To be used in intro section

Groundwater Recharge Projects Contents

Groundwater Recharge Projects Figures

Groundwater Recharge Projects Tables

Groundwater Recharge Projects – Overview
OVERVIEW [MM-01 to MM-06]

SUSTAINABLE GROUNDWATER MANAGEMENT (SGM) GRANT PROGRAM

OVERVIEW [MM-01 to MM-06]

Groundwater Recharge Projects – Overview

Project / Action Type	Managed aquifer recharge (MAR) projects, including Aquifer Storage and Recovery (ASR), Recharge Ponds, Flood-Managed Aquifer Recharge (Flood-MAR), Stormwater Recharge and Indirect Potable Reuse (IPR),
Similar / Related Project Types	Floodplain restoration: in addition to other benefits, allows for greater groundwater recharge from streams
Metrics	Groundwater levels. Groundwater storage. Applicable water quality constituents. Change in ground levels. Surface water flow rates. Surface water stage. Groundwater dependent ecosystems.
Measurement Units	Groundwater levels measured in feet in a consistent vertical datum. Recharge/demand volumes in acre-feet. Concentration or measurement of applicable groundwater quality constituents (typically mg/L). Change in surface elevation measured in feet from a consistent vertical datum. Surface water flow rate in cubic feet per second (streamflow). Surface water levels in feet (stage/depth, channel elevation). Vegetation vigor and plant surveys (root zone index, wetland species) of groundwater dependent ecosystems habitats.
Beneficial Users	Municipal and domestic water supply (MUN) Industrial service supply (IND) Industrial process supply (PROC) Agricultural water supply (AGR) Groundwater recharge (GWR) Freshwater replenishment to surface waters (FRSH)

Introduction

Groundwater recharge can occur naturally as part of the hydrologic cycle wherein precipitation, runoff, and surface water flow infiltrates into the aquifer system. Climate change is causing warmer temperatures, reduced snowpack, more intense precipitation, more intense droughts, and more intense runoff events, which cumulate to less infiltration potential. Groundwater recharge is a critical water management practice in California because groundwater aquifers in the State have much more storage capacity than surface reservoirs. Storing more water underground can help water users adapt to the loss of snowpack and increased flood risk, as well as improve conjunctive use operations to allow for more flexible water management.

A critical element of sustainable groundwater management is the replenishment of groundwater basins through means of prompting **active or in-lieu recharge** (DWR, 2018). Through effective management strategies, groundwater recharge projects can be designed and implemented specifically to facilitate recharge using an appropriate recharge method, either active or in-lieu, based on surface conditions and site-specific hydrogeologic conditions.

KEY TERMS

Active (or direct) recharge of the groundwater can occur through designed and constructed systems like injection wells or surface infiltration galleries such as ponds.

In-lieu recharge occurs when surface water is used instead of groundwater to purposefully allow for natural and applied recharge to occur.

Applied recharge can occur from infiltration of agricultural and landscape irrigation.

Incidental recharge can occur through unlined irrigation canals or leaky conveyance pipes.

Methods of making water available for recharge include a portfolio of water management actions, including surface water development (including stormwater), water conservation, recycled water, desalination, and water transfers. These methods can help make water available for groundwater replenishment by either increasing water supply directly or reducing demand on existing water supplies.

The Sustainable Groundwater Management Act (SGMA), which requires local water users to bring groundwater use to sustainable levels by the 2040s, has resulted in increasingly widespread interest in expanding recharge projects throughout California.

The primary benefits of implementing groundwater recharge projects relate to increasing groundwater levels and improving groundwater storage. Additional benefits include improved 1) surface riverine flows where groundwater and surface water are interconnected in a gaining condition; 2) environmental conditions as a result of increased flows and potential habitat enhancement, and 3) regional groundwater quality through recharge of good quality water or subsurface dilution of constituents of concern. In addition, recharge projects may reduce other potential adverse groundwater conditions such as seawater intrusion and subsidence. The individual Groundwater Recharge Projects Monitoring Methods (MM-01 to MM-06) discuss recharge methods, benefits, and potential impacts in more detail.

The groundwater sustainability plan (GSP) Regulations that specify components of GSPs prepared pursuant to SGMA require that groundwater sustainability agencies (GSAs) provide explanations of project and management actions (23 CCR § 354.44). Nothing in these Monitoring Methods supersedes the GSP Requirements as related to the development and implementation of GSPs, alternatives to a GSP, coordination agreements, and annual reporting requirements under SGMA.

Categories of Recharge Project Types

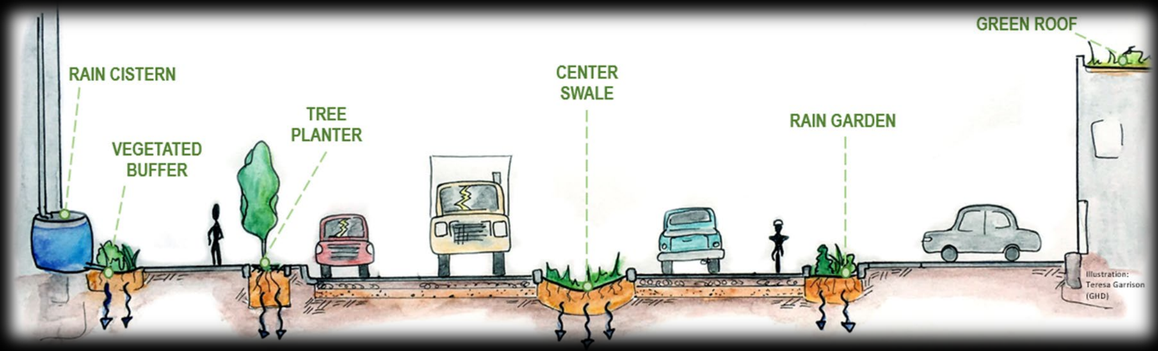
The most common active groundwater recharge projects include active injection through Aquifer Storage and Recovery (ASR) wells; stormwater recharge with Low Impact Development (LID) or Green Infrastructure (GI); diverting flood flows into recharge areas, referred to as Flood-Managed Aquifer Recharge (Flood-MAR), and using constructed recharge ponds for surface infiltration. In addition, indirect potable reuse is a type of recharge method that uses a specific water source (advanced treated water) and can apply to both recharge ponds and ASR.

Low Impact Development (LID) or Green Infrastructure

Systems and practices that use or mimic natural processes resulting in infiltration, evapotranspiration or use of stormwater. (EPA, 2022).

LID is an approach to land development (or re-development) that works with nature to manage stormwater as close to its source as possible

Examples include bioretention facilities, rain gardens, vegetated rooftops, rain barrels and permeable pavements.



The purpose of the Groundwater Recharge Projects Monitoring Methods Overview is to describe the main categories of groundwater recharge projects addressed in the accompanying Monitoring Methods (MM-01 to MM-06) to clarify the similarities and differences between them.[1] Figure MM01/06-1 illustrates the groundwater recharge categories described in the following Monitoring Methods, with a brief definition of each provided below. Groundwater Quality Improvement Monitoring Methods (MM-06) is also included in this section as it directly relates to groundwater recharge projects' overall success and benefits.

[1] Other project types may exist, but the five categories comprise the majority of the groundwater recharge projects. If a project does not fall directly into the defined categories a combination of the Monitoring Methods could be used.

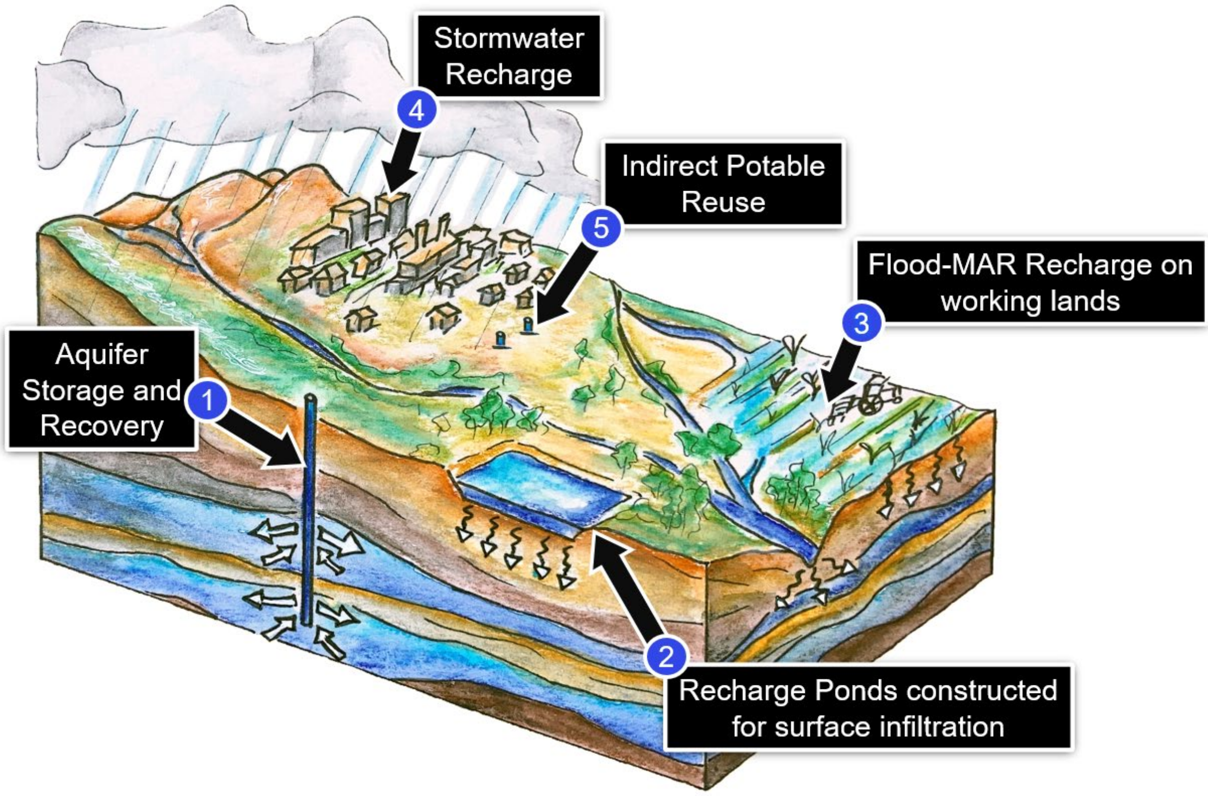


Figure MM01/06-1. Types of Groundwater Recharge Projects Applicable for Groundwater Implementation Projects.

1) **Aquifer Storage and Recovery (ASR)** – Wells are specifically designed for aquifer recharge using active injection into the aquifer and subsequent pumping to recover the stored groundwater (Pyne, 2005). The ASR well is designed based on the hydrogeologic conditions and depth of the aquifer. Monitoring often includes a groundwater model to evaluate the full benefits/effects of the ASR project. The water source used in ASR generally meets a high standard for water quality and often comes from excess surface water supplies or recycled water facilities.

   Monitoring – Groundwater levels (in the aquifer and perched zones), groundwater quality (especially constituents of concern), groundwater recharge volumes (water storage), and pumping volumes when recovering water.

2) **Recharge Ponds** – Recharge ponds are designed and generally engineered for infiltration into the aquifer. Source water for recharge includes surface water development (including stormwater), recycled water, desalination, and water transfers.

   Monitoring – Groundwater levels (in the aquifer and perched zones), groundwater quality (especially constituents of concern), and groundwater recharge volumes (water storage).

3) **Flood-MAR** – The use of flood water to inundate landscapes for direct infiltration into the shallow groundwater aquifer. Projects are designed to find suitable working lands where infiltration is possible, such as certain crop types (often vineyards and orchards) during the crop dormant season but can also be natural areas such as meadows and wetlands.

   Monitoring – Surface water flows and availability, and all parameters listed above for stormwater recharge.

4) **Stormwater Recharge** – Stormwater detention facilities are generally located in the urban setting, using LID facilities engineered into the communities for stormwater capture, treatment, control, and infiltration. These systems are designed into the existing landscape in suitable areas for infiltration. Recharge can either be passive through surface infiltration or active through a direct connection to groundwater, such as a with a dry well.

Monitoring – Groundwater levels (in the aquifer and perched zones), groundwater quality (especially constituents of concern), and groundwater recharge volumes (water storage).

5) **Indirect Potable Reuse** – Uses advanced treated recycled water for an engineered approach to store water in the ground for later recovery and use or to increase water stored in aquifers. Similar approach as ASR.

   Monitoring – Groundwater levels (in the aquifer and perched zones), groundwater quality (especially constituents of concern), groundwater recharge volumes (water storage), and pumping volumes when recovering water.

The last category included in this section of recharge projects specifically deals with the water quality of the groundwater recharged through the recharge projects categorized above. Groundwater quality issues can limit local water supply availability for beneficial use. Taking water quality recharge projects and water quality improvement projects into account can improve accessibility to the groundwater source previously impaired, minimize further migration of impacted groundwater, reduce contaminant concentrations, and protect human health and the environment. Therefore, the sixth category in the overall groundwater rechange focus on water quality improvement methods.

6) **Groundwater Quality Improvement** – The processes affecting groundwater quality vary widely and depend on many factors, including hydrogeology, local aquifer conditions, and human activities related to land use. The following groundwater quality remediation projects may be implemented to improve water quality: pump and treat; groundwater recirculation between extraction and injection wells with amendments for in situ remediations; permeable reactive barriers; enhanced in situ biodegradation or chemical oxidation injections; thermal reduction; soil vapor extraction, and excavation of contaminant sources.

   Monitoring – Groundwater quality (constituents of concern), and flow volumes (recharged, treated, pumped, etc.).

Implementation

Groundwater recharge occurs naturally as part of the hydrologic cycle, in which precipitation, runoff, and surface water flow infiltrates into the aquifer system. Groundwater recharge may be induced by humans via incidental recharge from constructed systems (such as unlined canals and ponds), or intentionally via active (or direct) recharge of the groundwater using designed and constructed systems such as injection wells, and recharge ponds/basins.

Groundwater recharge projects such as recharge ponds and ASR are related and can use the same implementation and monitoring approaches. In addition, although Flood-MAR does not typically utilize constructed, dedicated infrastructure for active recharge, Flood-MAR may share some monitoring methods and approaches.

In coastal areas, intentional recharge to create seawater intrusion barriers can prevent salty ocean water from entering freshwater aquifers. Recharge also can help the following items:

– prevent impacts from groundwater pumping, such as dry wells or subsidence,
– provide wetland habitat for birds and other species at ponds,
– reduce flood risk by diverting peak flows and redirecting for recharge, and
– store water for droughts.

Sustainability Indicators

The following Table MM01/06-1 provides the applicability of groundwater recharge towards the six sustainability indicators as outlined in SGMA. The higher the applicability the greater the project has towards providing a benefit to that indicator.

