Recharge Area Identification, Utilization, and Protection Resource Management Strategy

Draft Memorandum

CALIFORNIA WATER PLAN UPDATE 2023

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Acronyms and Abbreviations

3-D	three-dimensional
AEM	airborne electromagnetic
ASR	aquifer storage and recovery
CVHM2	Central Valley Hydrologic Model Version 2
DWR	California Department of Water Resources
DWSAP	Drinking Water Source Assessment and Protection Program
Flood-MAR	flood-managed aquifer recharge
GAMA	Groundwater Ambient Monitoring and Assessment
GRAT	Groundwater Recharge Assessment Tool
GSA	groundwater sustainability agency
GSP	groundwater sustainability plan
MS4	municipal separate storm sewer system
NPDES	National Pollutant Discharge Elimination System
O&M	operation and maintenance
OSWCR	Online System of Well Completion Reports
Portfolio	Water Resilience Portfolio
regional water board	regional water quality control board
RMS	resource management strategy
SAGBI	Soil Agricultural Groundwater Banking Index
SGMA	Sustainable Groundwater Management Act
State Water Board	State Water Resources Control Board
Water Supply Strategy	*California's Water Supply Strategy: Adapting to a Hotter, Drier Future*

1. Introduction

Purpose

This resource management strategy (RMS) advances water supply augmentation, resilience, and equity in California by providing summaries of the state of knowledge, applications, and available information and resources on recharge area identification, utilization, and protection.

Built and Natural Water Infrastructure

California's built and natural water infrastructure serve as the features that convey, store, and deliver water in the state and are important components to understanding groundwater recharge identification, utilization, and protection.

Built and natural water infrastructure refers to the systems that connect and benefit multiple regions throughout the state. Built infrastructure includes reservoirs, dams, canals, aqueducts, groundwater production wells, and managed groundwater recharge facilities. Natural infrastructure includes rivers, floodplains, and aquifers within alluvial groundwater basins and hard-rock (non-basin) areas (Figure 1).

Aquifers and groundwater basins are important components of California's natural infrastructure because they can be used to store water for annual and drought-year water supplies. In California, approximately 40 percent of the state's water supply during an average water year comes from groundwater basins and as much as 60 percent during dry years.

What is Groundwater Recharge?

Direct, or active, groundwater recharge occurs when water moves down (infiltrates) from the ground surface, or from the bottom of a waterway into an underlying aquifer; or when water is injected directly into an aquifer. An aquifer system commonly includes three recharge and discharge elements:

1. Recharge areas where surface water moves to groundwater.
2. Storage media (sands, gravels, silt, and clay) that store groundwater.
3. Discharge areas consisting of wells, springs, and surface water bodies such as rivers, lakes, and wetlands.

As with many natural systems, these elements interact in numerous ways. This RMS focuses on direct groundwater recharge.

Indirect, or passive, groundwater recharge is often referred to as in-lieu recharge. In-lieu recharge is the practice of using surface water instead of groundwater, thereby leaving groundwater in the aquifer. In other words, surface water is utilized "in-lieu" of groundwater. In-lieu recharge is a conjunctive use management strategy that can help groundwater managers offset groundwater withdrawals.

Figure 1 Groundwater System and Associated Groundwater Recharge Components

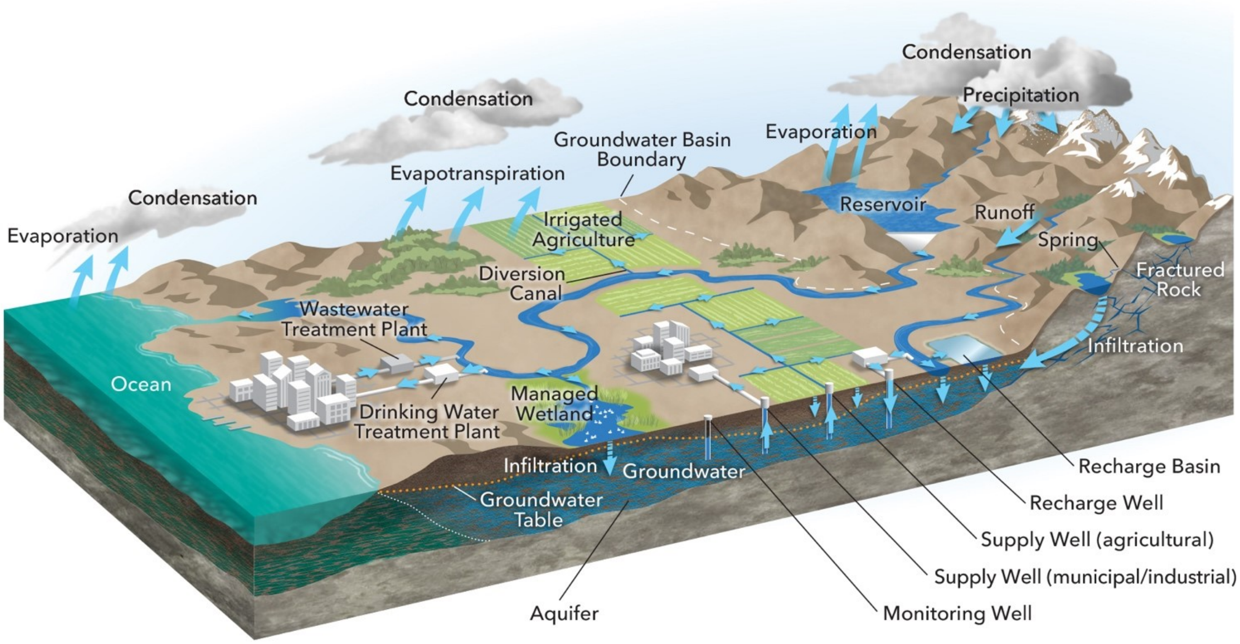


Figure 1 Source: [California's Groundwater Update 2020](#).

Natural Groundwater Recharge Areas and Aquifer Systems

Natural groundwater recharge can be accomplished in various ways, as long as water can percolate, or infiltrate, from the ground surface into an aquifer. The pathway that the recharge water takes can be short and direct or long and tortuous, depending on the permeability, porosity, and composition of the underlying materials; the depth and distance to groundwater; and whether the aquifer is shallow and unconfined or deep and confined.

Groundwater recharge can occur naturally through rivers, streams, lakes, agricultural fields, open space, unlined water conveyance infrastructure, permeable geologic outcrops, mountain meadows, and wetlands, but it can also be conducted in a more purposeful manner. Managed aquifer recharge can be implemented using engineered spreading basins, stormwater detention or retention basins, temporary dams, reservoirs, working lands built to receive water, or through injection wells. The choice of recharge method depends on the components of a basin's aquifer system and the intended use of the recharged water, as well as the geographic location of the basin. Recharge activities may be used to address the Sustainable Groundwater Management Act's (SGMA's) list of undesirable results by augmenting a basin's water supply, preventing seawater intrusion, improving water quality, or slowing the rate of land subsidence.

Recharge of Unconfined Aquifers

In unconfined aquifers, surface water moves down from the ground surface, or recharge area, and through an unsaturated zone until it reaches a saturated zone. The boundary between the two zones is called the water table (Figure 2). An unconfined aquifer's water table surface can be several feet or several hundred feet below the ground surface; the thickness of the unconfined aquifer can vary, and its lower boundary is commonly denoted by a confining bed, separating the confined aquifer below.

Replenishment of water in unconfined aquifers can take days, months, or years depending on the recharge pathway. Generally, water moves faster and easier through sand, gravel, and fractured rock than it does through silt and clay.

Recharge of Confined Aquifers

A confined aquifer is commonly located deep below the ground surface and has layers of low permeability material (aquitards or confining beds) located above and below it. Confined aquifers are under pressure; the groundwater elevation in a monitoring well is called the aquifer's piezometric surface or head. A confined aquifer's piezometric surface can be located above the depth of the confined aquifer and even above the ground surface. Flowing artesian wells are formed when the elevation of the aquifer's piezometric surface is above the ground surface.

The recharge area for a confined aquifer is generally located some distance from, or at a higher elevation than, the zone that is being used as a water supply. For example, in California's Central Valley, the recharge area for the deep confined aquifers is along the foothills of the Sierra Nevada and the Coast Ranges, where water infiltrates into permeable outcrops or through mountain meadows and streams. Replenishment of water in confined aquifers can take years or decades depending on the recharge pathway (Figure 3). An exception to this timeframe is the use of injection wells, which are used to inject treated surface water directly into a permeable geologic formation.

Figure 2 Diagram of the Different Zones and Areas Within an Unconfined Aquifer

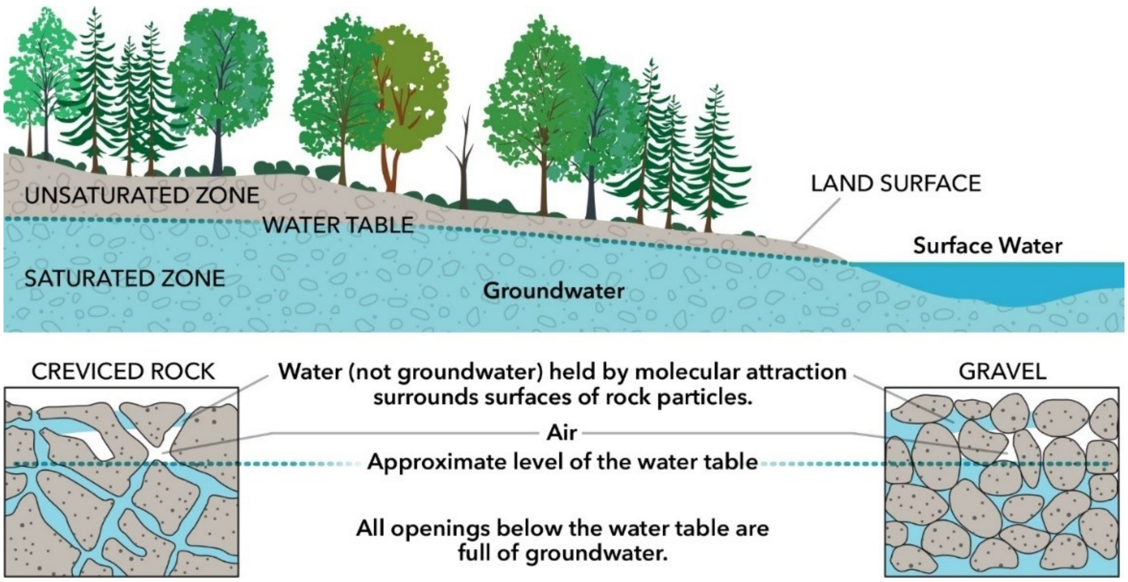
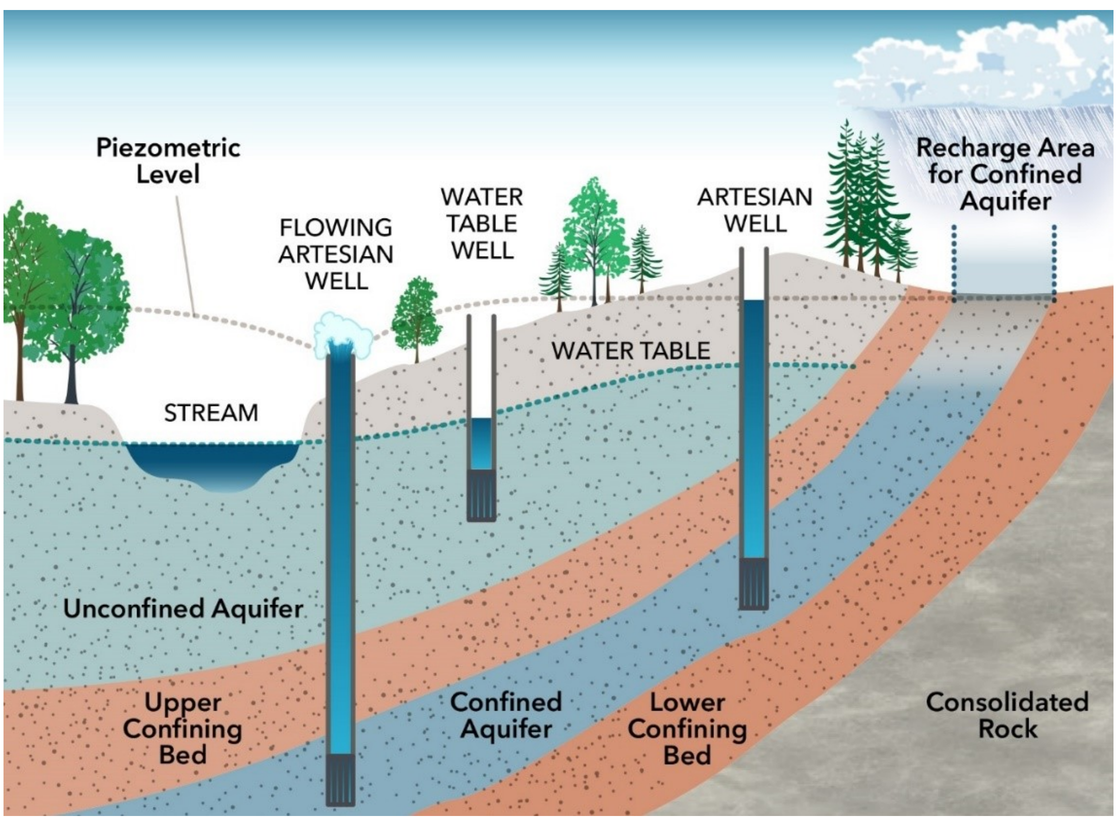


