PROTECTING GROUNDWATER QUALITY WHILE REPLENISHING AQUIFERS

Nitrate Management Considerations for Implementing Recharge on Farmland

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Sustainable Conservation

OVERVIEW

Under the Sustainable Groundwater Management Act (SGMA), Groundwater Sustainability Agencies (GSAs) are charged with developing Groundwater Sustainability Plans (GSPs) that outline how to meet sustainability goals. Agricultural Managed Aquifer Recharge (AgMAR) is one of several key tools identified in GSPs to improve groundwater sustainability by applying excess surface water on farm fields to recharge aquifers. The benefits of AgMAR for increasing groundwater quantity are well known, but there is also potential to simultaneously improve groundwater quality through dilution of contaminants. However, many people are concerned that AgMAR could also worsen water quality if implemented without thorough consideration of water quality impacts. To fully realize the potential of AgMAR to improve water quality conditions, we must understand the short- and long-term benefits and risks while engaging communities as partners in decision making.

This document represents a first step towards management guidance for on-farm recharge planners and practitioners to maximize benefits to water quality and to manage risks under AgMAR. This document is also intended to be used as a resource for communities so they can more fully participate in the GSA decision-making process. More research on this topic is needed, but with thoughtful stakeholder engagement – including communities, community-based organizations, growers, and GSAs – and careful consideration of drinking water quality, AgMAR can be an effective strategy for securing water resources into the future for all Californians.

COMMUNITY DRINKING WATER IMPACTS

Nitrate contamination of groundwater affects over 600,000 people served by public supply wells throughout California and is expected to worsen into the future, with or without AgMAR.[1, 2] Rural communities disproportionately share the largest burden of this challenge compared to their urban counterparts, due to agricultural leaching, leaky septic systems, and industrial discharges.[3] Instances of harmful nitrate concentrations predominate in private domestic wells and smaller water systems serving communities that do not have the resources to address contamination of their drinking water.

The intent of this management brief is to build understanding of how drinking water could be affected by AgMAR and identify management considerations that can be used to design AgMAR projects that are mindful of water quality. These considerations are neither prescriptive nor meant to cover the full scope of considerations needed to implement a successful recharge project or program (i.e., analysis of soil and crop suitability, hydrogeology, water rights and availability, and conveyance infrastructure, among other topics).

TABLE OF CONTENTS

For more detailed information on current research that supports each of the following sections, please reference the corresponding white paper, *Management Considerations for Protecting Groundwater Quality under Agricultural Managed Aquifer Recharge.*[4]

SECTION 1:
WATER QUALITY CONTEXT AND TRENDS

INTENDED AUDIENCE: GROWERS, PLANNERS, COMMUNITIES

Nitrate (NO_3^-) contamination in groundwater is expected to be an ongoing problem in California for many years to come. Historical land use and fertilizer applications over the last several years to decades determine how much applied nitrogen has already leached below the root zone, and is referred to in this document as legacy N. Depending on soil type and past irrigation practices, this legacy N is either gradually making its way through the vadose zone (unsaturated zone) or has already entered the groundwater (saturated zone), as indicated by current levels of NO_3^- pollution throughout California (Figure 1). Recharge may influence the timing of how legacy N enters the groundwater (i.e. legacy loads may reach drinking water wells sooner and at higher or lower concentrations) but it won't influence the total amount that will eventually enter the groundwater (Figures 2 and 3).

The Groundwater Ambient Monitoring and Assessment program (GAMA) has produced a useful series of online map tools to understand and assess water quality: https://www.waterboards.ca.gov/water_issues/programs/gama/online_tools.html

The Nitrate Control Program under the Basin Plan Amendment/ CV SALTS is focused on addressing ongoing impacts from legacy N pollution (more information in Section 6).