Table MM01/06-1. Recharge Benefit Levels to Six Sustainability Indicators Outlined in SGMA

	Six Sustainability Indicators Outlined in SGMA	Applicability*
	Depleted Interconnected Surface Water	★★
	Lowered Groundwater Levels	★★★
	Water Quality Degradation	★★
	Subsidence	★
	Reduced Groundwater Storage	★★★
	Seawater Intrusion	★

*Notes

★★★ = Primary Benefit (High Applicability)

★★ = Secondary Benefit (Medium Applicability)

★ = Situational Benefit (Applicability dependent on Location, Site Characteristics, and Aquifer Condition)

Monitoring Methods

The Groundwater Recharge Projects Monitoring Methods were separated into categories based on the type of recharge project implemented. Detailed Monitoring Methods for implementing groundwater recharge projects are provided under Aquifer Storage and Recovery (MM-01), Recharge Ponds (MM-02), Flood-MAR (MM-03), Stormwater Recharge (MM-04), and Indirect Potable Reuse (MM-05). The last category included in this section is Groundwater Quality Improvement (MM-06) which specifically deals with the quality of the groundwater recharged and is therefore applicable to all groundwater recharge projects.

Additional guidance and support can be found in the California Department of Water Resources' (DWR) Best Management Practices (DWR, 2016), which include Monitoring Protocols Standards and Sites and Monitoring Networks and Identification of Data Gaps, among other helpful information.

Data Standards

The following apply to all groundwater recharge projects.

– Groundwater, surface water, and water quality monitoring data should conform to the technical and reporting standards of the California Water Code (CWC) §352 *et seq*.

– Groundwater levels – Groundwater elevation measurements should be recorded relative to a consistent vertical datum. A general rule of thumb for recharge pond projects is that groundwater levels shall not rise to within ten feet of land surface due to recharge operations. Standard groundwater level measurement and groundwater quality monitoring protocols are described in DWR's Best Management Practice 1 Monitoring Protocols Standards and Sites (DWR, 2016).

– Groundwater quality – Concentrations of groundwater quality constituents of concern should be compared to maximum contaminant levels (MCLs) (California State Water Board, 2018) and other regulatory limits available from the SWRCB.

Source References

California Department of Water Resources. 2016. *Best Management Practices for the Sustainable Management of Groundwater, six-part series (BMP 1 Monitoring Protocols Standards and Sites, BMP 2 Monitoring Networks and Identification of Data Gaps, BMP 3 Hydrogeologic Conceptual Model, BMP 4 Water Budget, BMP 5 Modeling, and BMP 6 Sustainable Management Criteria DRAFT).* Sacramento (CA): California Natural Resources Agency. [Website]. Viewed online at:

https://water.ca.gov/Programs/Groundwater-Management/SGMA-Groundwater-Management/Best-Management-Practices-and-Guidance-Documents.

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Pyne RD and David G. 2005. *Aquifer Storage* and *Recovery: A Guide to Groundwater Recharge Through Wells Second Edition*. Prepared by: ASR Systems.

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Aquifer Storage and Recovery (ASR) Monitoring Method
MONITORING METHOD [MM-01]

SUSTAINABLE GROUNDWATER MANAGEMENT (SGM) GRANT PROGRAM

MONITORING METHOD [MM-01]

Aquifer Storage and Recovery (ASR) Monitoring Method

Project / Action Type	Aquifer Storage and Recovery (ASR) utilizes different water sources for managed aquifer recharge and recovery benefits within an aquifer. Many ASR projects inject highly treated or recycled water into deep aquifers. This typically occurs in historically over-drafted and high-demand basins to bank or recharge water for subsequent recovery and extraction.
Similar / Related Project Types	ASR directly and actively injects water into groundwater with immediate volumetric results. Other groundwater recharge projects (Recharge Ponds, Flood-MAR, Stormwater Recharge) are directly related and use similar implementation and permitting approaches to ASR. However, these other groundwater recharge methods are slower and more passive in recharging groundwater. ASR can be used to decrease surface water depletion, in interconnected surface waters, reduce seawater intrusion, and reduce subsidence, and are generally secondary benefits of ASR projects in California.
Primary Metrics	Groundwater levels. Groundwater storage. Applicable water quality constituents. Change in ground levels (situationally). Surface water flow rates (situationally). Surface water stage (situationally). Groundwater dependent ecosystems (situationally).
Measurement Units	Groundwater levels measured in feet in a consistent vertical datum. Recharge/demand volumes in acre-feet. Concentration or measurement of applicable groundwater quality constituents (typically mg/L), including disinfection byproducts, microbial communities, emerging contaminants such as Per- and Polyfluoroalkyl Substances (PFAS) or pharmaceuticals, arsenic, iron, manganese, nitrogen, salts, selenium, sulfur, metals, pesticides, or any other applicable constituent of concern.
Beneficial Users	Municipal and domestic water supply (MUN) Industrial service supply (IND) Industrial process supply (PROC) Agricultural water supply (AGR) Groundwater recharge (GWR) Freshwater replenishment to surface waters (FRSH)

Aquifer Storage and Recovery Overview

Aquifer Storage and Recovery (ASR) is an engineered approach to injecting and storing water in the ground for later recovery and use. ASR projects utilize surface water sources to create additional groundwater storage and recovery over what existed prior to the project's implementation (see Figure MM01-1). As a result, ASR projects can provide drought relief when typical surface water resources are curtailed or unavailable and improve local and regional water supply reliability and quality. The purpose of this Monitoring Method is to provide recommendations for monitoring and reporting to assess the effectiveness of ASR projects.

ASR projects are primarily associated with municipal drinking water supply, but more recent projects have been used to augment agricultural water supply. The specific goals of each project will be unique; however, the primary objectives of ASR projects are to mitigate the impacts of the chronic lowering of groundwater levels, reduction in storage, and degraded groundwater quality. Other potential mitigation measures for surface water depletion, seawater intrusion, and subsidence sustainability indicators are situational (based on location, site characteristics, and aquifer conditions). These sustainability indicators are discussed in the Sustainability Indicator Improvements Monitoring Methods (MM-07 to MM-10).

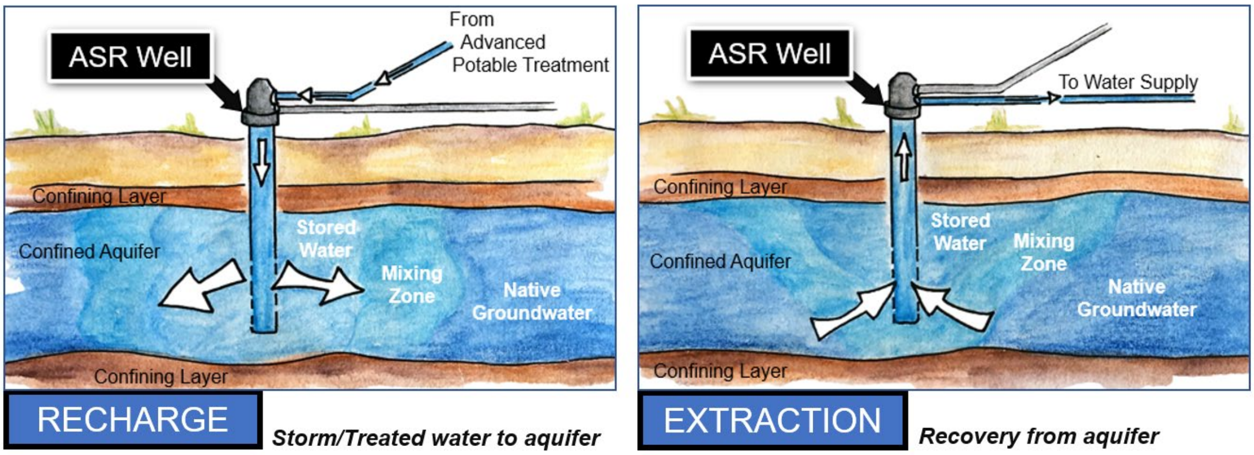

Figure MM01-1. Aquifer Storage and Recovery (ASR) Recharge and Extraction Mechanisms and Effects on the Aquifer

The groundwater sustainability plan (GSP) Regulations that specify components of GSPs prepared pursuant to the Sustainable Groundwater Management Act (SGMA) require that groundwater sustainability agencies (GSAs) provide explanations of project and management actions (23 CCR § 354.44). Nothing in these Monitoring Methods supersedes the GSP Requirements as related to the development and implementation of GSPs, alternatives to a GSP, coordination agreements, and annual reporting requirements under SGMA.

Monitoring Objective

Monitoring specific groundwater properties allows ASR project proponents to determine if the project provides the intended benefits or impacts beneficial users. Water quality monitoring is crucial to identify potential adverse effects caused by ASR, which might impact the viability of ASR recovery water or water quality in non-ASR wells adjacent to the project. Measuring the volume of water recharged to the aquifer is useful to quantify the project benefits. Water level monitoring is useful for measuring the groundwater level fluctuations and potential gradient changes related to injection and extraction cycles and assessing the benefits or impacts that changing groundwater levels or gradients may have on sustainability indicators. The applicability of ASR to the sustainability indicators is presented in Table MM01-1.

Table MM01-1. Level of Benefit to the Six Sustainability Indicators Outlined in SGMA

	Six Sustainability Indicators Outlined in SGMA	Applicability*
	Depleted Interconnected Surface Water	★
	Lowered Groundwater Levels	★★★
	Water Quality Degradation	★★
	Subsidence	★
	Reduced Groundwater Storage	★★★
	Seawater Intrusion	★

*Notes:
★★★ = Primary Benefit (High Applicability)
★★ = Secondary Benefit (Medium Applicability)
★ = Situational Benefit (Applicability dependent on Location, Site Characteristics, and Aquifer Condition)

Desired Outcomes or Benefits Resulting from ASR Projects

ASR projects can benefit groundwater conditions in numerous ways. The potential benefits of implementing an ASR system are described in Table MM01-2.

Table MM01-2. Potential Benefits Resulting from Project / Action

	Potential Benefits on SGMA Sustainability Indicators	Benefit / Not Applicable	Description of Benefits
	Depleted interconnected surface water	Benefit	Increase streamflow during dry periods through baseflow in a connected surface/subsurface interface from a shallow aquifer.
	Lowered groundwater levels	Benefit	Direct groundwater recharge results in increased groundwater levels and groundwater in storage that may provide direct or indirect benefits (e.g., domestic well protection).
	Water quality degradation	Benefit	May improve water quality by recharging the aquifer with potable water.
	Subsidence	Benefit	Maintain land surfaces without subsidence.
	Reduced groundwater storage	Benefit	Water supply augmentation and water banking by providing aquifer recharge during wet months that can be extracted during dry periods when water availability is low.
	Seawater intrusion	Benefit	Decrease, prevent, or reverse seawater intrusion into freshwater aquifers.

Potential Impacts

The primary potential impacts of ASR projects are unreasonable harm to nearby beneficial water uses resulting from: 1) excessive groundwater level rise that could affect subsurface structures or other sensitive land and water uses; and more commonly, 2) groundwater quality degradation from mobilization and flushing of chemical constituents. Potential impacts resulting from ASR are shown in Table MM01-3 and described below.

ASR projects may introduce or mobilize contaminants during injection cycles that are later recovered during recovery cycles. The injected water and groundwater form a mixing zone where geochemical reactions can take place. Some ASR operations have been shown to mobilize contaminants (such as arsenic and hexavalent chromium); the injection of chlorinated water has been shown to introduce disinfection byproducts to the aquifer, and injection of untreated water can contain harmful bacteria such as coliforms and *E. coli*. With ASR, there is a risk of unknowingly injecting emerging contaminants (such as Per- and Polyfluoroalkyl Substances (PFAS), pharmaceuticals, microplastics), and other potentially harmful constituents that may not be currently monitored or regulated directly into water supply aquifers. Sometimes mobilized contaminants can be above regulatory standards in the mixing zone, but a "bubble" of cleaner water can be maintained by frequent injection in the ASR well to prevent groundwater quality impacts to the well during recovery cycles.

Table MM01-3. Potential Impacts Resulting from Project / Action

	Potential Impacts on SGMA Sustainability Indicators	Impact / Not Applicable	Mitigation Measures to Address Impacts
	Depleted interconnected surface water	Not Applicable	
	Lowered groundwater levels	Not Applicable	Over injection into an aquifer might cause excessive groundwater level rise. Groundwater levels should be monitored, and injection discontinued if they rise to the ground surface.
	Water quality degradation	Impact	ASR can degrade water quality through geochemical reactions and introduction of contaminants. Water sources of high quality should be used for ASR. A "bubble" of clean water needs to be maintained around the ASR well through injection. Over-chlorination can result in the formation of disinfection byproducts or mobilization of naturally occurring metals through changes in oxidation-reduction potential (redox) conditions.
	Subsidence	Not Applicable	
	Reduced groundwater storage	Not Applicable	
	Seawater intrusion	Not Applicable	

Use and Limitations

Although the implementation of ASR wells has numerous advantages, there are also several limitations. The potential for water quality impacts is significant, especially if potentially contaminated water sources are used to directly inject water into the aquifer.

Results from ASR projects using the monitoring network established during facility construction may indicate that insufficient data are being obtained to evaluate the effectiveness of the ASR facility in relation to the established performance standards and/or that groundwater level rise or groundwater quality impacts may be of concern. These conditions can be addressed by developing and implementing a work plan to install additional monitoring wells and/or vadose zone piezometers, which would provide useful hydrogeologic information at targeted locations and provide additional critical monitoring points to evaluate project results.

Costs associated with ASR can be higher than other methods of groundwater recharge. Costs typically include installing monitoring wells, data collection, well drilling, infrastructure construction, frequent water quality sampling, and routine operations and maintenance such as chlorination, backflushing, and well rehabilitation. Projects proposing the use of ASR should include a cost-benefit analysis comparing benefits of the implemented project to life-cycle costs.

Permitting (and Design) Considerations

In general, the regulatory considerations for ASR are greater than more passive recharge projects because there is greater inherent risk related to direct injection of water into aquifers used for beneficial use. The State Water Resources Control Board (SWRCB) Water Quality Order 2012-0010 (General Order) outlines the regulatory requirements for ASR projects. The General Order outlines regulations in sections of the California Water Code and the United States Environmental Protection Agency Underground Injection Control Program that apply to ASR.

ASR projects require a California Environmental Quality Act study to avoid unintended environmental impacts from the project. In many cases, the project proponent may need to prepare an Environmental Impact Report to permit the project. The injection water source for public supply well ASR projects must comply with California Title 22 water quality standards for drinking water use (SWRCB, 2018).

Currently, ASR wells for agricultural use are less common, although one project in Westlands Water District was approved with less stringent water quality requirements as the only beneficial use of the injected and recovered water was irrigation (see Example of Method Application section).