Figure 3 Cross-section of a Confined Aquifer



Methods to Enhance Groundwater Recharge

When natural recharge is lacking or is disturbed, artificial methods to recharge may be necessary to replenish groundwater supplies. “Managed” or “artificial” recharge is becoming an important area of research and implementation, with studies and projects occurring across the state. These studies cover several goals, including recharging aquifers for supply reasons, preventing or reversing saltwater intrusion in coastal areas where saline waters are entering aquifers, and reducing or preventing land subsidence induced by over-pumping of groundwater.

The first documented artificial recharge activities in California began in the Los Angeles area in 1889. In the early 1900s, water agencies operated recharge programs in the San Joaquin Valley (California Department of Water Resources 2016). Additional areas for artificial recharge were established later in Southern California and in the San Francisco Bay Area.

Since the passing of SGMA in 2014, recharge activities by water management agencies have become more common, with areas for recharge locations being chosen that generally meet the following three conditions.

1. The sediment is coarse enough (sand and gravel) to allow surface water to infiltrate at a higher rate than through finer sediments (silt and clay).
2. There is hydraulic continuity from the recharge area to the aquifer where the groundwater is stored, and to the discharge area where wells extract the groundwater.
3. A local agency has access to the groundwater and land where the first two conditions exist.

General Categorization of Actual and Potential Recharge Areas

The size of existing recharge areas and the amount of water that is artificially recharged into aquifers is substantial, but there is no procedure in place that quantifies that amount on a statewide basis. With the new requirements under SGMA, groundwater sustainability agencies (GSAs) are required to identify a basin’s recharge areas and estimate the effect recharge has on the basin’s water budget.

For purposes of analysis and planning, actual and potential recharge areas can be assigned to one of three categories.

- Category 1. Active recharge areas under the jurisdiction of water management agencies. Ideally, the infiltration rate is high in these areas and they are carefully managed to maintain that high infiltration rate and to protect the quality of the groundwater being recharged. Most of these sites' monitoring activities track groundwater levels, rate of infiltration and movement of the recharge water into the aquifer, and geochemical changes.

- Category 2. Areas known to have high infiltration rates but are not under the jurisdiction of a water management agency. There may be little or no monitoring of these areas. Areas in this category should consider management programs that monitor recharge, prevent potential contaminating activities, and educate the public about the importance of protecting the quantity and quality of their water supply.
- Category 3. Areas with a lower infiltration rate that are less suitable for an artificial recharge program managed by a local water agency. These areas may have a lower degree of monitoring and management of potential contaminating activities.

Detention Basins

In the first half of the 20th century, the U.S. Army Corps of Engineers, in conjunction with local flood control agencies, built detention dams, such as Prado Dam in the Santa Ana River Watershed, in the canyons at the foot of several mountain ranges in California. These detention dams had three primary purposes.

1. When storms dropped large amounts of water high in the mountains, the dams stopped the uncontrolled rush of water into downstream residential areas.
2. Some of the water stored behind the detention dams infiltrated into the coarse sediment in the bottom of the detention area and recharged the local aquifer.
3. The dams were designed to release a smaller controlled amount of water into the flood control channels and streams so that the water would not cause damage downstream.

Some of these dams are also used to store excess water for release and use during the dry season. Many of these facilities are still functioning and some provide significant recreational opportunities during the dry season.

Spreading Basins or Recharge Ponds

In the last half of the 20th century, a different type of detention basin was built to capture water in wet seasons and allow the water to percolate into the ground. These spreading basins, or groundwater recharge ponds, consisted of excavated areas that were topographically lower than the surrounding land surface. The purpose of spreading basins and recharge ponds is threefold.

1. They can be used as recreational facilities during the non-storm season.
2. They fill with stormwater runoff, or stormwater runoff can be diverted to the basins during the wet season, thereby reducing flood risk.
3. Some of the water stored in these basins during the wet season recharges the local aquifer.

Diversions of surplus surface water can also be a source of water delivered to the basins. In any operation that uses urban runoff, adequate control must be exercised to prevent contamination of the aquifer by petroleum products and other urban contaminants.

Temporary Dams

A temporary dam, or check dam, is a small, temporary dam constructed across a drainage ditch, gully, swale, channel, or river to slow the movement of water or allow water to pond and percolate into the ground. Temporary dams may be constructed from logs, rock fill, an inflatable diaphragm, or pre-fabricated barriers. Consultation with, and approval from, the California Department of Fish and Wildlife is required before the installation of any temporary dam or alteration to streamflow.

Flood-managed Aquifer Recharge

Flood-managed aquifer recharge (Flood-MAR) is an integrated and voluntary strategy that uses floodwater resulting from, or in anticipation of, rainfall or snowmelt for managed aquifer recharge on agricultural lands and working landscapes, including refuges, floodplains, and flood bypasses (Figure 4). Flood-MAR can be implemented at multiple scales – from individual landowners diverting floodwater with existing infrastructure, to using extensive detention or recharge areas and modernizing flood management infrastructure and operations. DWR's Flood-MAR Program supports ongoing research and activities. It is a good source for Flood-MAR information.

Figure 4 Elements of Flood-MAR

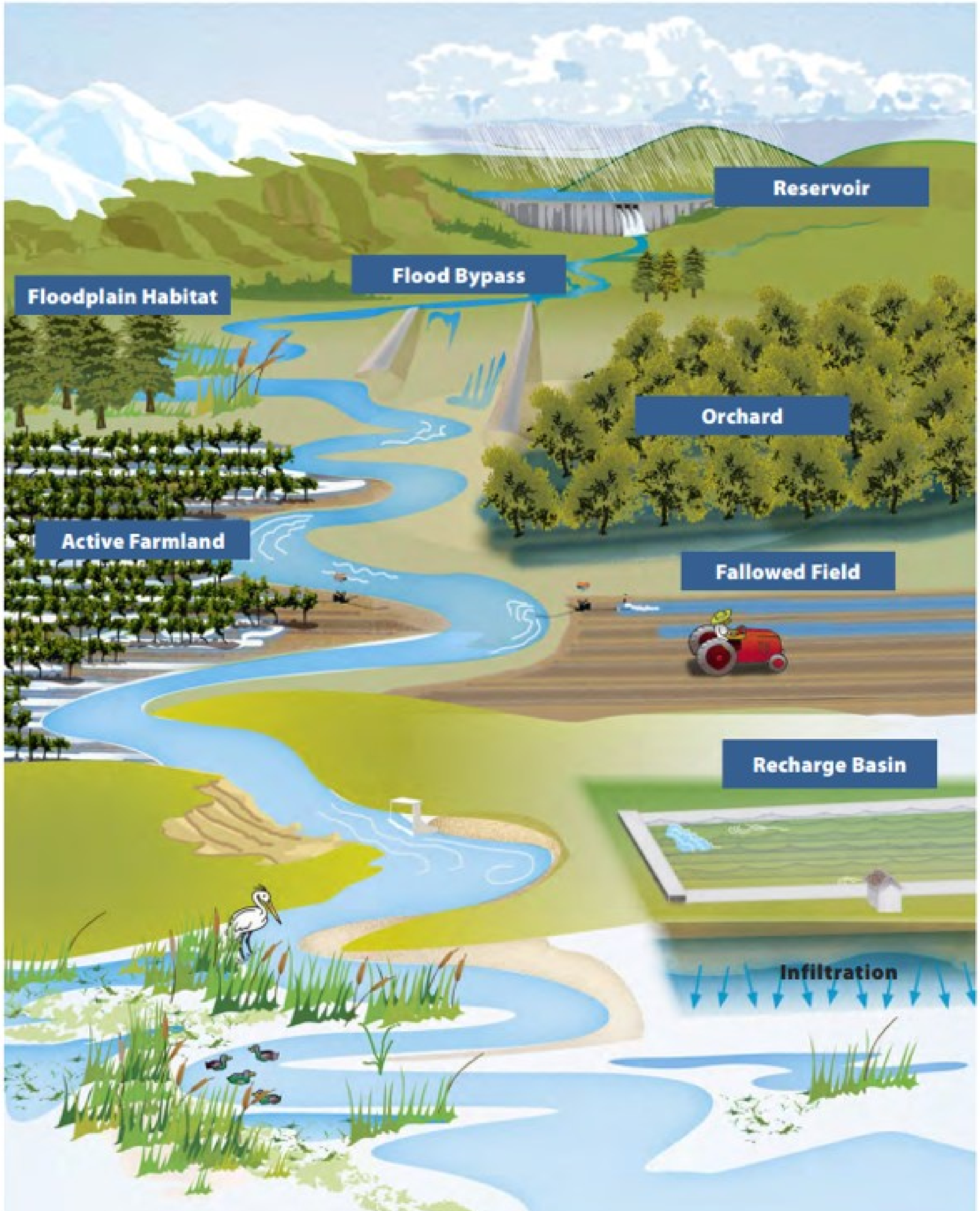


Figure 4 Source: California Department of Water Resources Flood-MAR white paper: *Using Flood Water for Managed Aquifer Recharge to Support Sustainable Water Resources*

Aquifer Storage and Recovery

Aquifer storage and recovery (ASR) projects directly and actively inject water into groundwater systems with immediate volumetric results. ASR projects may utilize different water sources for aquifer injection, and many ASR projects inject highly treated or recycled water. ASR projects are typically implemented in historically overdrafted and high-demand groundwater basins to bank or recharge water for subsequent recovery and extraction. ASR is also used to reduce seawater intrusion, improve groundwater quality, and reduce subsidence.

California's 58 counties are required by the California Water Code to regulate any type of water-related well, including injection wells, but the effectiveness of that regulation varies considerably depending on the county. Some injection wells are further regulated for groundwater quality purposes by the U.S. Environmental Protection Agency in accordance with the Underground Injection Control program authorized by the federal Safe Drinking Water Act.