GLOSSARY OF TERMS AND DEFINITIONS

N
Nitrogen applied as fertilizer

Legacy N
Nitrogen that was applied in prior years and decades and remains in the soil subsurface or has already entered the groundwater

NO_3^-
Nitrate is a compound that is formed naturally when nitrogen combines with oxygen or ozone

NO_3^--N
Nitrate-nitrogen is one way to measure nitrate concentration

10 mg NO_3^--N/L
Maximum Contaminant Level (MCL) for human consumption

FIGURE 1: **Ambient conditions for nitrate (mg/L as N) in the upper zone of groundwater basins/subbasins in the Central Valley.** *Source: Figure 3-23 from Final SNMP for Central Valley Water Board Consideration: December 2016.*

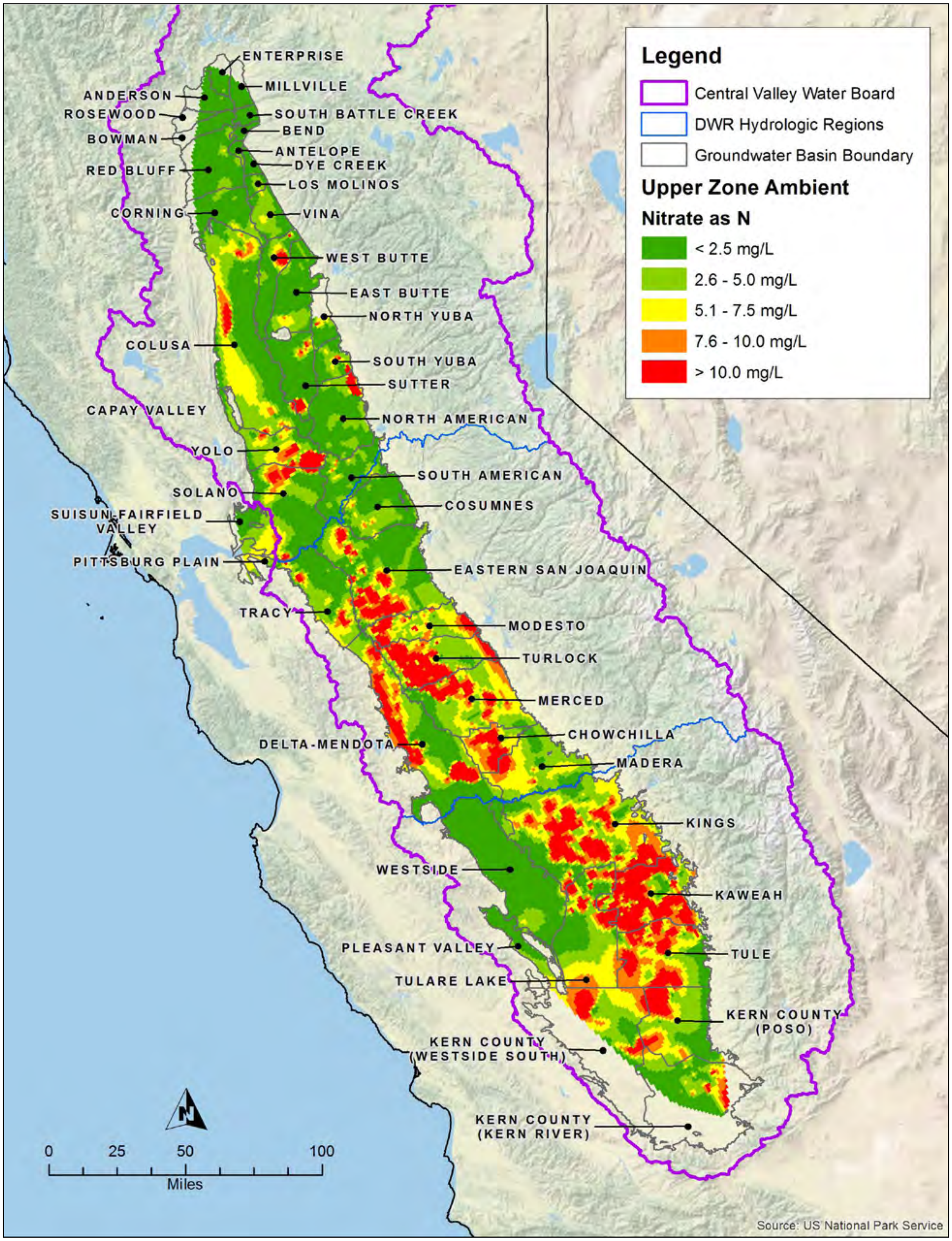


FIGURE 2: Legacy N continues to affect groundwater quality years after it was applied to fields. Even if all farms improve nutrient management today (in this figure, three thinner red bars near the root zone represent three recent years of less N applied), there will be ongoing N leaching – with or without recharge – from below the root zone (vadose zone) due to historic inefficient agronomic practices (thicker red bars below).

