be used to avoid exceeding crop tolerance.



According to Sustainable Conservation, San Joaquin Valley almond growers have experimented with recharge at different times throughout the year. Recharge reported by growers primarily occurred during dormancy, although water was applied into spring, especially in the wet year of 2017.

Almond growers also used water released by their District post-harvest to both refill the soil profile, which had been depleted by deficit irrigation, and for recharge.

Applying recharge during the growing season is not recommended and should be approached with caution, given the significant challenges of maintaining tree health and performing necessary management practices. The timing and effectiveness of fertilizer applications, pest, weed and disease management, and harvest activities – all critical for orchard health – can all be impacted by OFR activities.

Grower Profile: Nick Blom

Almond grower Nick Blom is a Modesto Irrigation District board director, who believes that farmland has the potential to be an important part of the solution in California water management. Blom was one of the growers that partnered with researchers to test the use of active farmland for groundwater recharge.

Blom's orchard was modified with big berms on the edges of the orchard to hold the flooded water. When water was applied, about 6 inches of stormwater infiltrated into the soil within 24 hours. An in-orchard rain gauge measured precipitation that added to the flood water applied. Researchers also inspected root growth and development over an extended period, and soil sensors measured the amount and movement of moisture in the soil. Results from Blom's orchard showed development of healthy roots and no disease or other adverse effects attributed to winter flooding of trees.

Blom secured the water for recharge through coordination with his irrigation district, highlighting the need for farmers to work with their local water agency to both maximize aquifer recharge and assist in avoiding downstream flooding.

What orchard management changes are necessary to perform on-farm recharge?

If recharge is done incorrectly, the root zone may remain saturated too long, potentially adversely affecting tree health and yields. When conducting recharge, growers should take the following steps to both maximize recharge and protect crop health.

Field selection and preparation for recharge

Field selection is key to successful OFR. Desirable characteristics for an orchard in which to conduct recharge include:

- Sandy or sandy loam soils or at least sandy streaks
- Flood irrigation valves, even if the crop is currently irrigated by a drip or sprinkler system
- Field berms or furrow checks
- Flowmeters

The potential for leaching legacy nutrients or other contaminants into the soil is another consideration assessed by looking at a given parcel's cropping history. Different rootstocks will also have different sensitivities to soil saturation, and potentially soil disease, which may drive recharge method and site selection decisions for growers.

Irrigation setup

Flood irrigation valves are helpful as flooding is the easiest way to recharge. While growers have had success with OFR using drip or sprinkler systems, flood valves tend to be more effective. Another alternative to flood valves is temporary pipelines with gated valves. These pipelines should be installed with orchard operations in mind, as equipment may need to access the orchard between recharge events.

Field Berms

Three types of field berms can be helpful:

- Within furrows, berms set up at intervals help slow the movement of water down orchard rows during a recharge event, enhancing infiltration and percolation, and preventing ponding of water at the end of a row.
- Tree berms help keep parts of the root system above water during recharge, mitigating risks to plant health.
- If a field is not set up for flooding, it may be necessary to construct a berm around the perimeter of a recharge field.

Particularly if there is short notice of water available for recharge, growers should prepare fields in advance by taking steps to protect irrigation valves from erosion during recharge. Berms and water control structures should be repaired and maintained, ensuring uniform distribution of water, as recharge application frequency may differ from a standard schedule.

Flowmeters

Irrigation districts will want to track the total volume of water received by the grower as well as the volume applied to specific fields, plus the infiltration rate of those fields. These data are needed to measure recharge volumes. Some Districts already have meters in place at turn outs, while others will need to invest in new measuring tools.

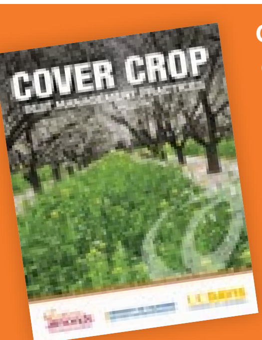
Enhancing infiltration

The following practices may improve infiltration and overall efficiency of a recharge field. Each grower will need to evaluate which practices work best in their orchard.

Alternate row irrigation or irrigation in sets avoids the complete waterlogging of the root zone during recharge. By only applying water to every other row, it leaves adjacent rows dry. Water can also be applied to consecutive sets of rows where trees are planted on raised berms, which is useful when turnout capacity is limited.