Drywells

Another method to increase recharge and reduce runoff is the installation of drywells. Unlike ASR projects that actively inject water into the ground, drywells are underground, gravity-fed structures (typically vertical structures) that can be used to capture water to infiltrate into the groundwater aquifer. The use of drywells for disposal of urban runoff can affect groundwater quality. To avoid contaminating the aquifer, certain best management practice are outlined in the State Water Resources Control Board's (State Water Board's) *California Drywell Guidance Research and Recommendations*. This guidance report provides a risk-based framework for siting, design, installation, and maintenance of drywell projects; for identifying scenarios where infiltration of stormwater through drywells could negatively affect groundwater quality; and for identifying solutions to mitigate scenarios that pose a high risk to groundwater quality (State Water Resources Control Board 2020).

Green Infrastructure

Some green infrastructure, or low-impact development can increase groundwater recharge by utilizing stormwater capture infrastructure and features, which allow water to pond and percolate into the ground. They can also be designed to be porous to allow water to infiltrate into the ground. Examples of low-impact development projects that support groundwater recharge include infiltration trenches, rain gardens, bioretention gardens, bioswales, and pervious pavement.

Why is Identifying, Utilizing, and Protecting Recharge Areas Important?

Identifying and utilizing groundwater recharge areas is important because these areas can be used for recharging aquifers, a critical part of California's natural infrastructure, that can help balance and replenish groundwater supplies for use during dry and drought years. Groundwater recharge is a key strategy throughout California to manage water through climate-driven weather extremes, such as prolonged drought and periodic intense storm events. As a result, it's important to identify, utilize, and protect potential recharge areas to maintain the quantity and quality of groundwater in the aquifers.

Recharge areas function properly when aquifer storage capacity is available, sufficient permeable surface is present to allow infiltration, an adequate supply of surface water is available to recharge the aquifer, and the infiltrating water and the recharge area is free of contaminants that could negatively affect the groundwater quality. Protecting existing and potential recharge areas allows them to serve as valuable components of a conjunctive groundwater management strategy.

Protection of recharge areas requires actions based on two primary goals:

- Ensuring that areas suitable for recharge continue to be available and capable of adequate recharge.
- Preventing pollutants from entering groundwater to avoid expensive treatment that may be necessary prior to beneficial use.

The Sustainable Groundwater Management Act

The Sustainable Groundwater Management Act (SGMA) was passed in 2014 to help protect California's groundwater resources. SGMA prioritizes local control of groundwater. In signing SGMA, Governor Jerry Brown emphasized that "groundwater management in California is best accomplished locally." SGMA initiated a decades-long process for communities to work together to understand the conditions of local groundwater basins, identify issues, and develop solutions.

SGMA empowered local agencies to form groundwater sustainability agencies (GSAs). GSAs in high- and medium-priority basins are required to prepare groundwater sustainability plans (GSPs) that describe their approach to reaching their basin's sustainability goal over a 20-year timeframe and to maintain sustainability over a 50-year planning horizon. A GSP describes the components of a groundwater basin, estimates water budgets, and identifies projects and management actions that will be implemented to reach the sustainability goal. Projects and management actions may include pumping allocations or restrictions, well registration and metering, stormwater capture for recharge, groundwater banking programs, and construction of new infrastructure to increase reliability of municipal water supplies.

Under SGMA, there is an increased interest at the local and State level to implement and maintain groundwater recharge projects to help reach the local sustainability goals. This interest has manifested in increased data collection and data analyses at the local and statewide scale to better understand and characterize groundwater recharge pathways.

The California Water Supply Solutions Act

The California Water Supply Solutions Act, also known as Senate Bill 659, was passed in October 2023 and is the latest legislative act aimed at supporting the implementation of SGMA and addressing California's water supply challenges. Beginning with California Water Plan Update 2028, the act requires DWR to include the latest actionable recommendations for increasing groundwater recharge throughout the state. The actionable recommendations include identifying opportunities for immediate and long-term solutions, with a priority for multi-benefit projects. The identification of these opportunities should include potential recharge locations, an estimate of the volume and source of water that can be recharged, legal and regulatory requirements, financial incentives, and how recharge activities would protect access to safe drinking water and provide water quality benefits. The act also requires the development of best practices to advance all benefits of groundwater recharge in the state. The best practices should define methods and processes to identify locations where groundwater recharge will be effective and protective of drinking water.

The passing of the California Water Supply Solutions Act underscores the importance of identifying, utilizing, and protecting groundwater recharge areas in California and the need for this RMS and its recommendations.

2. Recharge Area Identification, Utilization, and Protection in California

Resources for Identifying Potential Recharge Areas

Areas that are best suited for groundwater recharge have a hydraulic connection between the ground surface and aquifer. Typically, this hydraulic connection can be defined as a pathway from predominately coarse-grained materials that exist at the surface and connect down through the aquifer. The ground surface, aquifer, and groundwater characteristics described in the reports, data, and tools below can be integrated to identify areas that would be best suited for groundwater recharge.

California's Groundwater

California's Groundwater, also known as Bulletin 118, is the State's official publication on the occurrence and nature of groundwater in California. California's Groundwater defines the groundwater basin boundaries and summarizes groundwater information for each of the state's 10 hydrologic regions. As instructed by the California Water Code Section 12924, DWR is required to investigate the state's groundwater basins and release a report (California's Groundwater) of findings every five years.

DWR has also developed California's Groundwater Live to improve the access and timeliness of groundwater data submitted by local agencies. California's Groundwater Live is a web-based dashboard that utilizes many of the same datasets from *California's Groundwater Update 2020*. The data presented in California's Groundwater Live can also be found on the California Natural Resources Agency Open Data portal.

Statewide Reports

California's Groundwater – Statewide Report is updated every five years and features current knowledge of groundwater resources including information on the locations, characteristics, uses, management status, and conditions of the state's groundwater. The publication also presents findings and recommendations that support the future management and protection of groundwater. Future updates of this publication will provide an overview of existing and potential recharge areas in the state.

Regional Reports

Historic California's Groundwater – Regional Reports were published in the 1960s and 1970s to provide regional or cross-basin studies. The studies focused on analysis of the available data, groundwater conditions, and groundwater management activities at the time of publication for a given study area.

Basin Reports

California's Groundwater – Basin Reports describe most of the current groundwater basins in California and were last updated as part of *California's Groundwater Update 2003*. The reports include descriptions of basin boundaries, summaries of the hydrologic and hydrogeologic setting, groundwater storage capacity, water budget, groundwater level and quality trends, well yields, basin management, and references. These reports will be updated in future updates of California's Groundwater.

Basin Characterization Program – Data Collection and Analyses

California Water Code Section 12924 (a) directs DWR to conduct investigations of the state's groundwater basins and identify groundwater basins based on geological and hydrological conditions. Under that direction, DWR has launched a Basin Characterization Program to collect, analyze, and archive datasets that enhance the understanding of aquifer systems to support State and local agencies in managing this component of California's natural infrastructure. DWR will also conduct pilot studies, collect advanced geological and geophysical datasets, and develop tools to analyze new and existing datasets to develop state-stewarded texture and hydrogeologic conceptual models. All results of the analyses will be published in a future statewide report or regional report.

Groundwater Sustainability Plans

SGMA required GSAs to develop GSPs for the state's high- and medium-priority basins and subbasins, which can be found on the SGMA Basin Prioritization Dashboard. A GSP shows how a GSA will achieve the sustainability goal for its groundwater basin over a 20-year implementation period. Documentation of the best available data, knowledge of the groundwater basin characteristics, and groundwater management activities are required components of a GSP.

SGMA defines a "recharge area" as the area that supplies water to an aquifer in a groundwater basin. When developing a GSP, a basin's GSA(s) is required to identify existing and potential recharge areas and describe how recharge areas contribute to the replenishment of the basin. The recharge area maps are required to be provided to the appropriate local planning agencies to improve the coordination and consultation between California's water supply or management agencies and California's land use approval agencies.

In addition to delineating existing recharge areas, GSAs are required to describe projects and management actions that will help the basin reach sustainable conditions, which may include stormwater capture for recharge, ASR, and construction of new infrastructure to increase conjunctive management. GSPs can be accessed from DWR's SGMA Portal.

SGMA Data Viewer

As part of DWR's technical assistance to GSAs, other water managers, and the public, DWR has developed the SGMA Data Viewer. It provides access to groundwater-related datasets that are organized by the topics under SGMA and the required sections of GSPs.

The SGMA Data Viewer is a one-stop shop for the datasets and resources listed below. The datasets below are found under the Hydrogeologic Conceptual Model tab. When considering multiple datasets, feature colors and transparency can be modified to support visibility and data analysis.

Geologic Maps

Geologic maps display the distribution of materials that are present at the surface of the Earth. Materials are typically grouped by materials type, level of consolidation, and geologic age. Geologic maps provide information about surface conditions that are useful in understanding generalized surface recharge conditions.

The California Geological Survey's Geologic Map of California presents an overview of the geology and structure of the state. It represents the geologic features that could be found on a visit to any locality in the state. The restraints of scale limit the detail that can be shown, but the most important geologic features are depicted. The distribution of the major rock types and the major structural elements are shown with sufficient detail to be useful for many purposes, including identifying potential groundwater recharge locations.

Well Completion Reports

Well completion reports provide information about a well's location, construction, and casing, and a description of the lithology observed during drilling. Lithologic descriptions, commonly cataloged by a driller, can be interpreted for geologic texture and used to understand the distribution of coarse- and fine-grained materials at the well's locations. Well completion reports are an important resource for developing geologic texture models.

Anyone who constructs, alters, or destroys a water well, cathodic protection well, groundwater monitoring well, or geothermal heat exchange well must file a well completion report with DWR. DWR maintains these reports in the Online System of Well Completion Reports (OSWCR), a geospatial database and index of well completion reports in California.

Geologic Texture from Central Valley Hydrologic Model Version 2

The U. S. Geological Survey developed a hydrologic model for the Central Valley to aid water managers in understanding how water moves through the aquifer system, predict water-supply scenarios, and address issues related to water demand. The Central Valley Hydrologic Model Version 2 (CVHM2) is an extensive, detailed three-dimensional (3-D) computer model of the hydrologic system of the Central Valley (Faunt 2009).

In support of developing CVHM2, a geologic texture model was created to characterize groundwater basin materials. The geologic texture model shows the distribution of coarse- and fine-grained materials throughout the Central Valley. The model was developed by analyzing drillers' logs of boreholes and interpolating that data into a 3-D model space with a resolution of one square mile laterally by 50 feet vertically. The CVHM geologic texture data provide information about where there are pathways connecting coarse-grained materials at the surface to the deeper aquifer system. Additional information can be found on the U.S. Geological Survey's CVHM website. Depth slices of the CVHM texture data can be accessed on DWR's SGMA Data Viewer, under the Hydrogeologic Conceptual Model tab.

Shallow Subsurface Texture Map from Statewide Airborne Electromagnetic Surveys

As a part of DWR's Statewide Airborne Electromagnetic (AEM) Survey Project, AEM data were collected in all high- and medium-priority groundwater basins, where data collection was feasible. AEM data can provide valuable information about groundwater basin structure, to depths of 1,000 feet. The information improves the understanding of aquifer structures, the development or refinement of hydrogeologic conceptual models, and can help identify areas for recharging groundwater. All DWR AEM survey data are published on the California Natural Resource Agency Open Data portal.

Data collected during an AEM survey are typically displayed as cross-sections showing electrical resistivity versus depth, where electrical resistivity describes the ability of a material to resist an electric current. AEM data are interpreted from electrical resistivity to material texture (percent coarse fraction). This interpretation is supported by existing information, such as well completion reports, geophysical logs, water quality reports, and water levels. Analysis of the AEM texture data provides information that supports various aspects of groundwater recharge area identification, including identifying where there are pathways connecting predominately coarse-grained material at the surface to the aquifer system.