Relationship to Other Methods

Other Groundwater Recharge Projects Monitoring Methods including Recharge Ponds (MM-02), Flood-MAR (MM-03), and Stormwater Recharge (MM-04) are directly related and use the same implementation and monitoring methods. ASR detailed in the Aquifer Storage and Recovery Monitoring Method (MM-01) uses a more direct and active groundwater interaction process (injection) that has immediate volumetric results in the aquifer compared to the slower and more passive groundwater recharge project types. ASR projects can be used in parallel with or incorporated into other recharge projects to meet the multi-benefit objectives of the grant funding.

Implementing Aquifer Storage and Recovery Monitoring

The method for selecting appropriate monitoring locations and types for ASR implementation depends on the geological and geochemical makeup of the aquifers; the beneficial use of these aquifers; the recharge water source; the intended use of the water supply, and the anticipated benefits and impacts of the project. Aquifers are naturally dynamic, often changing over time with water quality concentrations both vertically and horizontally. ASR operations monitoring wells are recommended for measuring groundwater levels and water quality over time (i.e., disinfection byproducts, arsenic, total dissolved solids, etc.). In addition, ASR projects have both injection and recovery cycles, so monitoring should be designed to assess the benefits and impacts associated with both cycles.

Justification

ASR projects can potentially provide benefits for each of the six SGMA sustainability indicators; therefore, monitoring methods are dependent upon the goals of the project. The groundwater monitoring networks should be designed to assess project benefits and unintended consequences. At a minimum, the monitoring methods for ASR projects should measure the quality of the water injected, the effect of groundwater level change in the aquifer, and groundwater quality in the aquifer. The volume and rate of water injection and extraction to and from the target aquifers is valuable information for project operation and has water quality implications.

Primary Monitoring

Groundwater level monitoring is critical to assess the benefit and impacts of ASR projects. In general, the monitoring should include wells installed in the target aquifers and should consider and monitor impacts on the overlying shallower aquifers, if applicable. Groundwater level monitoring in and around the ASR area helps assess the increase in groundwater levels and associated groundwater storage, relative to dynamic background conditions. Groundwater level monitoring also can help identify changes to groundwater flow or gradient induced by increased volumes of groundwater in storage.

Groundwater quality monitoring should be implemented for ASR projects, as there are potential impacts to water quality. However, most ASR projects should provide clean water for injection in accordance with the SWRCB Title 22 water quality standards (SWRCB, 2018). Groundwater quality should be assessed in the target aquifers that will receive injected surface water. Water quality degradation can impact the ASR well and nearby beneficial users with wells in the same aquifer, so water quality monitoring should be implemented to track impacts related to both the ASR well and the nearby receptors. Contaminants can be introduced or mobilized during injection cycles and recovered during recovery cycles. Therefore, monitoring the injection supply water, the recovered water, and water quality within the aquifer is essential. The injected water and groundwater form a mixing zone at the **injection front** that can be tracked through sampling for added or **intrinsic tracers**. Monitoring the injection front can be useful for monitoring water quality impacts (refer to the definitions in the text box).

KEY TERMS

Intrinsic tracers are non-reactive constituents that can be used to track water fate and transport. Constituents should be notably different concentrations or values in either the aquifer or injected water source to be used as a tracer. Common tracers are salts, temperature, and non-reactive minerals or metals.

The **injection front** is the interface where the injected water mixes with the aquifer. Water quality degradation can occur at the injection front due to changes in water geochemistry.

Secondary Monitoring

Monitoring the volume and rate of injected and recovered water is an important consideration to assess project performance. The injection and recovery volume and rate are typically measured at the wellhead. If water quality impacts are known or anticipated in the aquifer or mixing zone then the project proponent may wish to inject more water than is extracted to maintain high-quality water near the well.

Additional Useful Monitoring

Monitoring of parameters related to reductions in streamflow depletion, subsidence, and seawater intrusion can have a range of applicability for ASR projects. Monitoring of these other parameters can be a priority depending on geographic and geologic conditions and the intended benefits of the ASR project. For example, an ASR project stated to provide benefits to seawater intrusion should monitor and report the sodium isocontours obtained from sodium water quality testing. These monitoring approaches are discussed in other methods.

A Step-by-Step Guide to Applying ASR Monitoring Method

Implementation of an appropriate and effective monitoring method for an ASR project includes the following strategies and steps:

1. **Safety plan:** All projects with fieldwork related activities should produce a Safety Plan. Planning for fieldwork and availability of access to the site, such as monitoring wells, is necessary to maintain project safety. ASR projects may require a Safety Plan to address these and other potential safety concerns.
2. **Monitoring network:** Identify and map drinking water supply well locations near the ASR project and design a monitoring network that can assess and track the risk of potential impacts to beneficial users by groundwater quality degradation. The location of the monitoring network should be easily accessible such that gaining access to the site does not inhibit gathering and downloading data (refer to Step 1).
3. **Water quality modeling:** Identify any known or potential water quality or aquifer geochemical conditions that might be affected by ASR operation. Review background geochemical data, review proposed recharge water chemistry compared to local groundwater chemistry, and confirm compatibility. Perform predictive geochemical groundwater modeling scenarios to assess if impacts to groundwater and beneficial users are anticipated. Use the information to adapt the project plan.

4. **Install ASR well:** Install ASR well or retrofit an existing well with ASR infrastructure for pilot testing.
5. **Install monitoring wells:** Install or identify monitoring wells in the aquifer where the ASR well is screened. Wells should be located between the ASR well and supply wells that may be impacted based on predictive groundwater modeling scenarios. Monitoring wells in other aquifers or at different depths in the same aquifer as the ASR well should be considered depending on the degree of hydrogeologic interconnection with the ASR well location and depths/locations of supply wells. Useful considerations, guidelines, and applications for locating monitoring wells at recharge project sites are provided in *Standard guidelines for managed aquifer recharge, ASCE/EWRI 69-19 / American Society of Civil Engineers* (American Society of Civil Engineers, 2020)
6. **Data collection:** Collect background groundwater level and quality data prior to ASR operation. Collecting seasonal data for up to 1 year prior to project implementation is useful for establishing a baseline.
7. **Pilot testing**: Perform ASR pilot testing consisting of injection and recovery cycle monitoring. Pilot testing should be performed at the design injection and recovery rates using water of similar makeup to the planned source for full-scale implementation. Monitor groundwater quality of injected water and recovery water at the wellhead and in monitoring wells close to the ASR well to assess water quality degradation in the aquifer and extracting water. Monitor groundwater levels in monitoring wells to assess changes in levels or gradient caused by injection and extraction that might cause groundwater mounding or surfacing or affect groundwater fate and transport.
8. **Permits:** Permit the project through the Regional Water Quality Control Board. Permits typically require a monitoring and contingency plan be in place for monitoring and addressing effects to beneficial users.
9. **Implement the project:** Full-scale implementation should include source and production groundwater quality sampling, groundwater level monitoring for changes, and measurement of injection and recovery volumes and rates, similar to the process described above for pilot test monitoring. During recharge events, groundwater levels should be collected continuously (at least daily) using groundwater level transducers to estimate changes in groundwater level and groundwater gradients. Water quality monitoring frequency and analyte lists can be determined in conjunction with the Regional Water Quality Control Board with jurisdiction over the project.

Data and Protocols – Fundamentals

Information/ Data Requirements

ASR monitoring typically consists of measuring changes in groundwater levels, monitoring groundwater quality impacts, and monitoring recharge rates/volumes. Table MM01-4 provides an example list of monitoring parameters that can be used in reporting and understanding the effects of a project in a quantifiable way over time. The fundamental monitoring methods for ASR projects include the following:

– Aquifer groundwater level monitoring using wells or piezometers installed in the saturated zone for evaluating changes in groundwater levels and gradients due to recharge operations. Groundwater levels are measured manually using electrical sounders and automatically using pressure transducers lowered into and/or installed in the monitoring wells and piezometers. Groundwater level monitoring protocols are provided in the Department of Water Resources (DWR) Best Management Practices (BMP) 1 Monitoring Protocols Standards and Sites (DWR, 2016). The use of dataloggers in association with pressure transducers allows automated collection and storage of water level measurements at frequent intervals.

– Water quality sampling of source water extracted water, and monitoring wells to evaluate water quality changes due to injection and extraction cycles. Water quality monitoring guidelines are provided in the ASR General Order (SWRCB, 2012a). Recharge may result in blending and reactions of source water with ambient groundwater and aquifer sediment, potentially mobilizing chemical constituents. Water samples can be collected directly from a tap at the wellhead during injection and extraction cycles. Groundwater quality monitoring in dedicated observation wells should follow protocols provided in DWR's BMP 1 Monitoring Protocols Standards and Sties (DWR, 2016).

- Volumes and flow rates of injected and extracted water in the ASR well should be measured using a flow meter installed at the wellhead.

Table MM01-4. Example Data Monitoring Report (Generally Annually)

Monitoring Reporting	
Total Injection	XXX AF
Total Extraction	XXX AF
Average Groundwater Level Change (Recharge Area / Background)	+/- XXX ft / +/- XXX ft
Average Groundwater Quality Constituent Change (list all identified, Recharge Area / Background)	+/- XXX mg/L / +/- XXX mg/L
Incurred Costs	$XXX

Data Analysis and Reporting

1. **Analyze monitoring data:** Monitoring data should be used to evaluate the effectiveness and performance of the ASR, determine any limiting factors on performance, and identify options for improving performance. This assessment also includes evaluating possible increasing concerns, as operations continue, for causing unreasonable harm to nearby land or beneficial water uses and if/how operations can be better managed to avoid significant risks.
2. **Prepare reports and manage data:** Includes compliance with regulatory and grant requirements and providing data to DWR, which is addressed in the Data Management and Monitoring Method (MM-12). Generally, data can be uploaded to the DWR system annually and progress on project implementation and monitoring can be provided in Annual Reports. If the project is associated with a GSP, the annual project summary should be provided in the Annual Reports, and a full project performance assessment should be provided in the 5-Year Assessment Report.

Data Standards

Groundwater and water quality monitoring data should conform to the technical and reporting standards of the California Water Code §352 et seq.

Groundwater levels - Groundwater elevation measurements should be recorded relative to a consistent vertical datum.

Groundwater quality - Concentrations of groundwater quality constituents of concern should be compared to maximum contaminant levels available from the SWRCB.

Key Protocols

The following protocols should be followed for required monitoring:

- The SWRCB ASR General Order provides many of the practical and regulatory considerations for ASR projects in California (SWRCB, 2012a).
- Standard groundwater level measurement and groundwater quality monitoring protocols are described in DWR's BMP 1 (DWR, 2016).
- Guidelines for establishing monitoring networks and resolving data gaps to reduce uncertainty are provided in DWR's BMP 2 Monitoring Networks and Identification of Data Gaps (DWR, 2016).
- State Water Resources Control Board – 2018. Water Recycling Criteria. Title 22, Division 4, Chapter 3, California Code of Regulations.
- The Division of Drinking Water will need to permit ASR projects intended to provide drinking water supply.

– Technical and reporting standards are included in California Water Code (CWC) §352 *et seq*.

Examples of Aquifer Storage and Recovery Applications

Roseville ASR Project

Location: Roseville, CA

Year: 1994-present

Description and Relevance: The City of Roseville utilizes 6 ASR wells and plans to expand to 14 wells in the future. The City prepared an Environmental Impact Report in 2012 for program implementation and a supplemental Environmental Impact Report in 2020 for program expansion. The water source for ASR is high quality surface water from Folsom Lake Reservoir on the American River. The water is treated at the City's water treatment plant prior to injection. Most injection occurs in the winter and spring when water supply is plentiful, and demand is lower. Each ASR well is accompanied by at least one monitoring well for groundwater level and quality monitoring. Surface water salinity is lower than groundwater, so injections and mixing improve salinity conditions in the aquifer near ASR wells. Other water quality impacts for disinfection byproducts, arsenic, hexavalent chromium was assessed and found to be insignificant.

Links to Resources: 2020 Supplemental Environmental Impact Report: https://p1cdn4static.civiclive.com/UserFiles/Servers/Server_7964838/File/Government/Departments/Environmental%20Utilities/Water/ASR%20environmental/_RosevilleDraftSupplementalEIR_August2020_final_8_3_20_1.pdf

Westlands Agricultural ASR Project

Location: Westlands Water District, Fresno County, CA

Year: 2017 to present

Description and Relevance: The Westlands Water District is in the early stages of scaling up a large-scale agricultural ASR program in the Westside Subbasin. The project utilizes direct recharge of surface water into retrofitted irrigation production wells in times of abundant surface water availability, and extraction when needed for irrigation, in times of surface water curtailments. ASR will not only provide additional water supply, but it will also benefit groundwater quality and subsidence sustainability indicators through injection of high-quality surface water and prevention of groundwater overdraft. A pilot study conducted in 2017 was used to prepare a Report of Waste Discharge and California Environmental Quality Act Initial Study / Mitigated Negative Declaration for regulatory acceptance for the ASR program. Westlands Water District expanded the pilot project during the 2020 Water Year; 15 ASR wells were used to inject and later recover 600 acre-feet of water from the aquifer. Full-scale implementation of the ASR program in 400 wells is estimated to average 12,300 acre-feet per year.

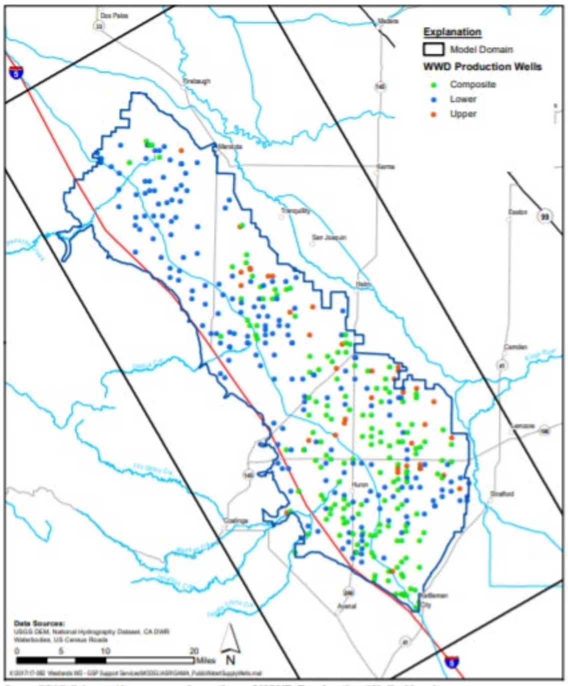

Figure MM01-2. Location of Production Wells Used for Aquifer Storage and Recovery (Westlands Water District, 2019).