Surge irrigation, or the intermittent application of water, improves distribution uniformity along a furrow, as water infiltrates into dry soil faster than wet. This increases the infiltration rate, limiting ponding.

Complete ponding of the entire field has been utilized by growers without adverse effects in the dormant season, particularly on soils with slower infiltration rates.



Cover cropping can increase soil pore space, creating pathways for faster downward water movement and preventing sealing. It also provides ground cover, protecting the soil surface from erosion. Extended use of cover crops can improve soil structure and water holding capacity. For more information on cover crops, see the ABC Cover Crop BMP guide at Almonds.com/CoverCrops.

Conduct field observations

A comparison field without recharge, but with similar crop characteristics (i.e., age, rootstock, variety, and soil type) is useful to monitor crop effects. There is no one-size-fits-all solution, so each grower must determine how to integrate OFR into their operation, if suitable. Grower observation of differential crop health due to disease, nutrient deficiency, or other issues should be addressed.

Potential disease risks

While recharge in almonds during the dormant season has been studied, excess water in or near orchards still requires careful consideration. The UC Integrated Pest Management program has guidance for managing diseases that can be caused by excess moisture, which is also useful for deciding whether recharge is a fit for a particular orchard. Particularly during the growing season, increased moisture in the soil and humidity in the canopy puts orchards at increased risk for the following diseases:

Phytophthora is a group of fungal-like water molds that can affect plant tissues at the crown or roots when conditions are moist and conducive for infection. The pathogen causes loss of nutrient and water uptake, leading to tree decline and eventual death. Root infections can occur when soils are saturated, so may be less of a risk in well-drained soils. While inoculum can be present in the soil it can also be brought in and spread with irrigation or recharge water. Infection rates are higher during the spring when the soil is cool, damp and the plant is active. Younger trees with smaller root systems are also more susceptible.

Management strategies include avoiding damaging roots through trenching; avoiding saturated conditions during spring (a vulnerable period); selecting resistant root stocks drawn from plum parentage (e.g. RootPacR, Marianna 2624, Krymsk-86); and planting into berms. Chemical treatments are fosetyl-al, mefenoxam, and phosphorus acid (phosphite, phosphonate).[18]

Alternaria is a fungal disease that appears as large brown spots on leaves and develops most rapidly in June and July, when it can result in almost complete defoliation. While it can occur anywhere in the Central Valley, it has been most serious in the southern San Joaquin Valley and northern Sacramento Valley. High canopy humidity from dew or orchard floor moisture increases disease likelihood, along with stagnant air.

Given that infections can often recur, some orchards use fungicides as chemical control on a regular basis. There is however a Disease Severity Model that can help determine risk and potentially avoid treatment. Management options include reducing humidity by moving from sprinklers to double-line drip and field monitoring in the spring for symptoms. Variations of flood irrigation systems, like alternate row flooding, are not likely to reduce humidity level. Given these factors, recharge in orchards with a history of Alternaria should be approached cautiously.[19]

Hull rot is caused by a number of fungi, with initial indications prior to harvest, when leaves on a shoot wither and die. The disease attacks and damages fruit and fruiting spurs. Depending on type, it is visible in brown or black fungal growth on the inside or outside of the hull. Hulls are susceptible from the beginning of hullsplit until the hulls dry.

Standard management is to reduce irrigation including regulated deficit irrigation and avoid standing water from the onset of hull-split to harvest. Growers should also avoid excess nitrogen fertilizer. Fungicides can also be used to reduce the incidence of the disease.[20]

Soil oxygen risk

Soil oxygen is critical for crop health, with extended low periods of oxygen being harmful to the tree. Field studies indicate that as soil saturation increases during any wetting event – regardless of irrigation type – soil oxygen decreases. Soil oxygen decreases faster in surface soils than in deeper soil layers, and rebounds following a soil saturation decrease. Short-lived soil saturation however, such as what happens during recharge, often does not immediatly cause anoxic conditions. To ensure adequate oxygen for trees, research suggests as a general rule of thumb that growers avoid standing water for more than two days. To reduce the amount of time that a field has high soil water saturation, plan recharge duration if possible based on past flood irrigation experience to develop soil-specific guidelines. These guidelines limit the suitability of certain orchards for OFR, particularly those with heavier soils.[21]