DWR developed a map showing the average AEM-derived texture in the shallow subsurface (the upper 50 feet) (Figure 5). This map supports identifying potential recharge pathways, where the upper 50 feet is dominated by coarse-grained materials. The shallow subsurface average map for the AEM-derived texture data can be accessed on DWR's SGMA Data Viewer, under the Hydrogeologic Conceptual Model tab. The AEM electrical resistivity and AEM-derived texture data can be viewed in a 3-D space in one of DWR's innovative AEM Data Viewers.

Groundwater Age from the Groundwater Ambient Monitoring and Assessment Program

The age of water in an aquifer can be determined by measuring its tritium concentration, a radionuclide present in the atmosphere as a result of nuclear testing in the 1950s and 1960s. Because the rate of decay of tritium is known, the concentration of tritium can be measured in groundwater and determine when groundwater last had contact with the atmosphere (time since it was recharged to groundwater). In areas of higher recharge, groundwater exhibits higher tritium concentrations. Figure 6 shows areas of younger groundwater in lighter colors (areas of increased tritium and less time since recharge), in comparison to areas of older groundwater in darker colors (areas of decreased tritium and more time since recharge). Areas of older groundwater are not prime areas for recharge, natural or artificial. This map is available online through an interactive application on the State Water Board's Groundwater Ambient Monitoring and Assessment (GAMA) Online Tools webpage.

Figure 5 Average AEM-derived Texture for the Shallow Subsurface

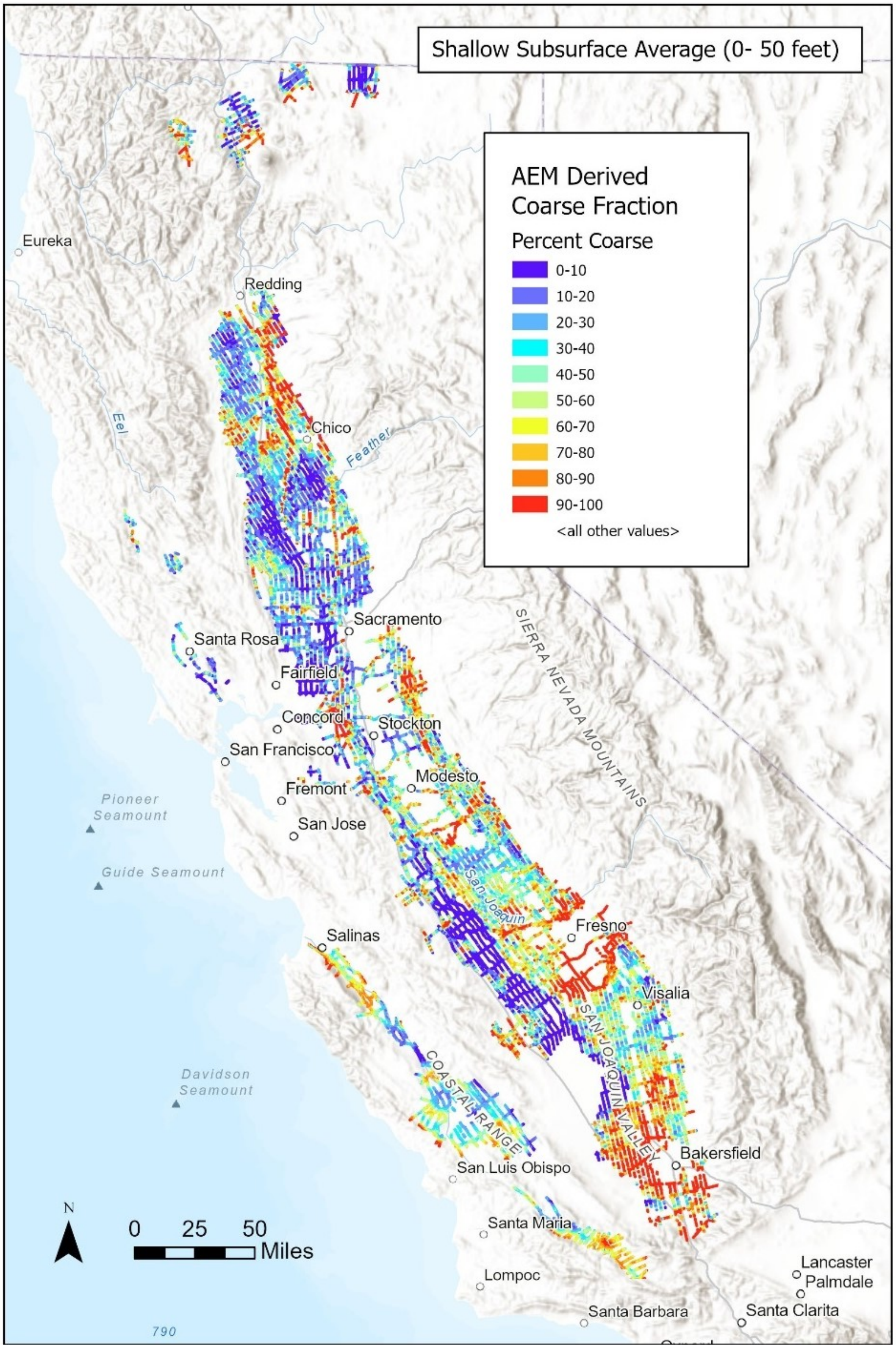


Figure 5 Source: [Sustainable Groundwater Management Act Data Viewer]

Figure 6 Groundwater Age Data

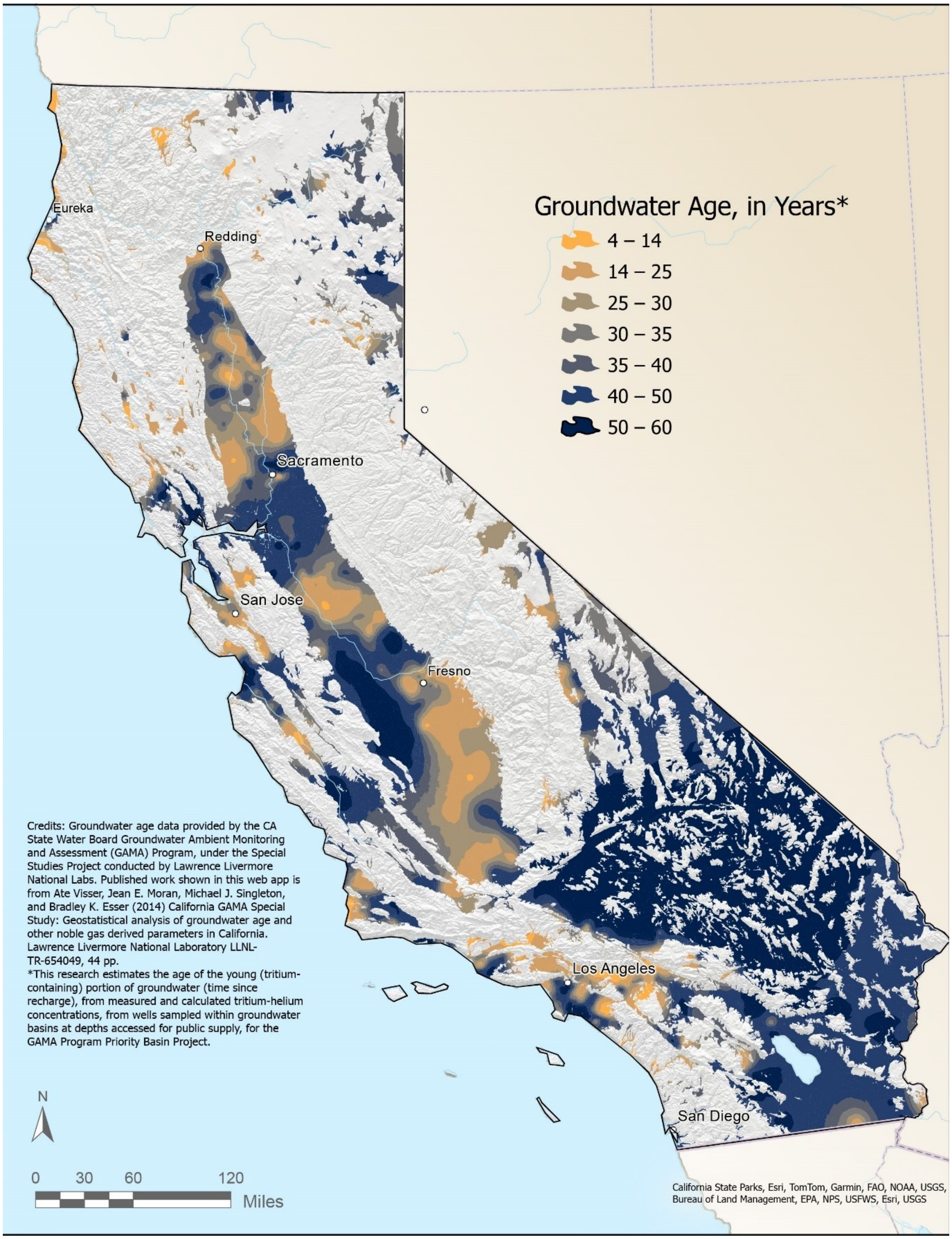


Figure 6 Source: California State Water Board Groundwater Ambient Monitoring and Assessment (GAMA) Program, under the Special Studies Project conducted by Lawrence Livermore National Labs (Visser et al. 2014)

Soil Agricultural Groundwater Banking Index

The Soil Agricultural Groundwater Banking Index (SAGBI) from the University of California, Davis, is a suitability index for groundwater recharge on agricultural land. The SAGBI is based on five major factors that are critical to successful agricultural groundwater banking: deep percolation, root zone residence time, topography, chemical limitations, and soil surface condition. More details can be found in the SAGBI article in California Agriculture.

Groundwater Recharge Assessment Tool

The Groundwater Recharge Assessment Tool (GRAT) from Sustainable Conservation and The Earth Genome, integrates hydrologic, agronomic, and geologic information to evaluate potential recharge locations. GRAT evaluates data to support determining when, where, and how much water can be recharged in the most cost-effective way. GRAT offers an online viewer to display the publicly available data that are analyzed in GRAT. It also offers specialized services for registered users to allow them to import additional data and run customizable scenarios.

Utilization of Groundwater Recharge Areas

Groundwater basins can serve as a drought buffer when managed sustainably and can provide a reliable water source when there is a reduction in surface water supplies because of less rain and snowmelt. As weather patterns have become more variable and extreme from the effects of climate change, resulting in more frequent and consequential droughts and high-flow events, groundwater recharge projects with a purpose of replenishing depleted groundwater basins have become an essential part of California's long-term water resilience and drought mitigation efforts. As part of the Newsom administration's water supply strategy, the State is looking at expanding groundwater recharge by at least 500,000 acre-feet in potential capacity, streamlining permits, and investing $1 billion for groundwater recharge projects. Significant expansion of groundwater recharge projects is seen throughout the state. By expediting groundwater recharge projects, the State can help local agencies prepare to take advantage of future heavy precipitation events.

DWR has begun advancing these local projects through financial assistance. In 2021 and 2022, DWR awarded $68 million to 42 groundwater recharge projects that can provide almost 117,000 acre-feet per year of potential recharge capacity. DWR will award additional grants in 2023 based on available funding. So far, applications for this funding include 52 proposed groundwater recharge projects, totaling

$211 million in cost. These State-funded projects, once vetted, permitted, and constructed, will increase the potential capacity of getting more water underground.