Links to Resources: https://wwd.ca.gov/wp-content/uploads/2019/08/westlands-agricultural-aquifer-storage-recovery-program.pdf; Westside Subbasin Groundwater Sustainability Plan, 2020 Annual Report

Groundwater Replenishment Reuse Project

Location: City of Oxnard

Year: 2017-Present

Description and Relevance:

The City of Oxnard Water Division has an ASR well test system that includes one ASR well, three monitoring wells, and pumping equipment. The testing phase of the project includes injection of recycled water from the Advanced Water Purification Facility into the local groundwater basin, 3-4 months of underground storage of the injected water, and the recovery of the injected water to test water quality. The testing results will be used to develop an operational and water treatment plan for future use as potable water. This indirect potable reuse project will help reduce reliance on costly imported water, protect groundwater resources, and provide a beneficial reuse of a scarce resource that would otherwise be discharged and the ocean.

For the fully expanded ASR project, several pairs of ASR wells will be developed, with each pair recharging discrete aquifers. The construction of ASR well facilities in discrete aquifer zones uses the isolation of natural clay layers to allow simultaneous operation of replenishment, retention, and reuse without mutual interference. Utilization of the confined aquifer system in this manner enables optimization of a continual ASR operation and full utilization of the wellfield as well as preserving the replenished water quality and minimizing mixing with native groundwater. This type of operation requires validation that the minimum detention time requirement is met.

Links to Resources: https://www.oxnard.org/wp-content/uploads/2017/12/Vol1_Oxnard-Title22EngineeringReport_Final.pdf

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Recharge Ponds Monitoring Method
MONITORING METHOD [MM-02]

MONITORING METHOD [MM-02]

Recharge Ponds Monitoring Method

Project / Action Type	Recharge Ponds are an effective means of storing water in aquifers via constructed infiltration basins. The recharge pond facility would be designed (pond size, depth, and layout) to accommodate surface and sub-surface site conditions.
Similar / Related Project Types	Infiltration galleries comprise another managed aquifer recharge (MAR) method/project that has similar or overlapping implementation approaches, requirements, and monitoring methods to recharge ponds. Infiltration galleries are in the subsurface. Indirect potable reuse (IPR) and stormwater capture projects can be implemented using recharge ponds.
Metrics	Groundwater levels. Groundwater storage. Applicable water quality constituents Change in ground levels (situationally). Surface water flow rates (situationally). Surface water stage (situationally). Groundwater dependent ecosystems (situationally).
Measurement Units	Groundwater levels measured in feet in a consistent vertical datum. Recharge/demand volumes in acre-feet. Concentration or measurement of applicable groundwater quality constituents (typically mg/L).
Beneficial Users	Municipal and domestic water supply (MUN) Industrial service supply (IND) Industrial process supply (PROC) Agricultural water supply (AGR) Groundwater recharge (GWR) Freshwater replenishment to surface waters (FRSH) (situationally)

Recharge Pond Overview

Recharge ponds are an effective means of storing water in aquifers via constructed infiltration basins. The recharge facility design (number of ponds, pond size, depth, and layout) can vary from less than an acre to hundreds of acres and can accommodate essentially any water source (surface water, recycled water, stormwater, etc.).

The purpose of this Monitoring Method is to provide recommendations for monitoring methods and reporting standards to assess the effectiveness of recharge pond managed aquifer recharge projects. Monitoring of recharge pond operations is recommended to review recharge volumes and evaluate the impacts and benefits of the project has towards groundwater sustainability. As summarized in Table MM02-1, **managed aquifer recharge (MAR)** using recharge ponds most applies to sustainability indicators lowered groundwater levels and reduced groundwater storage. It also can apply to the remaining indicators (depleted interconnected surface water, water quality degradation, subsidence, and seawater intrusion) depending on the location, site conditions, and goals of the recharge project. Figure MM02-1 shows an example recharge project in the Tonopah Desert (Arizona).

Managed Aquifer Recharge (MAR) Projects

Water management methods that recharge an aquifer using either surface or underground recharge techniques. The stored water is available for use in dry years when surface water supplies may be low.

Figure MM02-1. Tonopah Desert Recharge Project using Recharge Ponds (M&A, 2021).

The groundwater sustainability plan (GSP) Regulations that specify components of GSPs prepared pursuant to the Sustainable Groundwater Management Act (SGMA) require that groundwater sustainability agencies (GSAs) provide explanations of project and management actions (23 CCR § 354.44). Nothing in these Monitoring Methods supersedes the GSP Requirements as related to the development and implementation of GSPs, alternatives to a GSP, coordination agreements, and annual reporting requirements under SGMA.

Monitoring Objectives

Recharge pond monitoring is used to assess project effectiveness and performance based on regional and site-specific performance criteria. Monitoring specific groundwater components allows the project proponents to determine 1) if the project is providing the intended benefits, or 2) if it is causing any impacts to nearby beneficial users. Monitoring may be conducted to identify project progress relative to the applicable sustainability indicators. The applicability of recharge ponds to the SGMA sustainability indicators is presented in Table MM02-1.

Table MM02-1. Level of Benefit to the Six Sustainability Indicators Outlined in SGMA.

	Six Sustainability Indicators Outlined in SGMA	Applicability*
	Depleted Interconnected Surface Water	★
	Lowered Groundwater Levels	★★★
	Water Quality Degradation	★
	Subsidence	★★
	Reduced Groundwater Storage	★★★
	Seawater Intrusion	★

*Notes:
★★★ = Primary Benefit (High Applicability)
★★ = Secondary Benefit (Medium Applicability)
★ = Situational Benefit (Applicability dependent on Location, Site Characteristics, and Aquifer Condition)

Desired Outcomes or Benefits Resulting from Recharge Ponds

Recharge pond projects can potentially provide benefits for each of the six Sustainability Groundwater Management Act (SGMA) sustainability indicators, depending on the specific project goals of the project. Table MM02-2 shows the benefits from recharge pond projects for groundwater sustainability, relative to ambient conditions.

Table MM02-2. Potential Benefits Resulting from Project / Action

	Potential Benefits on SGMA Sustainability Indicators	Benefit / Not Applicable	Description of Benefits
	Depleted interconnected surface water	Benefit	Increased groundwater and surface water interaction that benefits in-stream and riparian habitat for critical species and groundwater dependent ecosystems (may or may not be applicable depending on recharge location).
	Lowered groundwater levels	Benefit	Decreases pumping lifts for groundwater recovery.
	Water quality degradation	Benefit	Improved groundwater quality if source water quality is better than ambient groundwater quality and mobilization of applied, legacy, or naturally occurring constituents is not incurred.
	Subsidence	Benefit	Decreased land subsidence (may or may not be applicable depending on recharge location).
	Reduced groundwater storage	Benefit	Allows for seasonal storage of excess water and subsequent recovery for put and take projects).
	Seawater intrusion	Benefit	Decreased seawater intrusion (may or may not be applicable depending on recharge location).

Although not a sustainability indicator, one of the primary benefits of recharge ponds is that they enable stormwater, wastewater, and other waters to be reused.

Potential Impacts

The primary potential impacts of recharge ponds projects are due to unreasonable harm to nearby beneficial water uses resulting from 1) excessive groundwater level rise that could affect subsurface structures or other sensitive land and water uses, and 2) groundwater quality degradation from mobilization and flushing of chemical constituents (whether applied, such as from previous agricultural land use, legacy contamination, or naturally occurring minerals in the pre-recharge vadose zone). These potential impacts are also related to the sustainability indicators “lowered groundwater levels”, “reduced groundwater storage”, and “water quality degradation”.

Recharge operations using recharge ponds would generally not be expected to have significant unintended effects on the remaining sustainability indicators “depleted interconnected surface water”, “subsidence”, and “seawater intrusion”. Recharge pond operations would only be relevant to “depleted interconnected surface water” and “seawater intrusion” if intentionally located very near a surface water feature or coastal area and of sufficient scale to cause an associated effect, which would be an intentional and positive effect. Recharge pond operations would only be expected to have a mitigatory effect on subsidence. Potential impacts resulting from recharge pond projects are shown in Table MM02-3.

Table MM02-3. Potential Impacts Resulting from Project / Action

	Potential Impacts on SGMA Sustainability Indicators	Impact / Not Applicable	Mitigation Measures to Address Impacts
	Depleted interconnected surface water	Not Applicable	
	Lowered groundwater levels	Impacts	Groundwater recharge can increase groundwater levels, which is generally beneficial. In some cases, too much recharge may have impacts. Mitigation of potential concerns for unreasonable harm begins with selection of a recharge site that has been characterized (during the feasibility investigation stage) as having a sufficiently large depth to groundwater level and absence of significant perching zones so that the aquifer storage capacity can accommodate the recharge goals. Design and implementation of an adequate project monitoring plan using the recommended monitoring methods. Criteria such as “alert levels” on water levels can be established to provide warning and not-to-exceed limits for recharge to avoid impacts related to water mounding. If impacts occur, recharge operations could be managed to minimize the potential for unreasonable harm, which could include a reduction in recharge rates or changes in the wetting and drying cycles of the ponds. Additional monitoring wells and/or vadose zone piezometers may need to be installed to better track the magnitude and extent of the excessively high-water levels (and/or degraded groundwater quality) to improve recharge management.
	Water quality degradation	Impacts	Recharge with high quality water sources could improve groundwater quality in most cases, but water quality degradation is possible at some sites. Similar mitigation strategies as for “Lowered Groundwater Levels”. The following strategies apply only to “Water Quality Degradation”: mitigation of potential concerns begins with selection of a recharge site that is relatively devoid of hazardous chemical constituents in both the vadose zone and saturated zone. Prior to and during recharge operations, use of the recommended monitoring methods becomes the critical action for characterizing and tracking changes in groundwater quality (localized and regional).

Subsidence	Not Applicable	
Reduced groundwater storage	Not Applicable	
Seawater intrusion	Not Applicable	

Use and Limitations

There are a few significant challenges associated with implementing the recommended monitoring methods. Depending on the scale of the recharge project/goals and hydrogeologic conditions, a substantial or extensive monitoring network (primarily monitoring wells and vadose zone piezometers) might be needed with associated monitoring requirements, which could result in significant costs. However, the monitoring efforts for groundwater levels and delivered water are very basic and can be automated (except for groundwater quality sampling). In addition, measuring / calculating operational parameters such as infiltration rates and recharge volumes are easily applied. Permitting efforts related to recharge facility implementation will depend on the complexity of the project, potential for adverse impacts to other nearby beneficial water and land uses, and State Water Resources Control Board (SWRCB)/Department of Water Resources (DWR) requirements specific to the project. These permitting efforts are generally not expected to be more involved or difficult than for any recharge method or application (e.g., ASR, stormwater recharge, or Flood-MAR).

Results of recharge monitoring using the monitoring network established during recharge facility construction may indicate that insufficient data are being obtained to evaluate the effectiveness of the recharge pond facility in relation to the established performance standards and/or that groundwater level rise or groundwater quality impacts may be of concern at or in the vicinity of the facility. These conditions can be addressed by developing and implementing a work plan to install additional monitoring wells and/or vadose zone piezometers, which would provide useful hydrogeologic information at targeted locations, as well as providing additional critical monitoring points.

Permitting and Design Considerations

A basin-wide hydrogeologic conceptual model allows for evaluating the general hydrogeologic setting for recharge ponds, which provides a basis for determining appropriate locations and depths for monitoring wells and vadose zone piezometers. In addition, GSPs may have a regionally specific hydrogeological model and calibrated groundwater flow model that could be utilized for the recharge pond project. These tools can be used for recharge pond feasibility studies and permitting.

During the design and permitting phase of the recharge pond project, the initial basin wide hydrologic conceptual model could be revised and refined to represent the recharge site better. In addition, the models may be modified based on available and new data for local and regional hydrogeologic conditions and initial recharge feasibility investigations at the project site.

The groundwater flow model could also be revised to include recharge pond design features and predicted operations to improve estimates of the vertical and lateral extent of recharge influence. Modeling recharge operations allows for the refinement of locations and depths of monitoring wells and vadose zone piezometers.

Recharge ponds have several permitting requirements that should be considered with project development:

- Project proponents may need to acquire a water right permit from the SWRCB Division of Water Rights.
- Water right permits require California Environmental Quality Act study to avoid unintended environmental impacts from the project.
- Streamlined permits are available specifically for groundwater recharge projects.
- The project proponent may need to prepare an Environmental Impact Report to permit the project.

– There are specific indirect potable reuse and stormwater permitting considerations that should be addressed in the Monitoring Methods for these projects (MM-01 and MM-04 respectively).

Relationship to Other Monitoring Methods

Other Monitoring Methods can apply and interrelate to this Recharge Ponds Monitoring Method. Groundwater Recharge Projects Monitoring Methods such as Aquifer Storage and Recovery (MM-01), Flood-MAR (MM-03), Stormwater Recharge (MM-04), and Indirect Potable Reuse (MM-05) are directly related and use the same implementation approaches. Groundwater and Surface Water Interactions (MM-07), Seawater Intrusion Management (MM-08), Subsidence Management (MM-09), and Groundwater Dependent Ecosystems (MM-10) Monitoring Methods can also benefit from recharge ponds.

Approach to Implementing Recharge Pond Monitoring

Recharge ponds can be used to increase groundwater recharge and benefit sustainability indicators. The recommended monitoring methods for measurement and tracking of project benefits and impacts include groundwater levels, groundwater and source water quality, water flow (delivery) rates, and infiltration rates. These data comprise the relevant parameters for assessing performance of MAR using recharge ponds. If the project falls under a GSP, performance standards and recharge goals for each GSP project can be developed based on relevant conditions and criteria for the recharge site.

Justification

These recommended monitoring methods for recharge ponds can provide monitoring data of sufficient accuracy and quantity to assess whether the recharge project providing benefits to the groundwater users and if applicable if the project is meeting goals established by the GSP (sustainability criteria). Monitoring actual recharge performance using the appropriate methods can evaluate groundwater level responses, groundwater quality benefits and impacts, recharge rates, volumes, and aquifer storage capacity. Monitoring these properties during recharge pond operations helps the project proponent develop aquifer management strategies to achieve sustainability. The monitoring description below is divided into the primary monitoring that can be conducted to assess whether the project is providing groundwater sustainability benefits; secondary monitoring that would be beneficial to track the overall project benefits both groundwater, social, and economic; additional useful monitoring that could help track overall project performance and help establish useful metrics for future project implementation.

Primary Monitoring

Groundwater level and groundwater quality monitoring are the primary monitoring for assessing benefits and impacts of recharge pond projects. The monitoring approaches for these parameters are discussed in detail in the step-by-step guide to applying methods below.

Secondary Monitoring

Monitoring the volume and rate of water applied and recharged is an important consideration to assess project operation. The volume of applied water could be measured at the project diversion point. After the water is diverted, there are system losses that could be accounted for and calculated as part of the groundwater recharge volume.