Recharge on fallow fields

Growers interested in recharge might consider leaving removed almond orchards fallow for a time before replanting. Fallow fields are well suited for on-farm recharge, especially if they are equipped with a flood irrigation system and water conveyance. This practice reduces overall water demand and helps reduce replant and other soil diseases, in addition to improving the aquifer. Research has established that most fields set up for flood irrigation can achieve a flood depth of 6 inches or less without the need for additional infrastructure. For flood depths above 12 inches, it would be necessary to construct berms to contain recharge water.[22]

Growers who are considering removing an almond orchard in the near future are encouraged to check out the Whole Orchard Recycling Guide, which can be found at **[Almonds.com/WOR.](Almonds.com/WOR)**

Fertilization management and protecting water quality

In addition to increasing groundwater storage, OFR can also dilute pollutants that may be present in an underlying aquifer, over time improving both groundwater quality and quantity.

The following practices help ensure water quality is protected, and potentially even improved, through recharge:[23]

- Practice good nutrient management, as outlined below.
- Use source water low in nitrates and salt, in significant and sustained volumes.
- Avoid recharge in sites that have high levels of introduced and naturally occurring soil pollutants (i.e., nitrates, arsenic, selenium, and boron), through awareness of crop history and soil testing.
- Consider the timing of recharge relative to the crop's annual nutrient application cycle by maximizing recharge during the dormant season and fallow periods and minimizing OFR during the growing season. If conducting OFR close to the growing season, avoid fertilizing before a planned recharge event. For example, if conducting a fall recharge program, do not apply nitrogen fertilizers in the fall.
- Size the recharge area to match the volume of water available, as well as the expected frequency. In the San Joaquin and Tulare Basins, for example, high magnitude excess flood flows occur, on average, 4.7 out of 10 years. To increase the annual frequency of recharge, water management arrangements with upstream reservoirs may be necessary.
- Concentrating recharge water in a smaller area repeatedly over the years can increase recharge effectiveness and reduce the quantity of residual nutrients vulnerable to leaching.[24]

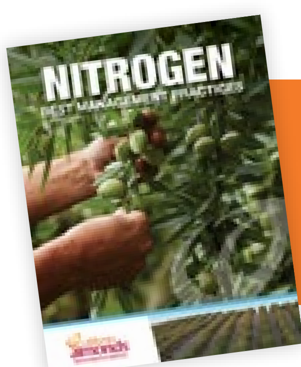
To both maximize crop benefits and protect the environment, ABC has long invested in research to improve nitrogen use efficiency. Nutrient use efficiency practices support OFR, by limiting potentially leachable nitrogen. Efficient, environmentally-sound and profitable nitrogen fertilization can be achieved when growers abide by the 4 Rs of Nutrient Management, which state that nitrogen must be applied at the Right Rate, at the Right Time and in the Right Place, using the Right Source of nutrients. The goal of nitrogen management is to apply adequate, but not excessive, amounts of nitrogen so that productivity is optimized and loss to the environment (and waste of the input) is minimized. Should a grower observe that their orchard appears to require greater amounts of nitrogen than recommended, that may be a sign that nitrogen is being lost to the environment and should conduct an assessment of the possible sources and causes of this loss.

4Rs of Nutrient Management

- **Right Rate**
- **Right Time**
- **Right Place**
- **Right Source**

Practical tips to apply the 4 Rs of fertilization:

- Test irrigation water and soil for nitrogen and adjust fertilizer applications accordingly.
- Estimate the orchard's yield and use that estimate to develop an annual fertilization plan.
- Apply nitrogen in frequent, small applications through the growing season, adjusting the amount applied based on changes in anticipated yield.
- Identify and correct issues to improve irrigation efficiency, especially distribution uniformity.
- Use practices that scavenge residual nitrogen, such as cover cropping.

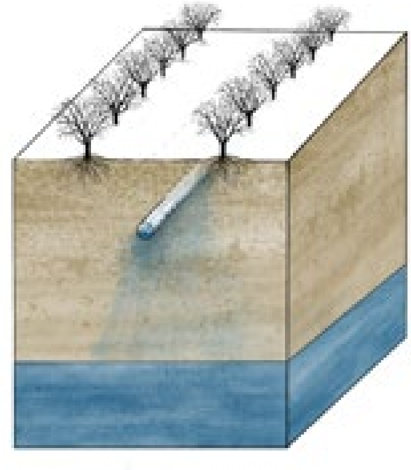


Growers can find the Nitrogen Management Guide to California Almonds at Almonds.com/Nitrogen

BELOW THE SURFACE OF AGRICULTURAL FIELDS

Conducting subsurface groundwater recharge using reverse tile drains was first 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 to avoid anoxic conditions that are harmful to crops. The adaptation of reverse tile drains instead applies excess water below the root zone into areas with overdrafted aquifers for the single purpose of recharge.