There is no centralized database of statewide recharge infrastructure and their capacities, which is necessary for effective management of groundwater. California Groundwater Projects Tools catalogued 344 groundwater recharge projects in the state that have received some form of financial assistance from DWR. The cumulative annual recharge capacity of these 344 projects can be as much as 2.2 million acre-feet. There are other existing recharge projects that are being operated by local agencies, and additional recharge projects are planned statewide that will increase the state's overall recharge capacity.

As storms hit the state in the winter of 2023, Governor Newsom issued an executive order on March 10, 2023, to temporarily lift regulations and allow the floodwater to be diverted to groundwater basins for recharging the basins. The order also suspended regulations and restrictions on permitting and use to enable water agencies and water users to divert flood-stage water for the purpose of boosting groundwater recharge. The State Water Board facilitated the diversions of flood water during the high-flow season. Under the governor's Executive Orders N-4-23, N-6-23, and N-7-23, more than 400,000 acre-feet of floodwater was diverted for groundwater recharge on almost 100,000 acres of land. Senate Bill 122 codified many of the provisions of the flood diversion executive orders into the California Water Code Section 1242.1.

It is expected that utilization of recharge areas will continue to grow as more advanced data collection methods, such as remote sensing and AEM surveys, are increasingly used to identify potential recharge areas throughout the state.

Protection of Recharge Areas

Protecting recharge areas is necessary to maintain the quantity and quality of groundwater in the aquifer. While there are a variety of methods and actions that can be taken to protect groundwater recharge areas, they are all based on two primary goals:

- Ensuring that areas suitable for recharge continue to be available and capable of adequate recharge rather than being covered by urban infrastructure, such as buildings, parking lots, and roads.

- Preventing pollutants from entering designated recharge areas that may interact with groundwater during infiltration, thus requiring expensive treatment of the groundwater prior to beneficial use.

It is important to achieve these goals of protecting recharge that is either occurring or that will potentially occur through both natural and artificial processes.

Methods of Protection

Recharge areas should be protected from potential contamination risks. Preventing contamination risks depends on controlling land use activities. Recharge areas should be designated so that greater control and management can occur where land use activities are a high risk for polluting these areas.

Defining, identifying, and mapping recharge areas are important steps toward protecting these locations and groundwater supplies. Several steps can be taken to characterize recharge areas and develop strategies to protect them. After the recharge areas are located, the following should be considered to determine the level of protection needed:

1. Analyze the susceptibility of the natural setting in the recharge areas to contamination.
2. Inventory existing potential sources of groundwater contamination to recharge areas.
3. Classify the relative vulnerability of recharge areas to contamination events.
4. Designate recharge areas that are most at risk to contamination events.
5. Protect recharge areas by minimizing activities and conditions that pose contamination risks.

Communities use a combination of regulatory and voluntary methods to address threats to the recharge areas and to prevent contamination from occurring. Examples of recharge area protection activities can include:

- Land use controls, such as zoning ordinances, can play a major role in protecting recharge areas by amending local codes to establish minimum live horticultural element requirements for parcels. While most zoning ordinances do not include specific groundwater recharge protection regulations, local governments can incorporate groundwater-recharge-area protection into their existing plans. Zoning can limit land use activities that have potential to introduce pollutants to recharge areas or limit lot sizes in designated recharge areas.

- Ordinances and reinforcements for hazardous waste; stormwater handling and disposal; septic, aboveground, and underground storage tank requirements.
- Bests management practices.
- Routine monitoring and site inspections.
- Individuals can take active roles and steps in protecting drinking water resources from contamination (e.g., using and disposing harmful materials and medications properly, limiting use of pesticides and fertilizers, and properly maintaining septic systems). Local governments can also use public outreach methods such as installing signage in natural recharge areas and using social media to communicate the importance of the protection of recharge areas.
- Hazard mitigation efforts and plans by water and wastewater utilities.

The development of these protection methods and strategies is an important step in the right direction, but the effectiveness will ultimately depend on the implementation. Groundwater recharge area protection policies and enforcement are more likely to be implemented and effective if local awareness, advocacy, and management exists. Local agencies have intimate knowledge about their communities, and they can select strategies based on the demographics and the goals of the jurisdiction.

Regional and Local Efforts to Protect Recharge Areas

Regional and local efforts undertaken across the state provide the framework for developing groundwater quality protection strategies. While some of these efforts do not specifically address the protection of groundwater recharge areas, policies and strategies have an important effect on the quality of water used for recharging groundwater.

Conservation, Development, and Utilization of Natural Resources

Government Code Section 65302 requires that California cities and counties review the land use, conservation, and safety elements of the general plan for the consideration of flood hazards, flooding, and floodplains to address flood risks. Cities and counties are required to identify rivers, creeks, streams, flood corridors, riparian habitat, and land that may accommodate floodwater for purposes of groundwater recharge and stormwater management in the conservation element (California Government Code Section 65302[d][3]). The intent is to conserve areas used for groundwater recharge and stormwater management and to minimize urban development in these areas. While this legislation only addresses groundwater recharge areas associated with floodwaters, it aligns with protection strategies for groundwater recharge areas.

California Government Code Section 65352.5 requires close coordination and consultation between California's water supply or management agencies and land use approval agencies. The intent of this legislation is to provide a standardized process for determining the adequacy of existing and planned future water supplies to meet existing and planned future demands on these water supplies and the effect of land use decisions on the management of California's water supply resources.

Basin Plans

The State Water Board is the agency responsible for protecting and maintaining the beneficial use of waters of the state, which include surface and groundwater resources. The State Water Board utilizes nine regional water quality control boards (regional water boards) to regulate water quality issues at a regional level. The basin plans are the overarching documents that provide the regulatory foundation in each regional water board jurisdiction and include groundwater quality regulations and protection strategies that focus on existing and potential land use activities in groundwater recharge areas.

As the strategies and practices for managing groundwater recharge areas evolves, existing policies may need to be strengthened, or new policies implemented, to address water quality concerns associated with recharge areas. The regional water boards continue their efforts to augment the basin plans and develop implementation strategies to protect recharge areas.

Groundwater Sustainability Plans

The passage of SGMA in 2014 set forth a statewide framework to help protect groundwater resources over the long term for all beneficial users and uses. In addition to delineating existing recharge areas, GSPs also describe projects and management actions that may include implementation strategies such as pumping allocations or restrictions, well registration, metering, and monitoring to protect recharge areas and increase reliability of municipal water supplies.

General Plans

Each California city and county must prepare a comprehensive, long-term general plan to guide the vision, goals, and objectives of the communities in terms of planning and developments. The plans define and protect existing resources while providing a blueprint for future growth. General plans have seven required elements.

Groundwater recharge area protection policies are typically located in the Land Use, Conservation, Open-Space, or Safety elements. General plans identify the importance of protecting groundwater recharge areas but the methods and level of actions to achieve this protection can vary greatly.

Addressing water quality issues associated with recharge areas requires the management of land use. As a result, it is important for regulatory agencies and water resources agencies that do not have direct authority to regulate land use decisions to collaborate with city and county planning departments to incorporate public policies that establish recharge area protection strategies through the land management.

Land Repurposing

Strategic repurposing of the land surrounding small, rural disadvantaged communities of the Central Valley can bring multi-benefit opportunities for achieving water sustainability and creating local socioeconomic benefits. As the main water users, California farmers have become more vulnerable to the increasingly unreliable surface water supply, leading them to overdraft underlying aquifers. While challenges faced by California's rural disadvantaged communities are numerous, California's new policies, such as SGMA, are starting to regulate groundwater sustainability and may present opportunities to address these challenges by incentivizing land repurposing that could benefit rural disadvantaged communities. For example, land repurposing strategies can reduce demand on overdrafted groundwater and manage aquifer recharge.

A study conducted in 2023 identified disadvantaged communities in the Sacramento Valley and the San Joaquin Valley regions and explored the potential for groundwater banking and managed aquifer recharge by repurposing the retired agricultural land (Fernandez-Bou et al. 2023). According to the findings of the study, aquifer recharge has the potential to increase groundwater storage and substantially reduce overdraft by repurposing agricultural lands in the Sacramento Valley and San Joaquin Valley regions, particularly in areas of current groundwater overdraft conditions.

The study included policy recommendations and a proposed framework for conducting feasibility studies in partnership with local interested parties to develop specific recharge projects. With correct policies in place, the framework can offer tools and strategies for farmers and interested parties in the industry to significantly improve the aquifer conditions using managed aquifer recharge and improve quality of life in disadvantaged communities.

Drinking Water Source Assessment and Protection Program

The Drinking Water Source Assessment and Protection (DWSAP) Program, currently administered by the State Water Board Division of Drinking Water, defines areas of protection for individual public drinking water wells. This program also has a proposed initiative to identify and limit potentially contaminating activities in headwaters and natural recharge areas. This initiative would include the use of public outreach, such as signage and educational opportunities, to limit potentially contaminating activities in headwaters and natural recharge areas.

National Pollutant Discharge Elimination System Stormwater Program

The National Pollutant Discharge Elimination System (NPDES) Stormwater Program regulates stormwater discharges from three potential sources: municipal separate storm sewer systems (MS4s), construction activities, and industrial activities. The permitting mechanism is designed to prevent stormwater runoff from washing harmful pollutants into local surface waters such as streams, rivers, lakes, or coastal waters. MS4 operators must obtain an NPDES permit and develop a stormwater management program.

Regulated MS4s are required to implement a stormwater management program to reduce the contamination of stormwater runoff and prohibit illicit discharges. While this document does not specifically address the protection of groundwater recharge areas, managing stormwater pollution has an important effect on the quality of water that will be recharging groundwater supplies. As a result, local agencies that are required to develop a stormwater management program have another opportunity to specifically target the protection of groundwater recharge areas and infiltrating water quality.

3. Benefits of Recharge Area Identification, Utilization, and Protection

There are clear benefits to identifying, utilizing, and protecting groundwater recharge areas. Groundwater recharge activities can provide multiple public and private benefits for Californians, infrastructure, and the ecosystems of the state (California Department of Water Resources 2018). Implementing groundwater recharge activities can benefit local, regional, or statewide economic, environmental, and water resources system conditions.

Flood Risk Reduction

Aging infrastructure, deferred maintenance, and climate change have intensified the flood risk to people and property. Groundwater recharge via Flood-MAR can reduce downstream flood risk by diverting flows from river channels to working landscapes (including floodplains and flood bypasses), thereby reducing peak river flow and stage. The reduction of flow and stage in river channels also provides reservoir operators with additional flexibility to manage flood releases to increase space in reservoirs — providing potential for flood-risk reduction benefits. Alternatively, groundwater recharge strategies coupled with reservoir reoperation and improved forecasting can further reduce flood risk by allowing reservoirs to release water for groundwater storage ahead of anticipated precipitation or snowmelt to increase flood storage space in reservoirs.

Drought Preparedness and Aquifer Replenishment

Groundwater recharge results in more water being stored in aquifers, which improves drought resiliency by keeping water in storage for dry years, droughts, or water shortages. Like "carryover" storage in surface-water reservoirs, groundwater may be dedicated and managed for use in the next season or future dry water years.

Because of several factors, including the recent historic drought, aquifers in many areas are in a condition of overdraft, and groundwater levels continue to decline. Recharging or replenishment of groundwater aquifers provides water resources that may be extracted for beneficial uses. But, in some cases, a water agency may strategically choose to leave water in the basin for the purpose of aquifer replenishment, to increase or maintain groundwater levels, or to store groundwater for later use when surface water supplies are reduced.