Other Useful Monitoring

A water budget may be useful to assess the project benefits. A calibrated groundwater model can be used to estimate the total volume of groundwater recharged and how much water was lost to evapotranspiration, lateral flow to other areas, discharge to streams, etc. Quantifying the water budget for recharge pond projects with field monitoring is possible; however, this can be challenging and costly with the technology that is currently available.

In some cases, other sustainability indicators might benefit from recharge pond projects. Monitoring for the depletion of Groundwater and Surface Water Interactions (MM-07), Seawater Intrusion Management (MM-

08), and Subsidence Management (MM-09) sustainability indicators are discussed in their respective Monitoring Methods.

A Step-by-Step Guide to Applying the Recharge Pond Method

Implementation of an appropriate and effective monitoring for a recharge pond project includes the following strategies and steps:

Safety plan: All projects with fieldwork related activities should produce a Safety Plan. Planning for fieldwork and availability of access to the site, such as monitoring wells, is necessary to maintain project safety. Recharge pond projects may require a Safety Plan to address these and other potential safety concerns.

Primary Monitoring Method

1. **Design a monitoring well network, if applicable the network should be consistent with GSP Regulations and guidelines specified in DWR's Best Management Practice (BMP) 2 Monitoring Networks and Identification of Data Gaps (DWR, 2016):** The monitoring network may be capable of capturing data on a sufficient temporal frequency and spatial distribution to demonstrate short-term, seasonal, and long-term trends in basin conditions for each of the relevant sustainability indicators and provide enough information to evaluate project performance. The location of the monitoring network should be easily accessible such that gaining access to the site does not inhibit gathering and downloading data. The following steps may be taken to design the monitoring network:
   - Determine the number and appropriate locations for monitoring wells and vadose zone piezometers based on site-specific and nearby hydrogeologic conditions (see example in Figure MM02-2) and on non-hydrogeologic aspects such as land ownership, proximity to other beneficial water uses, contaminant sources, and subsurface structures. Useful considerations, guidelines, and applications for locating monitoring wells at recharge project sites are provided *in Standard guidelines for managed aquifer recharge, ASCE/EWRI 69-19 / American Society of Civil Engineers* (American Society of Civil Engineers, 2020).

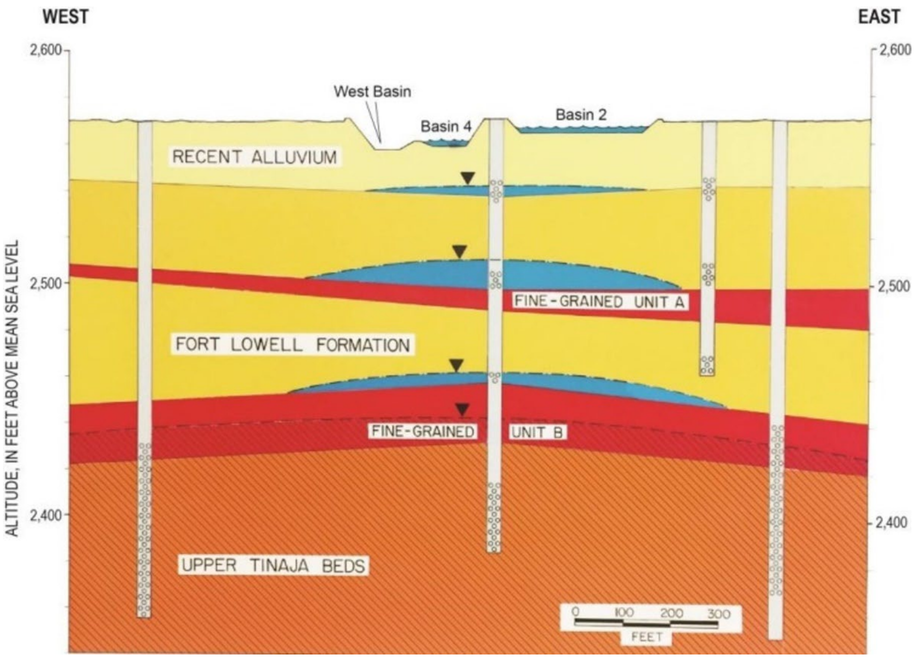

Figure MM02-2. Example recharge pond facility showing the localized hydrogeology with location and depth of monitoring wells for monitoring and measuring the project benefits to groundwater sustainability.

   - At a minimum, one monitoring well may be located up hydraulic gradient from the recharge pond and one monitoring well may be located down hydraulic gradient from the recharge pond to provide data for evaluating effects of recharge on groundwater levels and groundwater quality. However, three or more monitoring points would be needed to determine the magnitude and direction of the local hydraulic gradient in a given aquifer or aquifer zone, or to monitor more than one aquifer or aquifer zone. Projects using recycled water as the source are required by California Title 22 to have two downgradient monitoring locations between the recharge pond and downgradient drinking water wells. For further information on this subject, refer to the Indirect Potable Reuse Monitoring Method (MM-05).

- The spatial extent and frequency of monitoring for groundwater levels and groundwater quality will depend on background conditions and size of the recharge pond. In general, more spatially extensive monitoring can be needed for larger recharge ponds, projects with multiple ponds, and for sites with larger recharge rates. Monitoring may be more frequent for areas that are subject to larger fluctuations in groundwater conditions (for example, fluctuations in pumping or natural recharge in the surrounding area).
- Development of the monitoring well network may consider both unconfined and confined aquifers, and screened intervals and annular seals for monitoring wells should be carefully designed to target the specific aquifer or aquifer zone being monitored.

2. **Refine the specific "monitoring plan" if significant data gaps are identified based on results of initial monitoring:** The monitoring network should be dependent upon the initial hydrologic conceptual model and available data and will likely undergo refinement both temporally and spatially as recharge operations proceed and data are obtained that improve understanding of the monitoring needs so that necessary information can be efficiently integrated to demonstrate sustainability.
3. **Evaluate construction considerations for the monitoring wells and vadose zone piezometers:**
   - Wells that are part of the monitoring program may be dedicated groundwater monitoring wells with known construction information. The selection of wells may be aquifer-specific and wells that are screened across more than one aquifer may be avoided where possible.
   - If existing wells are used, the screened intervals may be known to interpret and utilize the water level or water quality data collected from those wells.
   - Monitoring wells and vadose zone piezometers may be drilled and installed in accordance with DWR Bulletin 74-81 and 74-90, or as updated.
   - When possible or feasible, use of a casing advancement drilling method may be advantageous because it uses no drilling fluids and seals off the borehole wall, which provides better lithologic information (representative cuttings of the depth interval being drilled) than rotary drilling methods. For vadose zone piezometers, either the hollow-stem auger method or a casing advancement method may be used because the piezometers cannot be developed to remove drilling fluids.
   - New monitoring wells in an unconfined aquifer may be constructed in the upper part of the pre-recharge saturated zone with the screened interval extending above the water table to accommodate water level rise from recharge operations. The length of screen below and above the pre-recharge water table will depend on the range of seasonal fluctuation of background water levels and the anticipated amount of water level rise from recharge.
   - Vadose zone piezometers may be installed to the tops of potential impeding layers that may cause development of perched groundwater conditions and lateral flow. Vadose zone piezometers may also be installed to provide monitoring points between the recharge ponds and locations of sensitive subsurface structures, contaminated sites, and other features that could potentially be affected by shallow groundwater.
4. **Implement monitoring well and vadose zone piezometer monitoring:** Protocols for monitoring of groundwater levels and groundwater quality are addressed in DWR's BMP 1 Monitoring Protocols Standards and Sites (DWR, 2016). Selected notable considerations for implementation of monitoring include the following:
   - All monitoring should be conducted in such a manner to produce reliable, consistent, high-quality, defendable data (see example in Figure MM02-3).

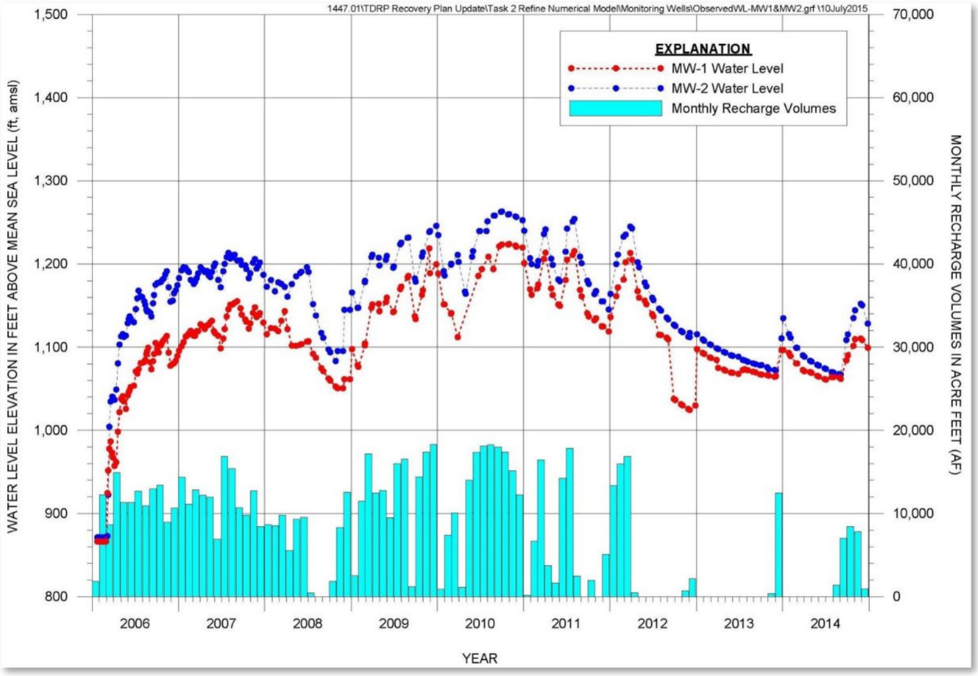

Figure MM02-3. Example groundwater level and recharge volume monitoring results provided in a high quality, reliable, consistent, and defendable manor.

- Conduct "baseline monitoring" in the monitoring wells prior to commencement of recharge operations to document groundwater levels and trends, and to characterize ambient groundwater quality and trends. While baseline monitoring for groundwater levels and quality may be conducted at a minimum prior to commencement of recharge operations, collecting baseline monitoring for at least one (1) year before recharge operations during prior seasonal low and seasonal high groundwater level periods would provide a more robust dataset to compare to project implementation data should groundwater level or quality impacts occur.
- Following commencement of recharge operations, implement "operational monitoring" as required to evaluate changing groundwater conditions and associated risk (e.g., unreasonable harm to beneficial uses), and to better manage recharge operations; the monitoring frequency for groundwater levels and the sampling frequency and chemical constituents to be analyzed for groundwater quality monitoring will be determined by the project proponent and regulating agencies.
- While semi-annual monitoring is required for groundwater levels at the basin-scale, more frequent monitoring (such as quarterly, monthly, or weekly) can be necessary for some projects to provide a more robust understanding of groundwater dynamics within the system. More frequent monitoring of groundwater levels (regional aquifer and perched groundwater) becomes critical for recharge operations management if/when water levels rise close to land surface or to sensitive subsurface structures or affect beneficial uses.

Secondary Monitoring Method

1. **Implement monitoring of water deliveries starting at commencement of recharge operations:** Monitoring for instantaneous flow rates should be as frequent as practicable if conducted manually and are recommended to be hourly (or more often) if measured electronically (data stored in a datalogger or SCADA-type system). Measurements of total cumulative volume can be obtained commensurate with instantaneous flow rate measurements.
2. **Implement monitoring of infiltration rates:** Use either the wetting cycle calculation method (volume infiltrated during a wetting cycle) or falling-head method (rate of water level decline in a pond) described previously. For both methods, the water volume lost to evapotranspiration can be factored in, also described previously. The frequency of monitoring can depend on the rotation cycle for the ponds or the operator's discretion for managing recharge operations and planning rehabilitation, with the goal of maximizing infiltration rates and recharge volumes.

Data and Protocols - Fundamentals

Recharge pond monitoring typically consists of 1) measuring changes in groundwater levels; 2) monitoring groundwater quality impacts, and 3) monitoring recharge rates/volumes. Table MM02-4 provides an example summary table of monitoring metrics that could be used for reporting on the benefits of recharge pond projects. **The fundamental monitoring metrics** for recharge ponds include the following:

- **Aquifer groundwater level monitoring** using wells or piezometers installed in the saturated zone for evaluating changes in groundwater levels and gradients due to recharge operations.
- **Vadose zone water level monitoring** in piezometers installed above perching layers (if present). Perched layers may cause water level rise close to land surface that could adversely impact infiltration rates and adjacent land and beneficial water uses.
- **Groundwater sampling of monitoring wells or piezometers** to evaluate water quality changes due to recharge. Recharge may result in blending of source water with ambient groundwater and/or mobilization and flushing of chemical constituents in the vadose zone as the water infiltrates.
- **Volumes and flow rates of water delivered to the recharge ponds using flow meters** installed at the diversion points. Diversion points can be pipelines or canals that provide a variety of water sources including surface water, recycled water, and storm water.
- **Recharge pond infiltration rate** for evaluating project performance, determining management strategies (e.g., wetting and drying cycles, rotation or filling of multiple pond systems), and the need for pond rehabilitation. Recharge ponds are typically managed to maintain or maximize infiltration rates.
- **Water lost to evaporation** can be monitored as needed to accurately determine infiltration and/or loading rates and associated recharge volumes. Evaporation can be measured using standard evaporation pans installed at the recharge site or estimated using meteorological data that are available from relatively nearby meteorological stations and associated databases.

Figure MM02-4. Example collection of well data.

Table MM02-4. Example Data Monitoring Report (Generally Annually)

Annual Monitoring Report	
Total Volume Entering Recharge Basin	XXX AF
Infiltration Rate	XXX in/hr
Evaporative Losses	XXX AF
Total Volume Entering Groundwater	XXX AF
Average Groundwater Level Change (Recharge Area / Background)	+/- XXX ft / +/- XXX ft
Average Groundwater Quality Constituent Change (list all identified, Recharge Area / Background)	+/- XXX mg/L / +/- XXX mg/L
Groundwater Basin Recharged	XX Basin
Incurred Costs	$XXX

The **fundamental monitoring tools** for recharge ponds include the following:

- Groundwater levels are measured manually using electronic sounders and automatically using pressure transducers lowered into and/or installed in the monitoring wells and piezometers. Groundwater level monitoring protocols are provided in DWR's BMP 1 Monitoring Protocols Standards and Sites (DWR, 2016). The use of dataloggers in association with pressure transducers allows automated collection and storage of water level measurements at frequent intervals.
- Primary tools for monitoring groundwater quality include dedicated or temporary pumps installed in the monitoring wells to purge the wells and obtain groundwater samples for laboratory analyses using protocols provided in DWR's BMP 1 Monitoring Protocols Standards and Sites (DWR, 2016). Passive sampling systems or bailers can also be used to sample, but it should be recognized that the method of sample collection could affect the constituent concentrations detected.
- Water deliveries are measured using flow meters installed in the delivery pipeline to measure instantaneous flow rate and total cumulative volume. For canal conveyance, instantaneous flow rates using flumes or weirs can also be used. Pressure transducers and dataloggers can be used to collect water pressure or head, that can be converted to flow rate using a discharge curve (see Flood-MAR Monitoring Method [MM-03]). Dataloggers allow for automated collection and storage of measurements at frequent intervals.
- Primary tools for measuring infiltration rates depend on the method used and can include 1) the flow meters described above to measure the volume of water added during a wetting cycle (then subtract evaporation losses and divide the remaining water volume by the pond area and by the wetting cycle time interval), or 2) a staff gauge (with pressure transducer and datalogger) to measure water level decline in a recharge pond during a falling-head cycle during which no water is added to the ponds.