A key benefit of the reverse tile drain system is that it does not require saturation of the root zone, thereby allowing water application without impact to growing season considerations. By separating field management needs – such as nutrient or pest management – from the availability of water and timing of recharge, it can expand total recharge. Cost of installation can be a drawback, however, as these systems require significantly higher capital expenses compared to other forms of OFR. Subsurface systems are currently used by growers based on incentives offered by their water storage districts. So far, 11 systems are known to have been installed in the Semitropic Water Storage District, Kern Water Bank Authority, and Shafter-Wasco Irrigation District. In early 2021, a new system was approved for construction in the Saucelito Irrigation District in Porterville.



Field selection and installation

Growers who are interested in a reverse tile drain system will need to install the tile drains and pipelines prior to planting their orchard, making this recharge option something to consider only if planting a new orchard or replacing an existing one.

Prior to installation, fields can be prioritized using SAGBI maps, soil coring, and remote sensing methods. As with all forms of recharge, the orchard must have permeable layers below the root zone to allow percolation of water into the groundwater aquifer. Ideal soils are sandy loam in the first few feet and a sandy layer below the root zone that extends down to the water table. In some installations, soil cores were used to better characterize local conditions down to the water table. Fields with a hard pan or high-water table should be avoided, unless the subsurface system can be installed below the hard pan.

To install the system the land must be planed and graded. Trenching machines then dig and lay plastic tile drainpipes and water supply manifolds about 8-11 feet below ground. The main line manifold pipes that supply water to tile drains should be installed above tile drains at 8-9 feet below the soil surface. The manifolds supply water to both the tile drain system below and surface irrigation system above. After installation, the soil is replaced and trees planted. Drip lines or micro-sprinklers are surface installed for normal crop irrigation. Water for recharge is then pumped into the tile drain system below the root zone.

Grower Profile: Greg Wegis

Greg Wegis of Wegis and Young Property Management, located in the Bakersfield area, installed one of California's first subsurface reverse tile drain recharge systems on a 40-acre field, later planted in almonds (Nonpareil, Monterey, and Fritz on hybrid Hansen rootstock). Soils are Kimberline sandy loam with depth to groundwater around 55 feet.

Securing future water supplies for growing almonds was a major motivation for the company's investment into recharge. Wegis and Young saw this recharge program as an opportunity to bank unallocated Article 21 State Water Project water. Wegis' District – Semitropic Water Storage District – offered incentives to growers to do recharge, including access to a percentage of groundwater recharged.

The Semitropic district – covering more than 220,000 acres in Kern County – was established to address chronic groundwater overdraft challenges and began its groundwater storage program as a proactive response to overdraft and water shortages. The District contains 128,000 acres of irrigated crop, 65% of which are nut crops.

Wegis and Young's subsurface system – installed at 9 feet depth – was designed to recharge 1,350 gallons a minute. The cost of installation was approximately $2,000 an acre, with an infiltration rate of 1.5 inches/acre/day.

In March and April of 2019, a total of 400 acre-feet was recharged by pumping water made available under the Article 21 program, with about 5 acre-foot/day being recharged underneath the 40-acre field. The water was pumped from a nearby canal through the drip system filters on Wegis' field and then into an open concrete air gap via gravity flow. The cost of pumping was estimated at $30/acre foot.

Subsurface recharge offered multiple advantages to Wegis. In fact, he chose this recharge method because he manages other orchards and wanted a system requiring minimal additional management. In that vein, no additional modifications were needed for fertilization and crop protection, and the system also offered flexibility to recharge at any time of the year. The only time he would not recharge is when the water table rises to within 12 feet below ground surface. Further, filters and pumps normally used for surface irrigation did not need to be upgraded to run the system.

Wegis said this subsurface system is convenient and cost-effective, offering growers flexibility by avoiding water quality issues related to the use of fertilizer nutrients. He added that incentive programs will be helpful as part of the effort to return the San Joaquin Valley to long term groundwater sustainability.

Orchard management considerations

Orchard management changes are not necessary on fields that use the tile drain recharge system.