SGMA Compliance

At the start of 2015, SGMA set in motion a foundational transformation to the governance, planning, and management of groundwater basins in California. SGMA takes a long-term, outcome-driven approach for groundwater management. Inherent in this approach is the understanding that it will take years, if not decades, to stabilize and restore groundwater basins, and that local proactive management will need to continue in perpetuity to deliver the intended outcomes. All changes mandated in SGMA are designed to prevent six undesirable results and support the sustainable use of water, including the requirement to identify and delineate existing recharge areas and to describe the management of groundwater recharge. Implementing groundwater management activities helps local agencies avoid undesirable results and meet their groundwater management sustainability goals.

Water Markets and Transfers

With the implementation of SGMA, GSAs may utilize water markets and water transfers, which are becoming more common in California, to augment supplies. Currently, water transfers are complex to implement and not always reliable, being affected by the amount of surface water available, conveyance timing, bottlenecks in the conveyance system (such as through the Sacramento-San Joaquin Delta), and by cost. Pairing managed groundwater recharge with water transfers potentially provides flexibility to the receiving agency or its members with additional water storage capabilities.

Water Supply Reliability and Water Equity

Groundwater is a critical and integral component of California’s overall water supply, serving residents, businesses, farms, and industries. Approximately 30 million Californians (approximately 75 percent) depend on groundwater for a portion of their water supply. On average, groundwater provides approximately 40 percent of statewide total annual agricultural and urban water uses, while some areas are 100 percent dependent on groundwater for their supply. In certain parts of the state, long-term groundwater use has had serious effects on water supply reliability, including declines in groundwater levels and storage and degradation in water quality. Groundwater recharge can significantly increase water supply reliability for agricultural, urban, and domestic well users, including disadvantaged communities.

Reduced Water Pumping Costs

Increasing groundwater levels via aquifer recharge will help groundwater users reduce their groundwater pumping costs by decreasing the lifting distance that groundwater needs to travel to the surface, thus reducing power consumption. It would also increase the lifespan of the well by avoiding premature wear-and-tear attributed to sanding and cascading water into the well and could avoid the need for wells to be deepened. This benefit of reduced pumping costs is likely only possible if all other factors remain the same (e.g., volume of water pumped, electricity rate remains the same) and only the groundwater elevation changes.

Ecosystem Enhancements

Groundwater recharge can provide ecosystem benefits by maintaining or reconnecting and inundating floodplains; creating floodplain habitat (e.g., riparian), marsh, and wetlands; supplementing baseflows; and supporting groundwater dependent ecosystems through the result of higher groundwater levels. Recharging groundwater supplies also has the potential to provide ecosystem benefits by boosting instream baseflow or reducing surface water temperature through surface and groundwater interactions.

Subsidence Mitigation

Groundwater recharge has the potential to reduce groundwater overdraft conditions and stop or slow land subsidence by maintaining pore pressure in fine-grained sediments to avoid or reduce its compaction. Land subsidence has been an issue in California for nearly a century and can significantly damage infrastructure, including water supply conveyance facilities, levees, and flood channels weakening the physical structures and reducing their water storage and carrying capacities by reducing hydraulic gradients (Faunt et al. 2016). Land subsidence can permanently reduce the water storage capacity of an aquifer and may damage ecosystems if surface drainage is altered, leading to anoxic (i.e., oxygen deficient) conditions.

Water Quality Improvement

Groundwater recharge can improve groundwater quality by increasing the amount of water in storage and potentially diluting impaired or contaminated aquifers, especially with respect to salts and nutrients. Salts and nutrients may occur across large aquifer areas at concentrations that are near or above regulatory levels. In such cases, dilution may provide significant benefits.

Seawater Intrusion Mitigation

Seawater intrusion in a coastal aquifer occurs when groundwater pumping lowers the groundwater levels and results in seawater being drawn inland toward freshwater zones in the aquifer. Seawater intrusion degrades groundwater quality and decreases the availability and amount of freshwater storage in the aquifer. Increasing groundwater levels through groundwater recharge can help prevent, slow, or, in some situations, reverse seawater intrusion into coastal aquifers by creating a subsurface pressure barrier.

Recreation and Aesthetics

Groundwater recharge activities and site protection have the potential to provide recreation and aesthetic benefits based on the land use of the recharge area. For example, increased flooding on refuges can improve bird watching, outdoor sporting opportunities, or creation of wetlands. Improved connection or reconnection of rivers and streams to floodplain habitat can improve the natural beauty of a landscape over non-vegetated, dedicated recharge basins.

4. Costs of Implementation

Costs for identification, utilization, and protection of recharge areas may include a wide range of activities, such as data collection, acquiring land, infrastructure development, operation and maintenance, and prevention of potential contamination of recharge sites.

Costs of Recharge Area Identification

Groundwater recharge areas are currently identified based on a wide range of criteria which include soil type, subsurface hydrogeologic characteristics, land uses, impervious surfaces, climate, precipitation, vegetation, and topography. The primary costs associated with recharge area identification are costs of field surveys, data collection and analysis, soil testing, aquifer parameter estimation, hydrogeologic investigations, and pilot studies.

Costs of Recharge Area Utilization

It is generally agreed, based on historical data, that groundwater recharge is one of the lowest cost-per-acre-foot water supply management strategies. A study published by Water in the West found that the costs of replenishing groundwater by putting water back into the ground range from $90 to $1,100 per acre-foot in 2014 U.S. dollars, based on 25th to 75th percentile costs of studied projects (Choy et al. 2014).

In contrast, raising dams to increase reservoir capacity to store water costs $1,700 to $2,700 per acre-foot (Lund 2014). Another study found the cost of recharging raw water ranges from $235 to $550 per acre-foot, whereas costs of recharging recycled water ranges from $1,430 to $2,330 per acre-foot because of treatment requirements for recycled water (Ross and Hasnain 2018).

Costs of using recharge areas vary depending on the nature and size of the project, frequency of use of recharge facility, sources of surface water supplies, and quality of surface water. Some recharge projects require relatively minor changes in operations or upgrades of existing infrastructure, such as increased sizing of pumps in existing wells or increasing releases of water from existing conveyance canals. Other recharge projects may require extensive projects such as new facilities that can include canal turnout structures, new pipelines and pumps, injection or extraction wells, or construction of new recharge basins. Flood-MAR projects, which utilize existing infrastructure to flood agricultural lands and recharge the underlying aquifers, offer a recharge solution that is very low cost if it is limited to individual or a group of landowners. Capturing and applying flood flows was calculated at $36 per acre-foot during a pilot project on farmland in the Kings River Basin. The primary goal of the project was to reduce damages associated with 10- to 100-year flood events (Bachand et al. 2016). The project costs included labor, land preparation, fuel, and farm-scale infrastructure improvements.

But the costs of a Flood-MAR project could also be high if the project calls for use of extensive detention or recharge areas, and modernizing flood management infrastructure and operations. In contrast, capital costs and conveyance costs are not applicable to natural channel bed or streambed recharge.

The objectives of groundwater recharge projects can vary and can be used for replenishment of groundwater, maintaining groundwater dependent ecosystems, groundwater water quality treatment, supplying drinking water and agricultural water, and preventing or reducing land subsidence and seawater intrusion. If the recharge project objective is groundwater replenishment, then there are no additional costs to recover the water resource. But projects with multiple objectives tend to require more planning, coordination, and larger capital investments.

There is a general lack of data on costs of recharge projects, especially the full life-cycle costs, because of a lack of record-keeping or data availability. DWR is advancing local recharge projects through financial assistance, which sheds light on the capital costs and projected benefits of recharge projects. In 2021 and 2022, DWR awarded $68 million in grants to 42 groundwater recharge projects that can provide nearly 117,000 acre-feet of potential recharge capacity. It should be noted that the DWR grants do not always cover the entire cost of a recharge project, but there are other sources of matching funding for these projects (e.g., local, and federal sources). As a result, the costs of recharge projects in terms of cost-per-acre-foot of recharge capacity is an elusive number. Annual operation and maintenance data is even more sparse. For example, of the 343 groundwater recharge projects catalogued in the California Groundwater Projects Tool, only four have reported annual operation and maintenance costs.

The cost numbers presented here must be treated with caution because of the data obtained from a small number of projects of various types. But the numbers give some indication of the cost differences among various types of recharge projects.

Cost Considerations for Planning Recharge Projects

There are several components that comprise the overall cost to plan, build, and operate a groundwater recharge project.

- Capital costs encompass the expenses required to plan, design, permit, and construct a recharge infrastructure project, as well as the land costs for the project footprint.
- Conveyance costs include the necessary infrastructure to move source water to the place of recharge or from the extraction points to a place of use.
- Pumping costs consist of installation of wells and the energy needed to pump water up (extraction well) or push water down (injection well). Pumping costs often are also associated with conveyance when using pressurized pipes or lift/pump stations.
- Long-term operation and maintenance (O&M) costs include those expenses required for continued energy use, equipment operations, and maintenance of facilities and infrastructure associated with recharge. Electricity costs are an important element of O&M expenses. For example, gravity-driven systems are cheaper than those requiring electrical and mechanical pumping. The expenses for cleaning basins (including the effect of temporarily decommissioning the basin during cleaning and drying) could also be significant.
- Some recharge projects have water treatment costs, but those costs may be included with capital or O&M categories.

The main factors that determine the relative costs of recharge projects include:

- Type of aquifer recharge and recovery technology used.
- Source of water and consequent conveyance facilities required.
- Quality of recharge water and related amount of water treatment required.
- End-use of the recovered water and the amount of water treatment required.

Other significant factors that affect recharge project costs include the project objectives, scale of the project, frequency of utilization and operating period, life expectancy of the project, and hydrogeological setting, including soil and aquifer characteristics.

Scale of project footprint is an important consideration for areas with limited space as well as a factor for influencing the rate of recharge. A percolation pond takes up more space than an injection well, but usually costs less because it requires much less infrastructure to implement and lower O&M cost. But the cost of a percolation pond project may increase if the land must be purchased. One way to keep percolation pond costs lower is to implement projects where access to land can be obtained for free from local authorities.

A Flood-MAR project may have an even greater footprint but is often a reuse of existing space, without requiring the permanent loss of other uses of the space (e.g., using an offseason or fallowed agricultural field for recharge). Bigger project footprints can mean bigger land requirements, which may be an important contribution to overall project costs.

Projects can also vary widely in terms of volume and rates of recharge. Local conditions (soil type, sediment thickness) affect percolation rates as well as the project design (extent of infiltration basin, depth of water). The rate of infiltration may drive decisions on project sizing or method of infiltration and directly affect the cost per acre-foot of recharge. For example, the rate of recharge per square foot is highest with an injection well, but so is the cost per acre-foot, especially considering long-term O&M.

The source of water for recharging is another component of project costs. Infiltration and spreading basins recharging natural raw water (untreated freshwater) are very common because of their relatively low cost. Raw water is typically the cheapest source water and includes water in reservoirs, stormwater runoff, flood flows, or other natural water sources. But raw water can also be unreliable, fully allocated, or otherwise unavailable for use.

Infiltration and spreading basins recharging recycled wastewater have relatively high costs compared with infiltration of natural waters because of the need to treat the water. Treated water (recycled or desalinated water) may be more expensive because of treatment costs, but more reliably available. Quality of source water may also become a factor in determining the type of recharge project to invest in. For example, recycled water has different treatment requirements in California for in-lieu recharge (at agronomic rates), surface spreading and infiltration, and direct injection (State Water Resources Control Board 2018).

Costs of Recharge Area Protection

Groundwater recharge is a major strategy for sustainable and resilient water management in California. It is also a climate adaptation strategy. As a result, there is an emerging need not only to identify and use recharge areas, but also to protect the recharge areas so they may continue to be used in the future. Costs that may be associated with protecting recharge areas include the following:

- Purchase or lease price of the land with high recharge potential that may be used for a recharge project.
- Design and construction of facilities to protect the recharge areas from encroachment.
- Loss of income from beneficial land use by landowners.
- Loss of tax revenues for the government associated with land use changes.
- Field monitoring of groundwater to detect potential contamination from activities near recharge areas.
- Groundwater remediation to mitigate contaminant releases near recharge areas.