Specific details for implementation of monitoring for a given recharge pond facility may be refined based on site conditions but should be commensurate with the complexity, risk, and sources of unreasonable harm for the proposed recharge pond operations.

Data Analysis and Reporting

1. **Analyze monitoring data:** Monitoring data can be used to evaluate the effectiveness and performance of the recharge pond, determine any limiting factors on performance, and identify options for improving performance if needed. This assessment also includes evaluating possible increasing concerns, as recharge continues, for causing unreasonable harm to nearby land or beneficial water uses and if/how recharge operations can be better managed to avoid significant risks.
2. **Prepare reports and manage data:** Includes compliance with regulatory and grant requirements and providing data to DWR, which is addressed in the Data Management and Monitoring Method (MM-12). Generally, data can be uploaded to the DWR system annually and progress on project implementation and monitoring can be provided in Annual Reports. In addition, a full assessment of the project performance can be provided in a 5-Year Assessment Report and may be required if the project falls under the direction of a GSP.

Data Standards

Groundwater, surface water, and water quality monitoring data should conform to the technical and reporting standards of the California Water Code (CWC) §352 *et seq*.

Groundwater levels - Groundwater elevation measurements should be recorded relative to a consistent vertical datum. A general rule of thumb for recharge pond projects is that groundwater levels shall not rise to within 10 feet of land surface due to recharge operations.

Groundwater quality - Concentrations of groundwater quality constituents of concern should be compared to maximum contaminant levels (MCLs) available from the SWRCB.

Key Protocols

The following protocols should be followed for required monitoring:

- Standard groundwater level and groundwater quality monitoring protocols as described in DWR's BMP 1 Monitoring Protocols Standards and Sites (DWR, 2016).
- Guidelines for establishing monitoring networks and resolving data gaps to reduce uncertainty are provided in DWR's BMP 2 Monitoring Networks and Identification of Data Gaps (DWR, 2016).
- Technical and reporting standards included in CWC §352 *et seq*.

Additional guidance or references include:

- Standard guidelines for managed aquifer recharge, ASCE/EWRI 69-19 / American Society of Civil Engineers. (American Society of Civil Engineers, 2020)
- Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2) Managed Aquifer Recharge. (National Resource Management Ministerial Council, 2009)

Example of Recharge Pond Application

Tonopah Desert Recharge Project

Location: Maricopa County, Arizona (See Figure MM02-5 for an aerial image of the recharge ponds)

Year: Recharge operations commenced in 2006 and are on-going

Description and Relevance:

Relevant example of monitoring and requirements for a large recharge pond facility permitted for up to 150,000 acre-feet per year. The facility includes 19 infiltration basins over 207 acres. The site monitoring includes two groundwater monitoring wells, one downgradient and one cross-gradient, and four vadose zone piezometer nests, each consisting of piezometers at two discrete depths. The monitoring plan for the site included contingency plans to address potential adverse impacts due to shallow groundwater levels (excessive mounding) and groundwater quality (approach or exceed established water quality standards). The contingencies could include reduction of recharge rates and other operational modifications or installation and monitoring of additional monitoring wells and/or piezometers.

Figure MM02-5. Tonopah Desert Recharge Project Ponds (Central Arizona Project, 2021).

Links to Resources: https://www.cap-az.com/

Harkins Slough Recharge Basin and Wells

Location: Pajaro Valley, Santa Cruz County, California

Year: Recharge and recovery operations commenced in 2002 and are on-going

Description and Relevance:

Relatively small recharge pond and recovery demonstration project that has been active since 2002, with cumulative recharge of about 10,000 AF and cumulative recovery of about 4,040 AF. The project has included detailed assessment of water quality, subsurface geophysics, and numerical modeling that can be used to design and monitor other recharge pond projects.

Links to Resources: https://www.pvwater.org/images/20210929_WSS-MARR_Recharge__Recovery_Investigation_ToPresent.pdf

Kern Water Bank Project

Location: Kern County, California

Year: Recharge and recovery operations commenced in 2011 and are on-going

Description and Relevance:

Large project consisting of 7,000 acres of ponds that recharge excess surface water supplies from the State Water Project, Central Valley Project, and Kern River. Annual recharge volumes can be as much as 338,000 AF. There are 85 recovery wells that can be used to recover about 240,000 AF per year. The project uses a network of 57 dedicated groundwater level and quality monitoring wells that are monitored for groundwater levels semi-annually and groundwater quality annually.

Links to Resources: https://www.kwb.org/

Source References

American Society of Civil Engineers. 2020. Standard guidelines for managed aquifer recharge, ASCE/EWRI 69-19. Reston (VA): American Society of Civil Engineers.

California Department of Water Resources. 2016. Best Management Practices for the Sustainable Management of Groundwater, six-part series (BMP 1 Monitoring Protocols Standards and Sites, BMP 2 Monitoring Networks and Identification of Data Gaps, BMP 3 Hydrogeologic Conceptual Model, BMP 4 Water Budget, BMP 5 Modeling, and BMP 6 Sustainable Management Criteria DRAFT). Sacramento (CA): California Department of Water Resources. California Natural Resources Agency. [Website] Viewed online at: https://water.ca.gov/Programs/Groundwater-Management/SGMA-Groundwater-Management/Best-Management-Practices-and-Guidance-Documents.

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Montgomery and Associates. 2021. Hydrogeologic Investigations for the Tonopah Desert Recharge Project. Water Resources Consultants, a report prepared for the Central Arizona Project. Sacramento (CA). [Website] Viewed online at: https://elmontgomery.com/projects/hydrogeologic-investigations-tonopah-desert-recharge-project/

Flood-MAR Monitoring Method
MONITORING METHOD [MM-03]

SUSTAINABLE GROUNDWATER MANAGEMENT (SGM) GRANT PROGRAM

MONITORING METHOD [MM-03]

Flood-MAR Monitoring Method

Project / Action Type	Flood-MAR uses unallocated surface water flood flows as a water source for managed aquifer recharge (MAR).
Similar / Related Project Types	Flood-MAR is generally used to describe groundwater recharge on agricultural lands and working landscapes. It is commonly referred to as “on-farm recharge” or “ag-MAR”. A related project type is floodplain restoration that in addition to other benefits, allows for greater groundwater recharge from streams.
Primary Metric	Groundwater levels. Groundwater storage. Applicable water quality constituents Change in ground levels (situationally). Surface water flow rates (situationally). Surface water stage (situationally). Groundwater dependent ecosystems (situationally).
Measurement Unit	Groundwater levels measured in feet in a consistent vertical datum. Recharge/demand volumes in acre-feet. Concentration or measurement of applicable groundwater quality constituents (typically mg/L), including nitrate, salinity, arsenic, selenium, boron, or other applicable water quality constituents of concern.
Beneficial User	Municipal and domestic water supply (MUN) Agricultural water supply (AGR) Groundwater recharge (GWR) Freshwater replenishment to surface waters (FRSH) (situationally)

Flood-MAR Overview

Flood Managed Aquifer Recharge (Flood-MAR) is a multi-benefit approach that uses flood water resulting from, or in anticipation of, rainfall or snowmelt to recharge groundwater, reduce flood risks, and in some cases improve ecosystem function. Flood-MAR typically makes use of working landscapes, typically dormant or fallowed agricultural lands, to recharge shallow groundwater in the winter months when flood flows are available. The purpose of this Monitoring Method is to provide guidance on monitoring methods and reporting standards to assess the effectiveness of Flood-MAR projects in order to help achieve groundwater sustainability. Depending on the project goals, Flood-MAR may benefit surface water interconnection, environmental conditions, regional groundwater quality, and depending on location, seawater intrusion, and subsidence. In some cases, recharge from Flood-MAR projects can mobilize contaminants in the soil and cause groundwater quality degradation, so projects should be carefully planned and monitored.

KEY TERMS

Flood-MAR is an integrated resource management strategy that uses flood water resulting from, or in anticipation of, rainfall or snow melt for managed aquifer recharge working landscapes, including but not limited to agricultural lands, refuges, floodplains, and flood bypasses.

Ag-MAR is agricultural, or on-farm managed aquifer recharge.

The groundwater sustainability plan (GSP) Regulations that specify components of GSPs prepared pursuant to the Sustainable Groundwater Management Act (SGMA) require that groundwater sustainability agencies (GSAs) provide explanations of project and management actions (23 CCR § 354.44). Nothing in these Monitoring Methods supersedes the GSP Requirements as related to the development and implementation of GSPs, alternatives to a GSP, coordination agreements, and annual reporting requirements under SGMA.

Monitoring Objective

Flood-MAR projects use flood waters or excess waters released from reservoirs to recharge groundwater on working landscapes. Monitoring specific groundwater components allows the project proponents to determine if the project is providing the intended benefits, or if it is causing any impacts to nearby beneficial users. Monitoring should be conducted to identify project progress relative to the applicable sustainability indicators. Table MM03-1 below identifies the relative level of benefit of Flood-MAR projects on the six sustainability indicators included in SGMA.

Table MM03-1. Level of Benefit to the Six Sustainability Indicators Outlined in SGMA

	Six Sustainability Indicators Outlined in SGMA	Applicability
	Depleted Interconnected Surface Water	★
	Lowered Groundwater Levels	★★★
	Water Quality Degradation	★★
	Subsidence	★
	Reduced Groundwater Storage	★★★
	Seawater Intrusion	★

*Notes:

★★★ = Primary Benefit (High Applicability)

★★ = Secondary Benefit (Medium Applicability)

★ = Situational Benefit (Applicability dependent on Location, Site Characteristics, and Aquifer Condition)

Desired Outcomes or Benefits Resulting from Flood-MAR

Flood-MAR projects potentially benefit groundwater conditions in numerous ways. Table MM03-2 shows the benefits from Flood-MAR for groundwater sustainability, relative to the background conditions.

Table MM03-2. Potential Benefits Resulting from Project / Action

Potential Benefits on SGMA Sustainability Indicators	Benefit / Not Applicable	Description of Benefits
Depleted interconnected surface water	Benefit	Increased groundwater and surface water interaction that benefits in-stream and riparian habitat for critical species and groundwater dependent ecosystems (if applicable).
Lowered groundwater levels	Benefit	Decreased pumping lifts for groundwater recovery.
Water quality degradation	Benefit	Source water quality that is better than ambient groundwater quality may improve groundwater quality through dilution. For example, Flood-MAR recharge may lower nitrate and salinity concentrations in degraded groundwater to concentrations below acceptable levels for beneficial use.
Subsidence	Benefit	Decreased land subsidence (if applicable).
Reduced groundwater storage	Benefit	Allows for seasonal storage of excess water.
Seawater intrusion	Benefit	Decreased seawater intrusion (if applicable).

Although not a SGMA sustainability indicator, one of the primary benefits of Flood-MAR projects is that it can reduce flood risk by diverting floodwater away from potential flood zones.

Potential Impacts

Flood-MAR projects generally improve groundwater quality since surface water used for recharge is typically of higher quality than groundwater. However, there is some potential risk for groundwater quality impacts related to leaching of applied, legacy, or natural constituents in soil, generally in the agricultural setting. Flood-MAR demonstration projects have primarily shown that the greatest risk to groundwater quality degradation is from nitrate and salt leaching, but there are numerous other site-specific constituents that could potentially leach to and impact groundwater. The risk of groundwater degradation can be reduced by selecting recharge sites that have lower current and historical nitrogen and salinity loads, and higher rates of recharge that improve dilution effects. The impacts to groundwater quality may be temporarily affected during the initial flushing of legacy contaminants in the soil matrix and improve with additional recharge events. Potential impacts resulting from Flood-MAR are summarized in Table MM03-3.

Table MM03-3. Potential Impacts Resulting from Project / Action

	Potential Impacts on SGMA Sustainability Indicators	Impact / Not Applicable	Mitigation Measures to Address Impacts
	Depleted interconnected surface water	Not Applicable	
	Lowered groundwater levels	Not Applicable	
	Water quality degradation	Impacts	There are numerous considerations to mitigate groundwater quality degradation from Flood-MAR. The most effective approach is to choose recharge sites that have lower nitrogen and salinity loads, such as fallow land and land without recent nutrient or chemical application, or other known natural sources of constituents of concern like salinity, selenium, and arsenic. If ambient groundwater quality is close to existing regulatory limits, then recharge sites should be selected that are lower risk for impacting wells (i.e., in areas with lower ambient nitrate or fewer domestic and public supply wells). To reduce the risk of groundwater quality impacts in susceptible areas, recharge areas should be confined to only highly permeable sites to avoid leaching over a larger area. Sites with coarser soils are preferable to locations with finer soils because higher recharge rates cause greater contaminant dilution. Longer duration single-flooding events are preferable to intermittent flooding events to prevent conversion and mobilization of nitrogen in soil to nitrate. Avoiding recharge over legacy nitrogen loads like manure lagoons and animal corrals is advisable. Grapes, alfalfa, and legumes are crops with low nitrogen fertilizer inputs that could make good recharge sites. Planting nitrogen fixing cover crops or carbon amendment prior to recharge events could lessen the nitrate leaching potential. The west side of the Central Valley has higher natural salinity and therefore only sites in this region with higher recharge rates should be prioritized to avoid salinization of the aquifer.
	Subsidence	Not Applicable	
	Reduced groundwater storage	Not Applicable	
	Seawater intrusion	Not Applicable	

Use and Limitations

Flood-MAR project monitoring can be challenging due to the potentially large regional footprint and potentially high levels of uncertainty regarding the fate of applied water in the agricultural setting. The large regional extent of Flood-MAR projects may require numerous representative monitoring locations to fully quantify the benefits and impacts of Flood-MAR implementation on groundwater levels, groundwater quality, or other applicable sustainability indicators. Interpretation of the data in areas with complex hydrogeologic settings can be a challenge. For example, not all applied water may recharge deeper groundwater aquifers; some applied water may not percolate, or only percolate slowly to the depths in the aquifer that would benefit most from increased groundwater levels. Lateral flow on perched or confining layers may result in recharge water returning to streams or recharging shallow aquifers or adjacent areas that are not the intended target for project benefits. Flood-MAR monitoring may also be complicated by potentially high rates of natural recharge and groundwater level increase during the wet timeframes when Flood-MAR is typically implemented. This challenge makes background monitoring essential for measuring project benefits relative to natural processes.