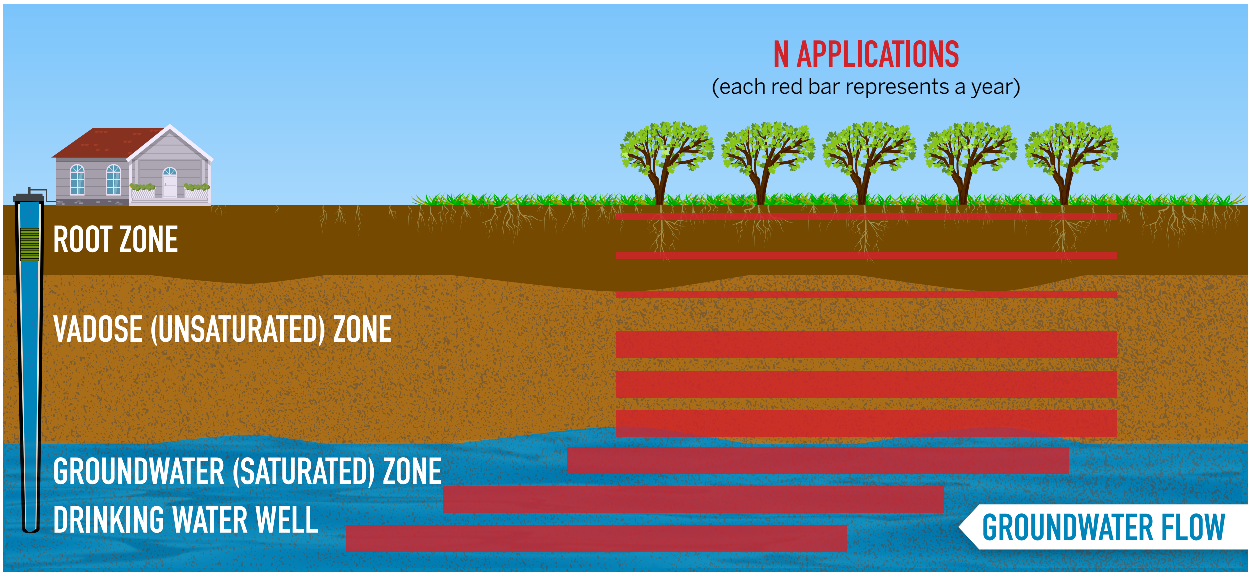
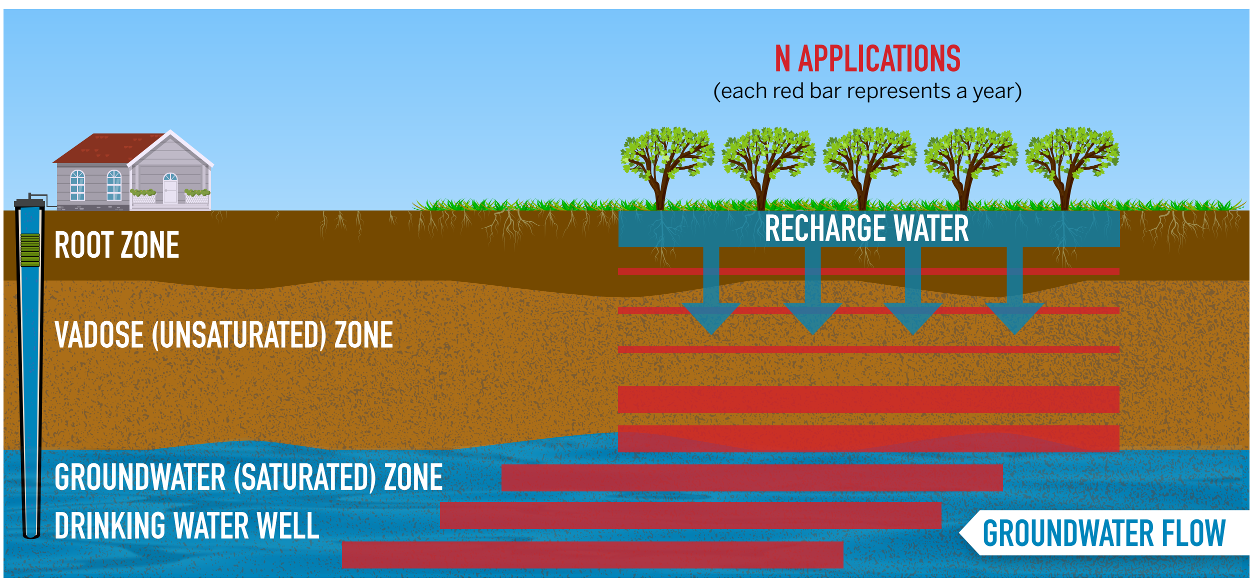