Enhancing infiltration

Initial system design takes into consideration the anticipated volume of water available for recharge. Options for increasing infiltration are limited after the system has been installed, so field selection is crucial. All water applied for recharge is first run through a gravity screen filter to prevent sediments from entering and clogging the tile drain. The same pumps and filters are used as in standard surface irrigation systems. Engineers have developed pressure hose injection systems to periodically flush the system, to avoid any potential for clogging in the underground systems.

Crop health considerations

No known adverse effects have been noted with reverse tile drain recharge.

Tile drain being installed for recharge in field prior to planting. Photo provided by Glen Drown.

Tulare Irrigation District's Swall recharge basin in foreground and Creamline basin below. Photo provided by Tulare Irrigation District.

BASINS OR WATER CONVEYANCE STRUCTURES

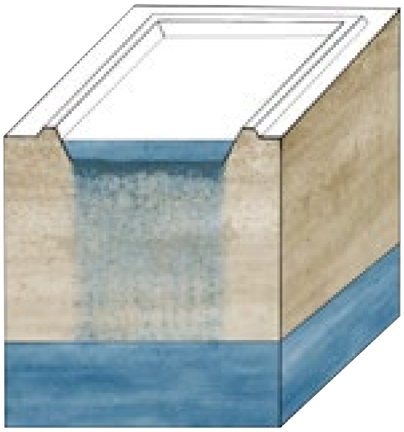
In addition to OFR and its distributed systems, large-scale specialized recharge basins – reliant on centralized Infrastructure – provide options for Districts and GSAs. Growers may also identify portions of their parcel that are better for recharge and take advantage of existing conveyance and distribution systems, leading to development of targeted, smaller on-farm basins.

Dedicated recharge basins

These large-scale permanent structures are constructed and managed by Districts and water agencies. The cost effectiveness of basins generally depends on the anticipated use frequency, which depends on surface water availability and the occurrence of wet years. There are many examples of Districts who use dedicated recharge basins as a part of their overall groundwater recharge strategy.

On-farm recharge basins

These are smaller basins that can be privately or semi-publicly owned and managed. Multiple functions are necessary as flood releases may only be available every few years. For example, growers can develop borrow pits to store rainwater and runoff from roads or surrounding fields and repurpose the basin as a recharge pond when conveyance and water are available. Growers may also consider converting natural depressions into mini recharge basins during wet years when flood release water is available, although they will need to address necessary regulations or permits. Growers may also convert part of their property to a recharge basin that has the best recharge characteristics and is less ideal for crop production.



Unlined canals and irrigation ditches

Unlined canals and irrigation ditches, while intended for irrigation water conveyance can be repurposed for active recharge. Usually owned and managed by Districts, this infrastructure typically isn't a method used by growers to increase recharge, but it can be considered as part of GSPs. As an example, the Madera Irrigation District utilizes its unlined canals for recharge.

These structures are particularly useful during winter periods when they can temporarily store and recharge available water, thereby reducing downstream flood risk. Adding temporary check structures or dams in a canal can help intentionally slow water movement, allowing it to seep into the soil and increase recharge.

What orchard management changes are necessary to install recharge basins?

Site selection

Installation of large-scale dedicated basin is a major undertaking. Districts will normally conduct site suitability studies to determine infiltration potential. When selecting a site for recharge, water managers also evaluate whether there is adequate conveyance to bring water to the location. Ultimately, the costs of purchasing land and constructing the basin and water control structures (costs that could be passed along to growers) must be justified by the frequency of expected water availability and total amount recharged.

For smaller on-farm basins, when designing or modifying existing ponds or natural depressions to meet recharge needs, growers must take into account design considerations such as water conveyance and availability, infiltration rate, safety, mosquito control, permit needs, and overall cost.

As water moves through soil, it can carry legacy contaminants, which can potentially degrade water quality. Therefore, when considering on-farm basins for recharge, growers should avoid sites that were previously used as dairy manure lagoons, had significant amounts of manure applied, or otherwise have a legacy of high nutrient loading.

Maintenance

In both dedicated and on-farm basins, maintenance of weeds and accumulated sediment is an ongoing activity to maintain readiness for use. Fencing or other safety and security measures are also needed to safely separate people, vehicles, and animals from the site. During wet years, activities should also include maintenance of equipment to measure inflow and pool elevation.

Those looking to use unlined canals or irrigation ditches for recharge should also consider that additional maintenance and operation activities will be required as storm runoff can cause erosion, requiring active management of vegetation, debris, and sediment before, during, and after storm events.