A unique characteristic for Flood-MAR projects that creates challenges for implementation and monitoring is the intermittent nature of the recharge events. This is a project that can only be operated in certain seasons and years when flood waters are available. This creates challenges for planning for long-term sustainability, as well as for investment in long-term monitoring. Since recharge events may be infrequent and only occur over a short duration, monitoring systems should be maintained so that they are available for use when recharge events do occur.

The greatest limitation to Flood-MAR operation and success is the potential risk to groundwater quality. Research is being conducted to better understand and potentially reduce groundwater quality impacts from these types of projects. Current research focuses on crop suitability and the ideal timing and duration of recharge for field crops, row crops, vineyards, and orchards to reduce groundwater quality degradation. Domestic well owners and disadvantaged communities may be disproportionately affected by groundwater quality degradation as their wells are typically the shallowest supply wells. Flood-MAR guidance from Department of Water Resources (DWR) suggests creating a contingency plan for addressing unintended groundwater quality impacts to beneficial users.

Results from an initial monitoring network (established during Flood-MAR facility construction), may indicate that insufficient data is being obtained to evaluate facility effectiveness in relation to the established performance standards and/or groundwater level rise or groundwater quality impacts may be of concern. These conditions can be addressed by developing and implementing a work plan to install additional monitoring wells and/or vadose zone piezometers, which would provide useful hydrogeologic information at targeted locations, as well as providing additional critical monitoring points.

Permitting and Design Considerations

Flood-MAR permitting requires specific considerations that are above and beyond this Monitoring Method but should be considered when planning for and designing the project. Careful consideration should be taken when diverting flood flows to not infringe upon environmental flow requirements or downstream users water rights. The State Water Resources Control Board Division of Water Rights oversees a streamlined permit process for groundwater recharge projects. The streamlined permit requires project proponents to conduct a California Environmental Quality Act study to determine that the project could not have unintended environmental impacts. An assessment of water available for replenishment is required for temporary 180-day and 5-year permits for groundwater recharge. These types of permits restrict the available water to be diverted for Flood-MAR projects to times when streams are not allocated for existing water rights or environmental use, flows in a given stream are greater than the 90^{th} percentile of historical flows, and diversions are no greater than 20% of the total streamflow. As such, streamflow measurements upstream and downstream of Flood-MAR diversions are typically required for permit compliance of Flood-MAR projects.

Relationship to Other Monitoring Methods

Other Groundwater Recharge Projects Monitoring Methods including Aquifer Storage and Recovery (MM-01), Recharge Ponds (MM-02), and Stormwater Recharge (MM-04) are directly related and can use the same implementation approaches described in this Monitoring Method for Flood-MAR. Groundwater and Surface Water Interactions (MM-07) and Groundwater Dependent Ecosystems (MM-10) can benefit from Flood-MAR projects. Although less common in projects implemented to date, Flood-MAR can theoretically be used to decrease seawater intrusion in coastal groundwater subbasins, relating to the Seawater Intrusion Management Monitoring Method (MM-08). An indirect benefit from Flood-MAR can be the slowing down land subsidence caused by rapidly dropping water levels, relating to the Subsidence Management Monitoring Method (MM-09).

Approach to Implementing Flood-MAR Monitoring

Flood-MAR is a relatively new approach being used to increase groundwater recharge and promote multi-benefit use of available flood waters. Water sources for Flood-MAR projects are flood flows in streams or reservoir releases timed to discharge water in advance of forecasted rain events (see Figure MM03-1 for example).

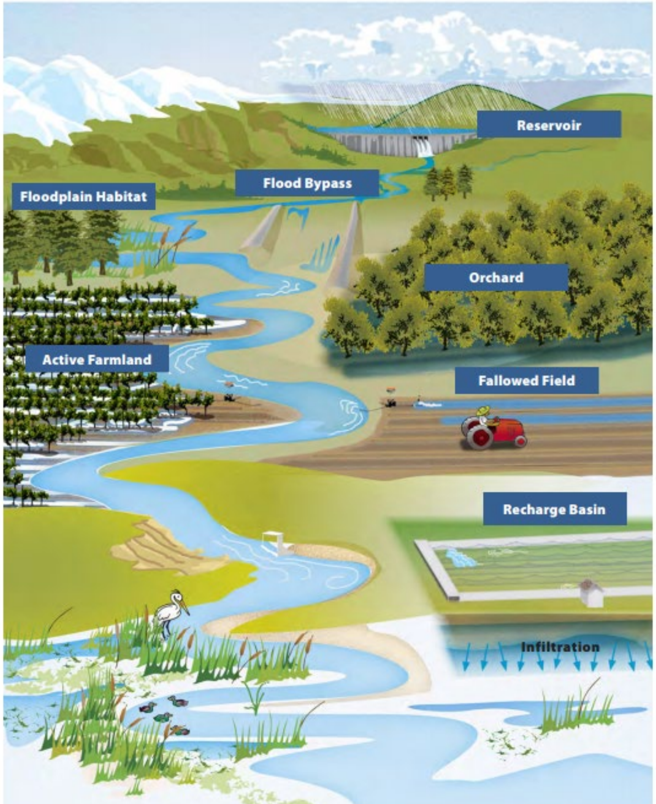

Figure MM03-1. General elements of a Flood-MAR project from DWR 2018.

The recharge mechanism is not specific to Flood-MAR, though many proposed or planned Flood-MAR projects intend to utilize an on-farm recharge approach (also known as Ag-MAR). On-farm recharge or flooding suitable dormant crops and fallowed land during the irrigation off-season, generally consists of spreading flood water over a large area at a relatively shallow ponding depth (generally 1- to 2-feet). Maintaining a shallow ponding depth provides recharge to shallow groundwater and limits potential risks associated with the approach, including soil erosion or damage to irrigation infrastructure. Identifying areas with more permeable soils and fewer low permeability perching layers can increase the rate of recharge while maintaining a shallow ponding depth (see Figure MM03-1 for an example Flood-MAR facility).

The primary concern about Flood-MAR projects is the potential to degrade groundwater quality with nitrate, salts, arsenic, and/or other constituents present in the soil matrix of the vadose zone. Surface water used for recharge almost always contains less nitrate, salts, and other applicable constituents than agricultural soils. Monitoring for these constituents of concern is important in assessing the effects of Flood-MAR recharge projects.

A secondary concern about Flood-MAR projects is slow percolation or ponding of water caused by low-permeability soils or soils with restrictive perching layers in the shallow subsurface. High water tables can cause waterlogging of roots, which promotes anaerobic conditions that might affect plant health due to the lack of oxygen. Slow percolation can increase mobilization of applied nitrate, chemicals, and salts from the unsaturated vadose zone to groundwater.

Justification

Flood-MAR monitoring methods are dependent on the goals of the project and should therefore be designed to assess specific project benefits and unintended consequences. The description below is divided into primary monitoring, that should be conducted to assess whether the project is functioning, secondary monitoring, which would be beneficial to track the overall project benefits for grant purposes, and additional useful monitoring, which could help track overall project performance and help establish useful metrics for future project implementation.

Primary monitoring

Groundwater levels and groundwater quality monitoring should be conducted for most Flood-MAR projects. Monitoring groundwater levels and groundwater quality allows the project proponent to measure project benefits and assess potential impacts to groundwater quality that might affect beneficial use. While Flood-MAR projects should generally benefit groundwater quality, there may be short-term impacts to groundwater quality from flushing constituents present in the soil matrix.

Groundwater level monitoring should include monitoring wells or piezometers installed in the shallow aquifer. Groundwater monitoring in deeper aquifers or permeable layers of the aquifer should be conducted to a depth where the project benefit or impact is negligible. Multiple layers of groundwater level monitoring in and around the recharge area can help assess increases in groundwater levels and groundwater storage due to recharge, relative to dynamic background conditions. Groundwater level monitoring upgradient and downgradient for a Flood-MAR project site can also help identify changes to groundwater flow or gradient induced by large volumes of groundwater recharge. In areas prone to perched groundwater, vadose zone piezometers may be installed to the tops of potential impeding layers to monitor development of perched groundwater conditions and lateral flow.

Groundwater quality should be assessed in the shallowest aquifers that could receive recharge water and subsequently deeper aquifer zones to assess the potential effect of flushing constituents of concern. Furthermore, groundwater quality monitoring should be conducted between the recharge site and beneficial users such as domestic or public supply well owners to identify potential risks to groundwater quality degradation in drinking water supply wells before they occur. If there are no drinking water supply wells near project sites, then groundwater quality monitoring is less critical as there are fewer receptors for degraded groundwater.

In areas where initial groundwater is far below ground surface and not affected by surface recharge, the project proponent may be able to demonstrate that groundwater monitoring is neither feasible nor beneficial. An analysis of groundwater occurrence and use beneath and downgradient of a project site should be conducted to determine whether monitoring is not needed or feasible.

Secondary monitoring

Monitoring the volume and rate of water applied and recharged is an important consideration to assess project operation. The volume of applied water should be measured at the project diversion point. After the water is diverted, there are system losses that could be accounted for and calculated to estimate the groundwater recharge volume at the project location.

Additional useful monitoring

A water budget may be useful to assess the project benefits. A calibrated groundwater model can be used to estimate the total volume of groundwater recharged and how much water was lost to evapotranspiration, lateral flow to neighboring areas, discharge to streams, etc. Quantifying the water budget for recharge projects with field monitoring is possible; however, this can be both challenging and costly with the technology that is currently available.

In some cases, other sustainability indicators might benefit from Flood-MAR projects. Monitoring for the depletion of interconnected surface water, subsidence, and seawater intrusion sustainability indicators are discussed in other Monitoring Methods.

A Step-by-Step Guide to Apply the Flood-MAR Monitoring Method

Implementation of appropriate and effective monitoring methods for Flood-MAR projects includes the following strategies and steps:

1. **Safety plan:** All projects with fieldwork related activities should produce a Safety Plan. Planning for fieldwork and availability of access to the site, such as monitoring wells, is necessary to maintain project safety. Flood-MAR projects may require a Safety Plan to address these and other potential safety concerns.
2. **Monitoring network:** Identify and map drinking water supply well locations near the recharge area to design a monitoring network that can assess and track the risk of potential impacts to beneficial users by changes in groundwater levels and groundwater quality degradation. The location of the monitoring network should be easily accessible such that gaining access to the site does not inhibit gathering and downloading data (refer to Step 1).

Figure MM03-2. Example of orchard utilized as Flood-MAR facility (DWR, 2018).

3. **Install monitoring wells:** Identify and/or install groundwater level and quality monitoring wells in each saturated zone or aquifer beneath the recharge area that may be influenced by groundwater recharge. This may include vadose zone monitoring if perched conditions are expected to develop because of the recharge project. Wells should ideally be placed in and around the recharge area, including upgradient, cross-gradient, and downgradient, to assess the changes to groundwater level, gradients, and quality from natural processes, relative to the Flood-MAR project.
4. **Baseline conditions:** Conduct “baseline monitoring” in the monitoring wells prior to commencement of recharge operations to document groundwater levels and trends, and to characterize ambient groundwater quality and trends. While baseline monitoring for groundwater levels and quality should be conducted at a minimum prior to commencement of recharge operations, collecting baseline monitoring for at least one year before recharge operations during prior seasonal low and seasonal high groundwater level periods would provide a more robust dataset to compare to project implementation data should groundwater level or quality degradation occur.
5. **Event monitoring:** During recharge events measure groundwater levels continuously (at least daily) using groundwater level transducers to estimate changes in groundwater level, groundwater gradients, and potential groundwater and surface water interconnection.
6. **Post-event monitoring:** After initial recharge events, groundwater quality for constituents of concern should be measured monthly. The frequency can be reduced to annually at the conclusion of the recharge event. Monitoring frequency for groundwater levels and/or quality can be reduced in subsequent recharge events if initial findings suggest that less frequent monitoring is necessary.
7. **Event reporting:** Compile estimates of groundwater diverted for Flood-MAR, recharge induced, and benefits and impacts on groundwater levels and groundwater quality annually.
8. **Groundwater modeling for refinement of project:** Use a calibrated groundwater model, as necessary, to refine estimates, or projections, of benefits and impacts related to the project.

Data and Protocols - Fundamentals

Information/Data Requirements

Flood-MAR monitoring primarily focuses on the effects that recharge may have on groundwater levels and groundwater quality. Additionally, it can be useful to monitor the volume of water diverted for recharge. The following monitoring tools, at a minimum, should be used to monitor Flood-MAR projects:

- Groundwater level changes should be measured in wells at different depths beneath and around the recharge area. The volume of water that recharges the groundwater aquifers or flows laterally on subsurface aquitards may be estimated using the change in groundwater levels in wells at different depths beneath and around the recharge area. Groundwater levels measured during baseline monitoring and after recharge events can be evaluated to assess changes to groundwater gradients related to project implementation.
- The monitoring network may use existing groundwater level monitoring wells if they are available and constructed appropriately. New shallow monitoring wells in an unconfined aquifer should be constructed in the upper part of the pre-recharge saturated zone with the screened interval extending above the water table to accommodate water level rise from recharge operations. The length of screen below and above the pre-recharge water table depend on the range of seasonal fluctuation of background water levels and the anticipated amount of water level rise from recharge. Vadose zone piezometers should be installed to the tops of potential impeding layers that may cause development of perched groundwater conditions and lateral flow. Since groundwater elevations are dynamic properties, background groundwater level measurements in upgradient, downgradient, and/or cross-gradient wells are useful to estimate natural changes in groundwater elevation unrelated to the groundwater recharge project.
- Groundwater quality should be assessed during implementation to avoid project impacts to beneficial use of groundwater for drinking water supply. Groundwater quality is best monitored by sampling and analysis at wells. The primary constituents of concern in the agricultural setting where many Flood-MAR projects are planned are nitrates and salts. Other potential constituents of concern in the agricultural setting are naturally occurring within the geologic material or are found in applied chemicals. Often, groundwater quality for beneficial use is assessed relative to the applicable maximum contaminant level for drinking water; however, in some cases can also be related to crop tolerance. Applied chemicals and natural constituents in the agricultural setting that may be useful to periodically monitor include pesticides, herbicides, soil fumigants (for example, 1,2,3-trichloropropane), arsenic, boron, selenium, and potentially other minerals, metals, and geochemical parameters. Other existing sources of groundwater quality data can be used to monitor project impacts if the wells are in the vicinity of the project area. Water quality in public supply wells is monitored and reported for large systems by the State Water Resources Control Board Division of Drinking Water and for small systems by local county Environmental Health Departments. Additionally, shallow domestic well water quality data are available in parts of the state (San Joaquin and Salinas Valleys) from the Regional Water Quality Control Board Irrigated Lands Reporting Program with expansion of the program into the Sacramento Valley planned to start in 2022.