FIGURE 3: In this figure, there is reduced N leaching below root zone for the past 3 years due to better recent agronomic practices (Section 2). Additional water from recharge moves any remaining legacy N in the vadose zone down into groundwater faster, potentially diluting or temporarily spiking NO_3^- concentrations (due to legacy loading) in groundwater, depending on conditions (Section 5).



SECTION 2: AGRONOMIC PRACTICES TO PROTECT WATER QUALITY

INTENDED AUDIENCE: GROWERS, PLANNERS

The single most important step to protect groundwater quality under AgMAR is to ensure current and future agronomic practices minimize any further leaching of nitrogen (N) below the root zone (Table 1). GSAs should ensure growers practice good nutrient management to be eligible to participate in recharge programs.

The Irrigated Lands Regulatory Program (ILRP) and the Dairy General Order are focused on reducing nitrate runoff and leaching from agricultural operations by improving on-site nutrient and irrigation management.

TABLE 1: Best Agronomic Practices.

Nitrogen Application	**Follow the 4 R's** of fertilization.[5, 6] ■ **Right Source:** use the form of fertilizer best suited to the crop and the environment. ■ **Right Rate:** apply nitrogen in proportion to crop demand. ■ **Right Time:** align nitrogen application timing with crop uptake. ■ **Right Place:** apply nitrogen to the active root zone or on foliage and, if possible, vary nitrogen application to address field variability in soils and yields.
	In accordance with nutrient management plans, **adjust N application rates** based on realistic yield goals (crop uptake), nitrate in irrigation water, nitrogen mineralization from organic matter, and residual nitrate in soil prior to planting or fertilization actions, in accordance with nutrient management plans.[7]
	Use fertigation (delivery of N through irrigation systems) to target low-concentration, frequent applications directly to root zone.[8, 9]
	Use controlled-release fertilizers and nitrification inhibitors or split applications.[9]
	Test end-of-season N to evaluate uptake efficiency during growing season.[8]
	Eliminate fall N applications if dormant crop needs can be met with residual soil N.[7]
Water Use	**Avoid excess irrigation** following nutrient application, which can move N below root zone.[10]
Cover Crops	**Consider using cover crops** to scavenge residual N after harvest and/or reduce need for synthetic N applications.[11]

SECTION 3:
FIELD-SCALE NITRATE CONSIDERATIONS

INTENDED AUDIENCE: GROWERS, PLANNERS

Growers can use this table to guide their field-scale decisions on if and how to engage in recharge activities on agricultural land. Planning agencies, such as GSAs and Irrigation Districts, can use the table to help develop local and regional recharge guidelines and prioritization tools.

TABLE 2: Field-Scale Nitrate Considerations.

Current Crop Management	Assess current land-use practices of a field site to estimate amount of annual nitrate leaching below the root zone. **Prioritize recharge sites with crops that have low N demand** and practice excellent N management.[2, 12]
Crop Suitability	When recharge is conducted on active farmland, **recharge should be applied on crops that can tolerate soil saturation** without impairing crop health, which can reduce the plant's ability to uptake N and leave more N vulnerable to leaching.[13, 14, 15]
Soil and Hydrogeologic Conditions	**Sandy, coarse-textured surface soils may be the best candidates** for recharge where no underlying restrictive layers are present and a good nutrient management plan is followed. At these sites, larger amounts of water could be applied, thereby more effectively diluting nitrate compared to heavier-textured surface soils.[16]
Nitrogen Management Under Recharge	**Do not apply N directly before a recharge event.**[17]
	Maximize recharge in dormant/fallow periods when N is not actively applied.[18]
	When possible, **recharge using longer-duration application periods** – rather than short, pulsed events – to decrease N mineralization potential (conversion of organic nitrogen to plant available nitrogen), increase denitrification potential (conversion of nitrate to dinitrogen gas) and decrease overall nitrate leaching to groundwater.[19]
Water Availability	See Table 3 for considerations about water availability. Although this is mainly a concern for planning agencies, growers should **consider duration and quantity of water available for recharge** to determine number and size of recharge sites that can receive sufficient water, which may help to dilute residual soil N.[20]

SECTION 4:
REGIONAL-SCALE NITRATE CONSIDERATIONS

INTENDED AUDIENCE: PLANNERS, COMMUNITIES

Planning agencies that are considering promoting Ag-MAR on multiple sites in a region as part of a recharge program can use considerations in Table 3 to evaluate the potential cumulative N effects of selected recharge sites.