5. Challenges and Considerations

Governance and Coordination

Governance and coordination may be the most critical challenge in implementing groundwater recharge projects. Governance and coordination are essential to understanding local and system needs and opportunities, developing the necessary partnerships and agreements, navigating the permitting process, facility operations, and adaptive management.

Water systems in California are very complex, not just in hydrology, but in the way water management is conducted and coordinated. Water infrastructure is owned, operated, and maintained by numerous local, regional, State, federal, Tribal, and private entities. Water management decisions need to be coordinated across jurisdictional boundaries, water sectors, interests, uses, and, in some cases, across hydrologic boundaries. Adding to this complexity is that surface water and groundwater are managed differently throughout the state but are collectively important for conjunctive management of available water supplies.

Water Rights

Local agencies or landowners need to have water rights in terms of the quantity of water and the ability to divert at the right time of year. Obtaining a new water right can take time and be difficult to navigate. The State Water Board developed a streamlined permitting process for diversions of water from high-flow events to recharge groundwater. The streamlined process aims to assist local agencies working to address SGMA and possible adverse impacts caused by their extractions. As a part of the permitting process, a water availability analysis is needed to ensure that there is no harm to existing rights and that environmental water needs are appropriately considered.

Although a streamlined process exists for obtaining a water right during a high-flow event, the State water-rights system creates challenges because of the separate regulation of surface water and groundwater, storage rights of importers, and water rights of landowners and groundwater agencies.

Conveyance to Recharge Areas

An important consideration for groundwater recharge projects is how to get the available surface water to groundwater recharge sites. In some cases, such as properties adjacent to rivers, channels, and irrigation canals, existing conveyance is sufficient, but areas that currently rely on groundwater may lack surface water conveyance facilities. In many areas of the state, lack of sufficient conveyance facilities and the associated capital cost to construct conveyance facilities are a constraint for groundwater recharge projects. Also, some areas within critically overdrafted basins do not have sufficient infrastructure for managed aquifer recharge.

Additionally, the conveyance of water will have specific physical characteristics (e.g., conveyance capacity) and system operations that may limit the amount, or affect the timing, of water available at a specific site. Capacity constraints can limit the conveyance of water to a groundwater recharge location. New or modified conveyance facilities and modified operation of existing facilities are required to maximize managed aquifer recharge statewide.

Identifying Potential Recharge Areas

Several physical parameters determine the suitability of a potential site for providing groundwater recharge benefits. As discussed in Section 2 under, "Resources for Identifying Potential Recharge Areas," there are several resources that exist to support identifying potential recharge areas. But datasets may be sparse or non-existent in some areas. Additional resources will be needed to provide better data coverage and reduce data uncertainty. Efforts may include conducting additional airborne and ground-based geophysical surveys to determine the physical properties of a potential recharge area for its suitability.

Land Access

Land access is one of the most important aspects of siting and developing a groundwater recharge site. Some of the most optimal recharge sites (those that have good groundwater recharge rates, where water is recharged into the producing zone of the aquifer, and there is surface water conveyance infrastructure) may not be accessible or available for use. In some cases, groundwater agencies may be able to work with the landowner to acquire, or get access to, those optimal recharge sites. When the landowner is a local or State agency, or non-governmental organization, they may be willing to provide access to the property during certain times of the year for groundwater recharge activities. But if the landowner is a private entity that may have existing agricultural or livestock operations, they may be less willing to provide access to the property. In some cases, a groundwater agency may need to utilize a less optimal recharge site because it is accessible and available for use.

Land Use

When implementing groundwater recharge on agricultural lands, it is important to understand how crops will tolerate inundation. If the method damages or kills current or planned crops, reduces crop yield, or increases disease risks, those lands may not be ideal for groundwater recharge activities. In urban areas, the footprint of the recharge project needs to be considered along with property ownership, access, and likelihood of contamination, which relates to capital costs, as described in Section 3, "Benefits of Recharge Area Identification, Utilization, and Protection."

Zoning

Zoning can play a major role in protecting recharge areas by amending local codes to establish minimum living landscape requirements for parcels to retain these sites as recharge areas. Some areas that would provide good opportunities for recharge have been paved over or built upon and are no longer available to recharge the aquifer. Local governments often lack a clear understanding of recharge areas and the need to protect those areas from development or contamination. Land use zoning staff should consider the need for recharge area protection for water quantity and quality. Staff should also implement methods to educate the public regarding the locations of these areas. Public outreach methods, such as installing signage in natural recharge areas and using social media to communicate the importance of protecting these areas are possible ways of implementing effective zoning for managed recharge.

Vector and Odor Issues

Standing water in recharge ponds or spreading basins attracts mosquitoes, dragonflies, and other insects whose egg, larval, and pupal stages mature underwater. Mosquitoes can be vectors for serious or deadly diseases. Existing recharge programs use large numbers of mosquitofish which feed on the mosquito larvae in the water. Odors can be generated by growth and decay of algae, organic matter, and other water-borne vegetation. Vectors and odors should be addressed in any recharge program that involves standing water.

Groundwater Resource Recovery and Accounting

The ability to extract groundwater resources that have been previously recharged is a critical component to implementing a successful groundwater recharge program. To be considered a water supply benefit, recharged water must be recoverable. To recover the water, enough wells must be present near the sites to extract water from the target aquifers when needed. Additionally, the wells must be able to pump water (or have a screened interval) in the portion of the aquifer where the water is being recharged.

Knowing the aquifer parameters and monitoring groundwater levels can aid in understanding the movement of groundwater resources in the subsurface. But improved methods are needed to account and report on recharged groundwater, such as where the water goes, the rate it moves, if it reaches the water table, how it moves based on existing groundwater levels, and if it flows out of the basin.

Some amount of recharged water will not be recoverable. Determining the percentage of recharged water that can be considered recoverable requires development of accounting tools, groundwater monitoring networks, and groundwater modeling tools. Water that is not recoverable for water supply is still beneficial for aquifer replenishment.

Water Quality

Flooding recharge areas could mobilize surface or soil pollutants from current or past land uses and contaminate aquifers. It is recommended that historical land use and potential existing soil or groundwater contamination be researched prior to developing a groundwater recharge site.

Increasing recharge could also further spread existing groundwater contaminant plumes by altering rates and direction of groundwater flow. As a result, many industrial and urban point-source pollution cases may not benefit from dilution solutions. It is anticipated that any potential adverse water quality changes will be short-term and local, followed by long-term and regional benefits as a result of dilution.

6. Costs if Not Implemented

Water supplies can be lost by not protecting recharge areas. The growth of urban areas with impervious roads, freeways, parking lots, and large warehouse-type buildings means that these areas no longer allow runoff to infiltrate into the ground. Instead, the runoff flows rapidly into streams which peak more quickly and at higher flow rates than before urban structures were built. This runoff may create more frequent flood flows, losing the opportunity for natural groundwater recharge. Urban facilities are needed to artificially recharge the groundwater runoff, possibly at a cost to ratepayers. In a few urban areas, injection wells have been built to take the place of recharge areas that were lost to urban development. Injection wells are expensive, require careful technical control, and are not always able to be as productive as planned. But urban flood-flow injection wells may be cost-effective solutions compared to the high cost of urban land in many cities and the gained local resiliency by reducing the reliance on imported water supplies.

Subsidence

Land subsidence attributed to declining groundwater levels caused by excessive groundwater extraction has historically occurred, and continues to occur, in portions of California. From June 2015 through June 2018, more than 2,000 square miles in the Tulare Lake Hydrologic Region experienced subsidence of 0.25 foot (3 inches) to 3 feet, with a maximum rate of 1.5 feet per year. During Water Year 2022, approximately 3,500 square miles in the Tulare Lake Hydrologic Region experienced more than 0.2 foot of subsidence. Other than the San Joaquin Valley, land subsidence caused by groundwater extraction is occurring in basins within the Sacramento Valley and several other areas around the state.

Groundwater recharge could effectively slow the rate of land subsidence by raising the water levels where subsidence is occurring. If groundwater recharge projects are not implemented at an accelerated rate to maximize the use of recharge areas and high-flow events, California will face more land subsidence, leading to huge financial costs associated with damaged infrastructure, buildings (including homes), and conveyance facilities.

Dry Well Response

The statewide trend for dry well reporting over the past eight water years (2015–2022) shows a correlation between extended dry periods and declines in local groundwater levels caused by pumping to compensate for the shortage in surface water supplies. During the eight-year span, 4,669 new dry-well reports were received by DWR. More dry wells were reported during the critical years of 2015, 2021, and 2022 than any other year since 2013. In 2022, 1,494 new dry well reports were received by DWR, which is the highest number of dry wells reported in any single year since the Dry Well Reporting System started in 2013. The economic and social costs of dry wells are enormous and disproportionately affect the livelihood of economically disadvantaged areas of the state (Legislative Analyst's Office 2021).

Groundwater recharge projects can reverse this trend and decrease the number of wells going dry during periods of drought. If groundwater recharge projects are not implemented at an accelerated rate to maximize the use of recharge areas and high-flow events, Californians will continue to experience more dry wells, leading to huge financial and social losses because of inequitable distribution of historical locations and occurrences of dry wells.

Groundwater Quality

Many potentially contaminating activities, such as farming, animal husbandry, dairies, and industrial operations, have routinely been allowed in, or near, recharge areas and resulted in contamination leaching into aquifers. Because groundwater processes and the potential for contamination are not well understood by the public, many of these practices continue. Remediation of contaminated aquifers can take decades or longer, cost millions to billions of dollars, and increase the rate of global climate change because of carbon dioxide (CO_2) emissions from remediation systems. Groundwater remediation may never remove all contaminants completely from the aquifer. In many cases, the extracted groundwater must be treated or blended at the wellhead at a significant expense before it is suitable for potable and other uses.

The lack of protection of recharge areas could decrease the availability of usable groundwater. Because of the low velocity of groundwater movement through the aquifer, contamination that occurs today may not arrive at down-gradient wells for 10 years. When the contamination does arrive at the down-gradient wells, treatment may be needed before the groundwater can be used, thereby increasing the cost of water to users. Protecting recharge areas now may help to prevent costs from escalating excessively in the future by reducing the need for expensive groundwater treatment. Protecting recharge areas by retaining those areas for recharge and preventing contamination today will reduce future costs of drinking water. Restoration of recharge areas may also help to keep future costs lower by preventing possible future contamination.

7. Climate Change

The changing climate is affecting water resources in California and will continue to do so because the State's demand for water for urban, agricultural, industrial, and environmental purposes is likely to increase. Overall, warmer temperatures will continue to melt the snowpack faster and earlier, making it more difficult to store and use surface water during dry periods. By the end of this century, California's Sierra Nevada snowpack is projected to experience a 48 percent to 65 percent loss from the historical April 1 average (California Department of Water Resources 2015). Climate change is also expected to result in more variable weather patterns throughout California, including longer and more severe droughts and floods that occur more frequently.

During drought periods, Californians depend on groundwater to support the many uses and needs because surface water becomes less available. California's groundwater basins offer natural underground reservoirs that can store far more water than all the state's surface reservoirs combined, which will become increasingly important for drought planning and resiliency. Existing groundwater storage capacity can be used to capture more runoff and have more flexibly to cope with California's changing climate conditions.