Enhancing infiltration

Regular maintenance helps maintain infiltration rates. Screens or settling ponds may be required to prevent coarse sediments and debris from being blown or washed in during storm events.

Depending on a site's characteristics, chemical or mechanical treatment measures may be needed to prevent soil sealing – crusting of the soil surface can create a seal that limits water infiltration and reduces recharge effectiveness.

CASE STUDY: TULARE IRRIGATION DISTRICT'S RECHARGE STRATEGY

The Mid-Kaweah GSA, which includes Tulare Irrigation District (TID), the City of Tulare, and the City of Visalia, utilizes recharge basins and unlined canals as key strategies for returning the sub-basin to sustainability. TID's recharge basins and 300 miles of unlined canals help regulate flows of irrigation water from the Central Valley Project's Friant-Kern Canal and Kaweah River to over 70,000 acres of irrigated crops including about 20,000 acres of almonds, pistachios, and walnuts. The canals also perform a recharge function in wet years.

GSA General Manager Aaron Fukuda describes siting recharge basins above a cone of depression caused by urban well pumps. Cones of depression are formed through localized lowering of the water table relative to the surrounding aquifer and can extend several miles from an urban supply well field. Agricultural groundwater pumping has also been associated with local groundwater overdraft.

Maintaining infiltration rates at design standards is key to making their basins operate economically. Gradual declines in infiltration rates in basins have been addressed by changes in management practices. Settling basins help reduce the amount of fine sediment entering the main basin, which can clog the basin floor and reduce infiltration. Pulsing recharge flows and applying water at intervals followed by a drying cycle increases total amount recharged. TID is planning some limited removal of a clay layer in a basin during dry periods when heavy equipment can be used without causing soil compaction.

Because large basin capacities are inadequate for capturing flood waters, growers may have an important role in addressing overdraft in their sub-basin. TID is exploring the potential of mini recharge basins (1-2 acres) near irrigation turnouts on grower fields, with a water trading system to incentivize grower participation. If a majority of growers participate, total recharge potential would dramatically increase while limiting the burden on any single grower.

Identifying fields suitable for recharge is especially important in Tulare given Corcoran clay layers in some areas. TID has partnered with Stanford University to deploy the Tow-TEM (Transient Electro-Magnetic) technology, which uses electromagnetic resistivity imaging to select the most suitable sites for recharge. Research into the application of this technology in the Kaweah basin is partially funded by ABC.

Grower Profile: Mark McKean

Mark McKean, a third-generation grower in the Fresno area, is the board chair of his local GSA (North Fork Kings GSA), and holds numerous leadership roles in the agricultural community. In addition to growing almonds (Nonpareil, Aldrich, Monterey, and Independence on Nemaguard rootstock), McKean farms over 5,000 acres of pima and upland cotton, wheat, corn, tomatoes, alfalfa and wine grapes.

Even prior to SGMA passage, McKean felt recharge would be necessary to reach sustainability in his subbasin. During the 2010-2011 crop year, Mark began experimenting with the timing of flood irrigation and recharge in his almond orchards during dormancy. With no adverse health effects observed, McKean identified a baseline for what his crop could handle, which helped him develop a recharge plan.

Below his orchard, depth to groundwater is less than 200 feet, with sandy loam soil providing good infiltration for his dual flood and drip irrigation system. In 2016 and 2019 he tried recharge on 3-year-old almond trees. By 2020, McKean had tested recharge on a total of 350 acres of almonds, finding that on his fields shorter run times worked better for infiltration and percolation than constant application.

His 2016 trial delivered around 2 acre-feet/acre of recharge, while 2019 results were slightly less at 1.4 acre-feet/acre. McKean's ability to recharge has been limited due to pump capacity. He generally floods his whole field, although he will apply to every other row if there is a need to keep rows dry for management (e.g., bloom sprays). McKean follows UC nutrient application guidelines, with some small alterations to limit leaching: 25% applied in the fall to non-recharge fields, but only 10-15% on recharge fields.

Mark's main OFR concern is nitrate leaching, and believes continued research is needed to keep recharge viable. He looks forward to the development of new incentive programs to help growers implement recharge.

Unlined irrigation ditch in Fresno County used to convey water for recharge. Photo provided by Ladi Asgill

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MISSION
Expand global consumption of California almonds through leadership in strategic market development, innovative research and accelerated adoption of industry best practices.