TABLE 3: Regional-Scale Nitrate Considerations.

Groundwater Hydrogeology	**Assess hydrogeology and groundwater gradients**, including influence by regional pumping and recharge, to help predict when and where effects of AgMAR activities might be expected.
	Note that **local groundwater gradients** can shift due to recharge activities, potentially increasing the transport of nearby contaminated groundwater towards drinking water wells.[21] Thus, even in ideal recharge site conditions, investigation of potential impacts to local drinking water wells is still warranted.
Community Water Access	**Assess and map wells used for drinking water** and other domestic uses that are in the vicinity of recharge activities. In close coordination with communities, consider prioritizing recharge in areas where wells are already vulnerable to drying up and/or are already contaminated, with special care taken to protect or improve water quality.
Water Availability	When projected water available for recharge is limited, **consider focusing recharge on a limited number of sites** (that use appropriate nutrient management) with sufficient amounts of water, rather than recharging large areas (or rotating recharge fields annually), in order to reduce the rates of overall nitrate leaching into the aquifer.

Homes and communities are often in close proximity to agricultural fields. Photograph from Adobe Stock.

SECTION 5:
RECHARGE SITE PRIORITIZATION UNDER AGMAR

INTENDED AUDIENCE: GROWERS, PLANNERS, COMMUNITIES

Prioritizing sites for recharge can be especially helpful in years when water available for recharge is limited. Table 4 can help to prioritize sites based on existing local groundwater quality and legacy N loading, **assuming appropriate nitrate management practices are followed currently and into the future** (Section 2).

It is important to note that past irrigation practices will influence legacy N loading, where a history of flood irrigation might mean there is less legacy N in the vadose zone than a site that has drip irrigation. Further programmatic collection of site information from interested growers/landowners may be warranted (e.g. deeper examination of fertilizer application records, well water testing, and history of irrigation/recharge).

Sites with a significant accumulation of organic nitrogen in the vadose zone (e.g., manure lagoons, animal corral areas) pose a potentially significant additional risk to groundwater quality. At these sites, AgMAR would lead to potentially large mineralization of organic matter to inorganic nitrogen, such as nitrate, and subsequent nitrate leaching. AgMAR at such sites is not generally recommended.

Nitrogen loading in vadose zone varies depending on type of irrigation (left: flood, right: micro sprinklers) and nutrient application rates. Left photograph from Adobe Stock. Right photograph by Lance Cheung for USDA.

TABLE 4: Site Prioritization. This table can help prioritize sites according to relative risk by evaluating local groundwater quality and legacy N loading. Scenarios A, B, and C are further discussed in the graphs below.

GROUNDWATER QUALITY	LEGACY N	RELATIVE RISK FOR NITRATE LEACHING	CONSIDERATIONS	SCENARIO
Good/Marginal	Low	Low risk recharge site.	Use clean water for recharge.	A
	Medium	Medium risk site for continued rise in nitrate concentrations, with or without recharge.	Use clean, abundant, reliable water for recharge. Impacted communities must be decision makers. Develop a monitoring program and contingency plan.	B
	High	Highest risk site for continued rise in nitrate concentrations, with or without recharge. *		
Poor	Low	Low risk recharge site.	Recharge may improve conditions. Use clean water for recharge.	C
	Medium	Medium-low risk site for continued rise in nitrate concentrations, with or without recharge	Use clean, abundant, reliable water for recharge. Impacted communities must be decision makers. Develop a monitoring program and contingency plan.	
	High	Medium risk site for continued rise in nitrate concentrations, with or without recharge.		

* A site with a history of high N loading and local good/marginal groundwater quality may indicate that legacy N has not yet traveled to the aquifer. If this is the case, recharge may mobilize a new flush of legacy N into the groundwater (see Scenario B), which may or may not be diluted depending on many variables. An assessment of short-term and long-term impacts to nearby downgradient domestic or public water supply wells is recommended.