Climate Change Adaptation

Resiliency and adaptation involve the ability of a conjunctively managed water supply system to resist impairment or recover after times of stress, but it also involves the time for that system to respond and recover. Understanding the resiliency of the groundwater system and adapting to climate change will help understand the response that groundwater systems have after times of stress, whether long term (i.e., climate change) or short term (i.e., drought). Examples of stress include lowering groundwater levels as a result of below-average precipitation and groundwater demand that exceeds recharge. A groundwater system's ability to maintain the functionality of that system is an example of its resiliency. Groundwater recharge (whether natural or artificial) can increase the resiliency of that groundwater system by protecting and prolonging the uses of that system.

The effects of climate change, such as reduced snowpack, late season water supply, and lack of reservoir space to store surface water are anticipated to have wide-reaching impacts on the way water is managed in California. Because of more runoff, there will be an increase in flood risks as the climate changes. Changes in hydrology caused by climate changes will require modifications to the way reservoirs and flood management infrastructure are operated.

Groundwater recharge improves the flexibility of the water resources management system to adapt to the extreme events that are expected to become more common in a changing climate. System operations adjustment, such as groundwater recharge, will be needed to compensate for earlier snowmelt runoff, increased rain runoff, and potential changes in water demand. Groundwater recharge can help mitigate extreme precipitation events in an integrated way.

Climate Change Mitigation

Mitigation for climate change includes the reduction of greenhouse gas emissions utilized in water management. Reduced energy use for pumping or conveyance distance results in lower greenhouse gas emissions. Groundwater recharge prevents water tables from dropping and then being pumped from lower depths with high energy costs. Greater reliance on local groundwater in many areas of the state is less energy intensive than relying on imported or desalinated water, which is energy intensive. Recycled water of adequate quality can supplement other sources of available water to recharge groundwater basins. More recharge areas, treatment facilities, conveyance facilities, and expanded capacity of existing facilities will be needed to fully utilize the state’s available recycled water supply used for groundwater recharge. This could result in greater energy intensity, and lead to greater greenhouse gas emissions, meaning there are trade-offs to be considered.

8. Water Resilience Portfolio and California's Water Supply Strategy

The *Water Resilience Portfolio* (Portfolio) was issued in July 2020 at Governor Newsom's direction through Executive Order N-10-19. The Portfolio is a comprehensive roadmap providing a broad set of actions to build California's water resiliency. The Portfolio consists of 142 actions assigned to multiple State agencies intended to address the changing climatic conditions being experienced. The actions are designed to ensure California can thrive into the future. In August 2022, in response to severe drought conditions, State leaders created *California's Water Supply Strategy: Adapting to a Hotter, Drier Future* (Water Supply Strategy). The Water Supply Strategy expanded on the actions defined in the Portfolio by specifying enhancements to address aridification of California's climate, which included setting specific quantified targets and metrics.

The Portfolio and Water Supply Strategy outline actions that direct State agencies to clarify and streamline processes necessary to expand recharge efforts to replenish groundwater basins. These actions serve as a buffer against drought and improve climate resiliency. The following actions related to groundwater recharge are defined in the documents:

- Streamline groundwater recharge and banking efforts that do not exacerbate water quality issues.
- Provide technical assistance to support diversion and recharge of high flows for recharge while ensuring protection of fish and wildlife.
- Make funding available for recharge projects.
- Conduct aerial electromagnetic geophysical and other investigations to identify key recharge areas to inform land use planning and protection of these areas while supporting recharge project planning.
- Expand average annual recharge by at least 500,000 acre-feet.
- Provide technical assistance to aid projects to procure necessary permits, including 180-day temporary permits to capture high flows and the waiver of the required fees for projects conducted under DWR's grants and Flood-MAR process.
- Expand watershed studies to evaluate water available for recharge.

These actions are a few of the specific actions occurring in the implementation of the Portfolio and the Water Supply Strategy. In addition, many of these actions are conducted consistent with the implementation of SGMA and the local GSPs to achieve sustainable groundwater conditions by 2040–2042.

9. Recommendations

The State should promote identification, utilization, and protection of recharge areas by implementing the following recommendations. The California Water Supply Solutions Act of 2023 directs and gives DWR authority to conduct several of these recommendations.

1. Create policy and incentives to enhance groundwater recharge projects across the state to support the implementation of the Sustainable Groundwater Management Act and the California Water Supply Solutions Act.
   A. Provide grant opportunities to non-governmental organizations to work with local governments to increase low-impact development and increase natural recharge.
   B. Provide avenues of communication between these organizations and GSAs, as part of developing best management practices for the area.
   C. Continue to support, implement, and fund projects and programs that investigate managed aquifer recharge methods.
   D. Modify water rights permitting process to increase the ease of getting water rights permits to divert excess surface water for the beneficial purpose of groundwater recharge.
   E. Support counties, cities, and GSAs in navigating challenges to implementation of groundwater recharge projects.
   F. Encourage the construction of new groundwater recharge projects in urban and rural areas that utilize urban stormwater, non-urban stormwater, and floodwater (resulting from floods or in anticipation of floods).
2. Continue groundwater recharge site characterization, data collection, and data analysis through DWR's Basin Characterization Program and archive results in California's Groundwater (also known as Bulletin 118).
   A. Delineate pathways for groundwater to be recharged into aquifer systems and enhance the understanding of this component in California's natural infrastructure.
   B. Identify areas of natural recharge and areas that could be used or enhanced for groundwater recharge.
   C. Implement pilot studies to gather additional information to characterize resources, methods, benefits, and costs.
3. Compile and synthesize organizations already conducting groundwater recharge and centralize operational data location maps.

   A. Publicly available maps should include locations of existing recharge projects, the type of recharge project, and emergency recharge locations that can be used for Flood-MAR.
   B. Identify the State program and funding source(s) that will centrally track all recharge areas and projects in California. No official effort currently exists.
4. Support the local implementation of recharge projects to better understand and communicate benefits and challenges.
   A. Analyze benefits and impacts of recharge operations to determine how benefits change over time.
   B. Support research to determine crops that can tolerate water inundation and are ideal for groundwater recharge.
   C. Identify the cost of needed infrastructure to protect and utilize groundwater recharge projects.
5. Increase research into understanding the effects of climate change on the amount and timing of water available for groundwater recharge.
   A. Develop tools and resources to support understanding the forecasted amount and timing of water available for groundwater recharge.
   B. Perform analysis on groundwater recharge project resiliency and its benefits to climate change.
6. Enhance protection of water quality.
   A. Provide guidance to county environmental programs for the proper destruction of abandoned water wells, monitoring wells, cathodic protection wells, and other wells that could become vertical conduits for contaminating the aquifer that would degrade higher-quality recharge waters.
   B. Use the existing Drinking Water Source Assessment and Protection (DWSAP) Program of the State Water Board's Division of Drinking Water to develop and implement source-water protection measures.
   C. Continue research into water quality requirements for managed aquifer recharge.
   D. Require that source water protection plans required by the DWSAP include an element that identifies major recharge areas.
7. Develop policy and guidance to support protection of groundwater recharge areas.
   A. Protection efforts can include restrictions of urban expansion and development, limited land use permissions, and requirements for

promoting recharge on new developments to mitigate the use of impervious construction materials.

B. Public involvement should be an integral part of protecting water resources. Develop a public outreach initiative to the DWSAP to develop a road signage network to notify people that they are entering an area of recharge protection, and that improper disposal of waste can contaminate water supplies. These signs should provide a phone number to call for reporting accidental spills and a website for learning more about protecting water resources. This initiative could highlight the importance of recharge areas and increase public awareness and knowledge of groundwater.
C. Develop recommendations for county and other local zoning boards to implement measures to protect recharge areas.

10. Related Resource Management Strategies

The following resource management strategies have connections to recharge area identification, utilization, and protection.

- Conjunctive Management.
- Flood Management.
- System Reoperation.
- Municipal Recycled Water.
- Groundwater/Aquifer Remediation.
- Urban Stormwater Runoff Management.
- Salt and Salinity Management.
- Agricultural Land Stewardship.
- Ecosystem Restoration.
- Land Use Planning and Management.
- Watershed Management.
- Outreach and Engagement.

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12. Useful Web Links

Basin Characterization Program
https://water.ca.gov/Programs/Groundwater-Management/Bulletin-118/Basin-Characterization

California's Groundwater
https://water.ca.gov/Programs/Groundwater-Management/Bulletin-118

California's Groundwater Live
https://sgma.water.ca.gov/CalGWLive/

California's Groundwater Update 2020
https://data.cnra.ca.gov/dataset/calgw_update2020/resource/d2b45d3c-52c0-45ba-b92a-fb3c90c1d4be

California Groundwater Project Tools
https://experience.arcgis.com/experience/00197adac22f4b06a3f410068d43a641/

California Natural Resources Agency Open Data portal
https://data.cnra.ca.gov

California's Water Supply Strategy: Adapting to a Hotter, Drier Future
https://resources.ca.gov/-/media/CNRA-Website/Files/Initiatives/Water-Resilience/CA-Water-Supply-Strategy.pdf

California Natural Resources Agency's Data Viewers webpage
https://data.cnra.ca.gov/dataset/aem/resource/29c4478d-fc34-44ab-a373-7d484afa38e8

Drinking Water Source Assessment and Protection (DWSAP) Program
https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/DWSAP.html

Dry Well Reporting System
https://mydrywell.water.ca.gov/report/

DWR Airborne Electromagnetic (AEM) Surveys Data
https://data.cnra.ca.gov/dataset/aem

Flood-Managed Aquifer Recharge (Flood-MAR) Program
https://water.ca.gov/programs/all-programs/flood-mar

Geologic Map of California
https://maps.conservation.ca.gov/cgs/gmc/

Groundwater Ambient Monitoring and Assessment (GAMA) Online Tools
https://www.waterboards.ca.gov/water_issues/programs/gama/online_tools.html

Groundwater Recharge Assessment Tool
https://suscon.org/GRAT/

Groundwater Recharge Assessment Tool – Online Viewer
https://gratviewer.earthgenome.org

Groundwater Recharge Assessment Tool – Specialized Services for Registered Users
https://grat.earthgenome.org/

National Pollutant Discharge Elimination System (NPDES) Stormwater Program
https://www.epa.gov/npdes/npdes-stormwater-program

Online System of Well Completion Reports (OSWCR)
https://water.ca.gov/Programs/Groundwater-Management/Wells/Well-Completion-Reports

Sustainable Groundwater Management Act (SGMA)
https://water.ca.gov/Programs/Groundwater-Management/SGMA-Groundwater-Management

SGMA Basin Prioritization Dashboard
https://gis.water.ca.gov/app/bp-dashboard/final/

SGMA Portal
https://sgma.water.ca.gov/portal/gsp/all

SGMA Data Viewer
https://sgma.water.ca.gov/webgis/?appid=SGMADataViewer

Soil Agricultural Groundwater Banking Index (SAGBI)
https://casoilresource.lawr.ucdavis.edu/sagbi/

Statewide Airborne Electromagnetic Survey Project
https://water.ca.gov/Programs/SGMA/AEM

Streamlined Processing for Standard Groundwater Recharge Water Rights
https://www.waterboards.ca.gov/waterrights/water_issues/programs/applications/groundwater_recharge/streamlined_permits.html

Underground Injection Control program (U.S. Environmental Protection Agency)
https://www.epa.gov/uic

U.S. Geological Survey's Central Valley Hydrologic Model
https://ca.water.usgs.gov/projects/central-valley/central-valley-hydrologic-model.html

Water Resilience Portfolio
https://resources.ca.gov/Initiatives/Building-Water-Resilience/portfolio

Water Supply Strategy: Adapting to a Hotter, Drier Future
https://resources.ca.gov/-/media/CNRA-Website/Files/Initiatives/Water-Resilience/CA-Water-Supply-Strategy.pdf

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