SHORT-TERM VS LONG-TERM EFFECTS

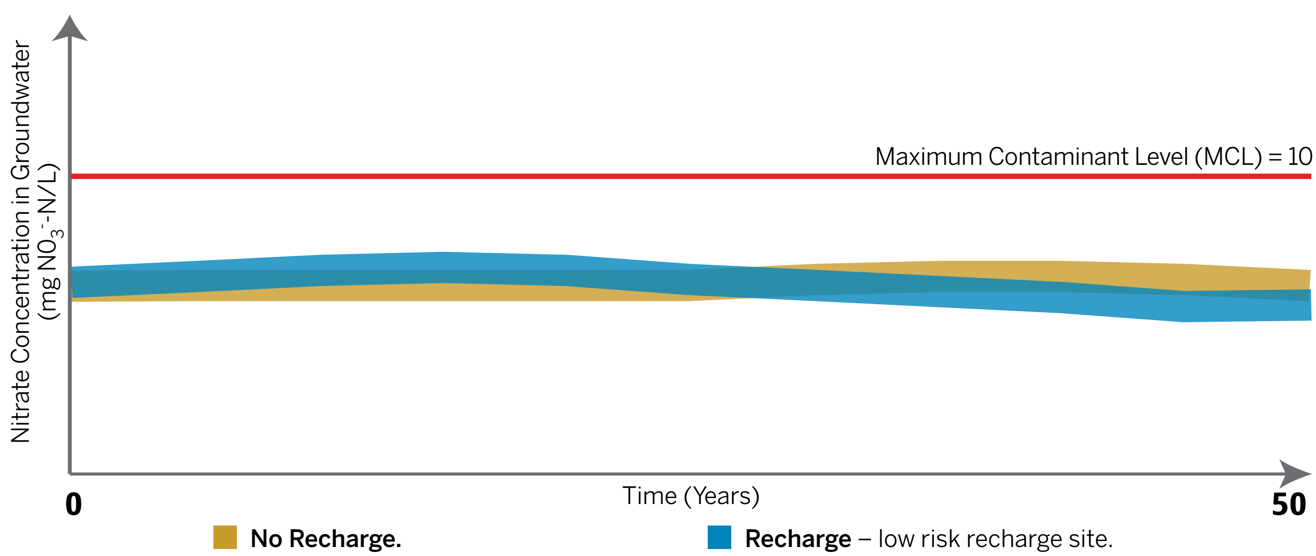
The short-term and long-term potential effects of recharge depend on a variety of site conditions. Scenarios A, B, and C illustrate general water quality trends over time based on conditions outlined in Table 5. The thick bands in the scenarios represent an upper and lower range of uncertainty that is dependent on many site variables. These figures are conceptual only and do not reflect actual site conditions.

Although longer-term improvement may justify short-term impacts, communities impacted by water quality issues must be part of AgMAR decision-making. "Short-term" is relative (could be 10-20 years) and therefore people will need to make these difficult decisions together (e.g. temporary worse water quality in exchange for long term water security) – keeping in mind that worsening water quality is the fate of many places in California, with or without recharge, as legacy N inevitably moves through the system.

SCENARIO A:

Existing Groundwater Quality: Good/Marginal
Legacy Nitrogen: Low

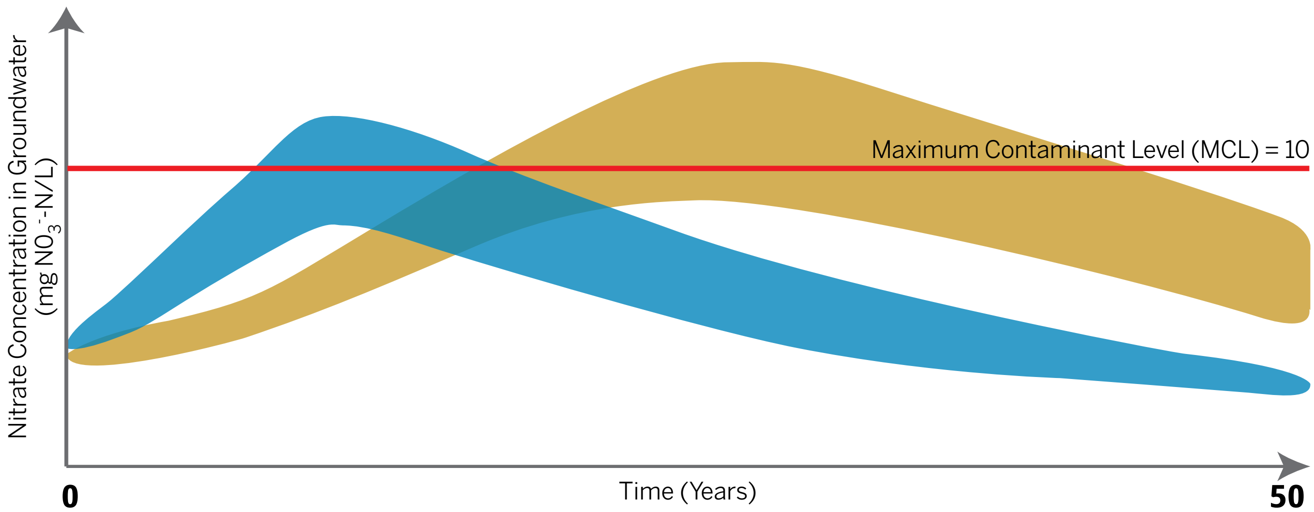
Sites with relatively low legacy N and low NO_3^--N concentration in groundwater are not likely to cause significant water quality degradation into the future, with or without recharge.[2,12]



SCENARIO B:

Existing Groundwater Quality: Good/Marginal
Legacy Nitrogen: Medium/High

At sites with low NO_3^- concentration and medium/high legacy N, recharge could improve conditions in the long term but potentially worsen conditions in the short term, which may or may not exceed the MCL. Note that water quality may worsen before it gets better regardless of recharge activities.



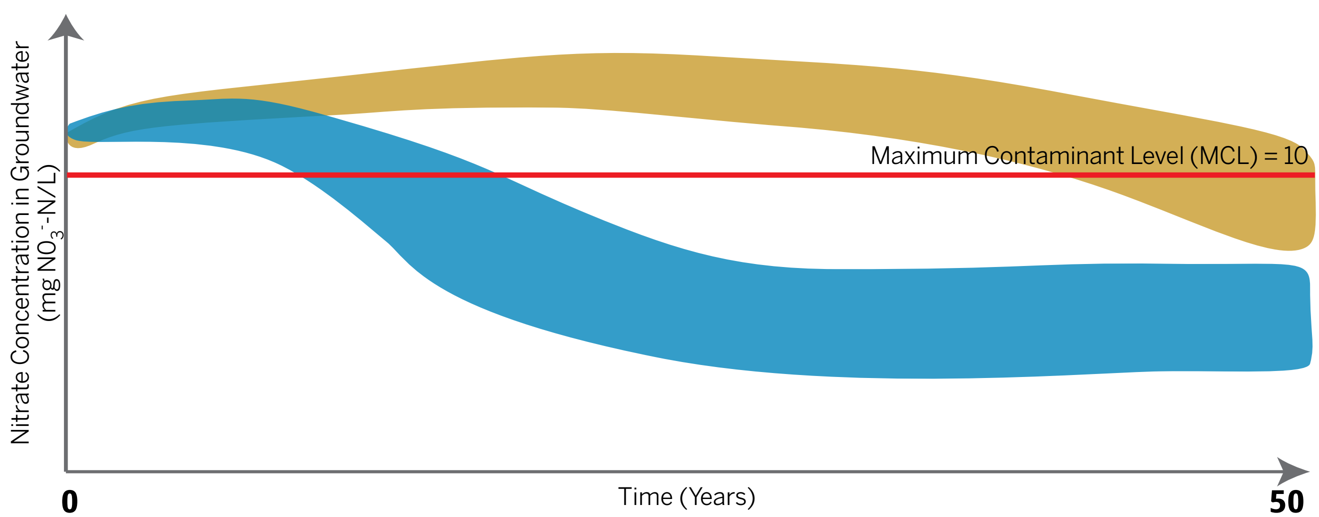
No Recharge – spike in NO_3^- occurs later and for longer period of time. May or may not exceed MCL depending on conditions.

Recharge – spike in NO_3^- occurs sooner and for shorter period of time. May or may not exceed MCL depending on conditions.

SCENARIO C:

Existing Groundwater Quality: Poor
Legacy Nitrogen: Low/Medium/High

Recharge improves water quality conditions in the shorter- and longer-term if water quality is already poor (indicating that legacy N may have already leached into the groundwater) and enough water is applied to dilute any remaining legacy N.



No Recharge – eventually, NO_3^- plume moves through the system.

Recharge – may improve conditions much sooner than without AgMAR.

SECTION 6:
MONITORING AND CONTINGENCY PLANS

INTENDED AUDIENCE: PLANNERS, COMMUNITIES

GSAs and planning agencies should plan ahead and in coordination with local communities, community-based organizations, and nitrate-related programs to identify priority recharge sites based on desired recharge benefits and assessment of recharge suitability and risks. If higher risk sites are expected to be included in the recharge program and are located in areas where drinking water is a concern, the GSA or planning agency should have a plan (including funding identified) for monitoring and addressing any impacts that may occur prior to the application of recharge water. This section gives some recommendations on how this might be approached.

The Nitrate Control Program Management Zones (MZ) are new regulatory pathways where permitted dischargers – including agriculture – will collectively address existing and future groundwater nitrate contamination at a regional scale, by monitoring water quality, providing alternative water supplies, and reducing groundwater contamination over time.

GSAs should coordinate with MZs where applicable, including coordinating monitoring programs.

Groundwater samples collected at a well site in Sutter County on August 11, 2017. Photograph by Kelly M. Grow for California Department of Water Resources.

TABLE 5: Monitoring Program Considerations.

Monitoring Well Network	**Identify and map drinking water wells** that could be impacted by recharge activities (area of influence). Use information gathered from regional-scale assessment (Table 3) to prioritize the monitoring of drinking water wells that could be impacted by recharge activities.
	Examine data from local wells to establish baseline water quality conditions and evaluate potential for these wells to be used concurrently as monitoring wells – based on location, proximity to drinking water wells, depth to water, well screen depth, groundwater gradients, and accessibility, among other considerations.
	Coordinate monitoring efforts with nitrate-related regulatory programs such as ILRP coalitions, Central Valley Dairy Representative Monitoring Program, and Nitrate Management Zones.
	Coordinate monitoring efforts with non-profit and community-based organizations that are monitoring drinking water wells.
	Install new monitoring wells if needed, in coordination with the network outlined in the GSP, to fill in data gaps and prioritize monitoring of drinking water wells in the area of influence.
	Locate monitoring wells along the groundwater flow path, and at the appropriate depth, between AgMAR sites and area of influence.[21, 22] Note that groundwater flow directions can be highly variable and multi-directional, depending on seasonal conditions and pumping activities.
	For recharge sites that will need monitoring, **the distance of monitoring wells from potentially impacted water supply wells should allow for sufficient time to trigger early warning and enactment of contingency plan.** [21, 22]
Well Sampling Plan	**Frequency of well sampling** should be robust enough to capture changes in contaminant concentrations due to magnitude and proximity of recharge activities. The frequency and parameters monitored may vary among wells in a network, depending on the objectives and design of the network.
	Consider other water quality factors to measure, including contaminants of concern as well as indicators such as pH.

CONTINGENCY PLANS

GSAs should work with local communities, local community-based organizations and existing regulatory programs such as the Nitrate Control Program Management Zones (MZ) to identify the water quality threshold at which contingency plans are triggered (e.g. 75% of Maximum Contaminant Level) and coordinate potential alternative water supplies in the case that recharge activities accelerate worsening water quality (exceeding water quality objectives). Some alternative water supplies include bottled and tanked water, water kiosks, point-of-use water filtration/treatment systems, connecting to nearby municipal systems, deepening drinking water wells, establishing new small public water system, and remediating contaminated water.

CONCLUSION

AgMAR is one of several key tools that will be crucial in bringing California's groundwater into sustainability. Because nitrate contamination has the potential to impact human health, special care should be taken to locate and manage sites appropriately under AgMAR and in direct coordination with potentially affected communities. Thoughtful stakeholder engagement, combined with emerging research on this topic and consideration of potential long- and short-term benefits and risks, can ensure that AgMAR will be an effective strategy for securing water resources for all Californians.

Groundwater recharge on a Madera County vineyard. Photograph by Paolo Vescia for Sustainable Conservation.

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