Additional useful monitoring to assess the project effectiveness and performance includes the volume of applied water, fate of applied water, and benefits to other sustainability indicators:

- The volume or rate of surface water used by the project can be measured upstream or at the diversion and downstream of the diversion. Streamflow is typically measured using a discharge curve developed for different stream stages at a stream gage or stilling well. Stream levels or stage are typically measured at least daily with pressure transducers.
- Water flux in the vadose zone can be estimated using tensiometers for measuring soil water tension. Vertical hydraulic conductivity soil and sediment properties in the vadose zone can either be measured or estimated to calculate a recharge volume from tensiometer data.
- The volume of water that returns to streams and benefits interconnected surface water can be estimated using shallow groundwater level measurements in wells or piezometers generally perpendicular to the stream. In some cases, streamflow measurements upgradient and downgradient of the recharge locations are useful for assessing interconnected surface water (see interconnected surface water monitoring section).
- Water lost to evapotranspiration can be measured using a combination of weather data, lysimeters, and soil moisture measurements.

Table MM03-4 provides an example summary table of monitoring metrics that could be used for reporting on the benefits of Flood-MAR projects.

Table MM03-4. Example Data Monitoring Report (Generally Annually)

Monitoring Reporting	
Annual Precipitation / % of Avg Precipitation	XXX inches / +/- XXX %
Number of Flood-MAR Events	XXX
Total Diversion	XXX AF
Estimated Total Recharge to Pumping Aquifers	XXX AF
Average Groundwater Level Change (Recharge Area / Background)	+/- XXX ft / +/- XXX ft
Average Groundwater Quality Constituent Change (list all identified, Recharge Area / Background)	+/- XXX mg/L / +/- XXX mg/L
Incurred Costs	$XXX

Data Analysis and Reporting

1. **Analyze monitoring data:** Monitoring data should be used to evaluate the effectiveness and performance of Flood-MAR projects. Determine any limiting factors on performance and identify options for improving performance, as needed. As operations continue, this assessment should include evaluating possible areas of increasing concern of unfavorable impacts or risks, such as causing unreasonable harm to nearby land or beneficial water uses. In addition, the evaluation should address if and how operations can be better managed to avoid significant impacts and/or risks.
2. **Prepare reports and manage data:** Reporting includes compliance with regulatory and grant requirements and providing data to DWR, which is addressed in the Data Management and Monitoring Method (MM-12). Generally, data should be uploaded to the DWR system annually and progress on project implementation and monitoring should be provided in Annual Reports. If the project is associated with a Groundwater Sustainability Plan, the annual project summary should be provided in Groundwater Sustainability Plan Annual Reports and a full project performance assessment should be provided in the GSP 5-Year Assessment Report.

Data Standards

Groundwater, surface water, and water quality monitoring data should conform to the technical and reporting standards of the California Water Code §352 et seq.

Groundwater levels - Groundwater elevation measurements should be recorded relative to a consistent vertical datum.

Groundwater quality - Concentrations of groundwater quality constituents of concern should be compared to maximum contaminant levels available from the State Water Resources Control Board.

Key Protocols

The following protocols should be followed for required monitoring:

- Groundwater level and groundwater quality monitoring protocols as described in DWR's Best Management Practice (BMP) 1 Monitoring Protocols Standards and Sites (DWR, 2016).
- Guidelines for establishing monitoring networks and resolving data gaps to reduce uncertainty are provided in DWR's BMP 2 Monitoring Networks and Identification of Data Gaps (DWR, 2016).
- Technical and reporting standards included in California Water Code §352 *et seq*.

Additional guidance or references include:

- Surface water discharge measurement protocol, available from the United States Geological Survey (USGS, 2010).

Example of Flood-MAR Application

Terranova Ranch On-Farm Recharge Demonstration Project

Location: Kings County

Year: 2015-present

Description and Relevance:

Experimental flooding of agricultural fields in the off-season was first conducted in California at the Terranova Ranch. Flood-MAR experimentation has focused on the efficacy of various flooding methods, crop suitability, and potential mobilization of constituents of concern.

Links to Resources: https://escholarship.org/uc/item/1vd7b35c
https://pubs.acs.org/doi/10.1021/es501115c

Merced Flood-MAR Reconnaissance Study

Location: Merced County

Year: 2017-present

Description and Relevance:

This comprehensive DWR-funded study examines the regional suitability potential for Flood-MAR to reduce flood risk, increase surface and groundwater supply reliability, and enhance ecosystems in the Merced River Watershed. This study explores the potential, feasibility, and effectiveness of Flood-MAR concepts, testing theories, and assessing strategies in overcoming barriers and challenges to project planning and implementation.

The study assesses current conditions of the Merced River watershed and the vulnerability of these watershed management characteristics to a range of potential climate change futures. Public and private benefits that may be achieved through Flood-MAR strategies and quantifies a range of benefits that Flood-MAR could provide in or adjacent to the Merced River watershed are described. The study identifies barriers and constraints to implementing Flood-MAR projects in the Merced River Basin and makes recommendations on how to overcome them.

Links to Resources:

https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Flood-Management/Flood-MAR/Merced-River-Flood-MAR-Reconnaissance-Study.pdf

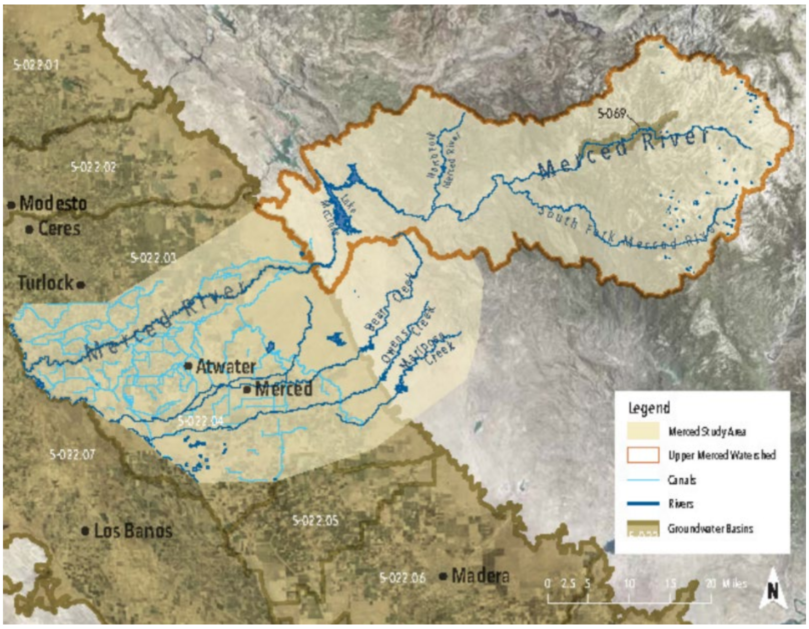

Figure MM03-3. Merced River Flood-MAR Study Area (DWR, 2020)

Cosumnes River Flood-MAR Studies

Location: Sacramento County

Year: 2020-present

Description and Relevance:

University of California, Davis (UC-Davis) has explored restoration for groundwater recharge for many years in the Cosumnes River floodplain, including an applied research project examining Flood-MAR with vineyards that is in progress. In 2020, Flood-MAR on agricultural fields was implemented at two vineyards between the Cosumnes River and Deer Creek. A network of monitoring wells was established beneath the site to measure groundwater levels and groundwater quality. Geophysical data collected from well installations and surficial surveys was used to delineate potential recharge pathways through a near-surface confining layer that forms a perched groundwater table. The study background is available in the scientific literature but applied Flood-MAR research has yet to be published.

Links to Resources:

https://cwc.ca.gov/-/media/CWC-Website/Files/Documents/2021/04_April/April2021_Item_9_Attach_3_PowerPoint_Recharge.pdf

Source References

Resources

DWR General Information

– DWR, 2018. Flood-MAR White Paper https://groundwaterexchange.org/wp-content/uploads/2020/09/DWR_FloodMAR-White-Paper_06_2018_updated.pdf

  Provides a broad overview of Flood-MAR implementation and monitoring considerations.

– DWR, 2019. Flood-MAR Research and Data Development Plan https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Flood-Management/Flood-MAR/Flood-MAR-RDD-Plan_a_y_19.pdf

  Identifies data gaps and the approach to collect information needed for effective Flood-MAR implementation and monitoring.

Groundwater Quality Management and Monitoring Considerations

– Management Considerations for Protecting Groundwater Quality Under Agricultural Managed Aquifer Recharge. https://suscon.org/wp-content/uploads/2021/06/Management-Considerations-for-Protecting-Groundwater-Quality-Under-AgMAR.pdf

  Summarizes in detail groundwater quality issues, implementation, and monitoring approaches for Flood-MAR.

– Protecting Groundwater Quality While Replenishing Aquifers. https://suscon.org/wp-content/uploads/2021/06/Protecting-Groundwater-Quality-While-Replenishing-Aquifers.pdf

  Higher level summary of previous document.

Useful Tools

There are a number of useful tools including:

– University of California Davis' Soil Agricultural Groundwater Banking Index (SAGBI). Webpage: https://casoilresource.lawr.ucdavis.edu/sagbi/

  Useful tool for siting Ag-MAR locations

– Water Available for Replenishment and Water Rights Web map. Webpage: https://gispublic.waterboards.ca.gov/portal/apps/MapJournal/index.html?appid=b2188e89dfea4e44b156600370f1edf7

Provides a map of fully allocated streams to identify streams with water available for replenishment. Provides details on the timing and volume of available water rights on each stream system.

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

  Spatial model tool used in Merced Flood-MAR Study to assess relative Flood-MAR benefits and impacts. Could be useful approach for future Flood-MAR evaluations.

– United States Geological Survey (USGS) Discharge Measurements at Gaging Stations. Webpage: https://pubs.usgs.gov/tm/tm3-a8/tm3a8.pdf

  Protocol for measuring stream stage and discharge.

References

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California Department of Water Resources. 2016. *Best Management Practices for the Sustainable Management of Groundwater, six-part series (BMP 1 Monitoring Protocols Standards and Sites, BMP 2 Monitoring Networks and Identification of Data Gaps, BMP 3 Hydrogeologic Conceptual Model, BMP 4 Water Budget, BMP 5 Modeling, and BMP 6 Sustainable Management Criteria DRAFT).* Sacramento (CA): California Department of Water Resources. [Website]. Viewed online at: https://water.ca.gov/Programs/Groundwater-Management/SGMA-Groundwater-Management/Best-Management-Practices-and-Guidance-Documents.

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——. 2019. *Flood-MAR Research and Data Development Plan: Priority Actions to Expand Implementation of Effective and Efficient Flood-MAR Projects in California.* Sacramento (CA): The Flood-MAR Research Advisory Committee. [Website]. Viewed online at: https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Flood-Management/Flood-MAR/Flood-MAR-RDD-Plan_a_y_19.pdf.

——. 2020. Merced River Flood-MAR Reconnaissance Study Technical Memorandum 1 Plan of Study – Draft. Sacramento (CA): California Water Library. [Website]. Viewed online at: https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Flood-Management/Flood-MAR/Merced-River-Flood-MAR-Reconnaissance-Study.pdf

Waterhouse H, Broadhead H, Massell A, Dahlke H, Harter T, and Mountjoy D. 2021. *Management Considerations for Protecting Groundwater Quality Under Agricultural Managed Aquifer Recharge*. San Francisco (CA): Sustainable Conservation. [Website]. Viewed online at: https://suscon.org/wp-content/uploads/2021/06/Management-Considerations-for-Protecting-Groundwater-Quality-Under-AgMAR.pdf.

Sustainable Conservation. 2021. *Protecting Groundwater Quality While Replenishing Aquifers: Nitrate Management Considerations for Implementing Recharge on Farmland*. San Francisco (CA): Sustainable Conservation. [Website]. Viewed online at: https://suscon.org/wp-content/uploads/2021/06/Protecting-Groundwater-Quality-While-Replenishing-Aquifers.pdf.

Stormwater Recharge Monitoring Method

MONITORING METHOD [MM-04]

MONITORING METHOD [MM-04]

Stormwater Recharge Monitoring Method

Project / Action Type	Providing groundwater recharge in an urban environment using Low Impact Development (LID), regional, and distributed structural best management practices (BMP) stormwater facilities.
Similar / Related Project Types	Groundwater recharge projects (Flood-MAR, Recharge Ponds, and ASR) are directly related and often use the same implementation approaches.
Metric	Groundwater levels. Applicable water quality constituents. Groundwater storage (situationally). Change in ground levels (situationally).
Measurement Unit	Groundwater levels measured in feet in a consistent vertical datum. Concentration or measurement of applicable groundwater quality constituents (typically mg/L), potential constituents include microbial communities, nitrogen, salts, metals, pesticides, or any other applicable constituent of concern.
Beneficial User	Municipal and domestic water supply (MUN) Agricultural water supply (AGR) Groundwater recharge (GWR) Freshwater replenishment to surface waters (FRSH)

Stormwater Recharge Overview

California’s growing water shortages increasingly require water resource management strategies designed to integrate stormwater, drinking water, and wastewater programs to maximize benefits and minimize costs. There are two main types of stormwater capture projects within the region:

1. Large, centrally located infrastructure projects such as park retrofits with underground infiltration vaults or constructed wetlands; and
2. Smaller, **distributed stormwater projects** such as bioretention, biofiltration and infiltration units distributed throughout a more regional watershed for groundwater recharge.

Both types are effective means of reducing pollutant loads to receiving water bodies, augmenting water supply, and reducing flooding and hydromodification of natural streams. Groundwater recharge from stormwater generally includes distributed or regional projects, specifically stormwater projects with a Green Infrastructure (GI) or Low Impact Development (LID) focus in an urban environment. The purpose of this Monitoring Method is to provide recommendations for monitoring and reporting to assess the effectiveness of stormwater recharge projects.

Low Impact Development was initially a term used for large- and small-scale development projects requiring post-construction runoff to be equal to or less than the pre-construction runoff. LID aims to maintain the natural balance, reduce mobilization of pollutant loads, and reduce hydromodification of natural streams through sensible site design techniques. Best management practices incorporate natural features and structural implementation such as detention ponds, bio-swales and infiltration facilities.

KEY TERMS

Distributed Stormwater Projects are projects that retain rainfall and stormwater runoff on-site (at end user locations) to infiltrate into and replenish local groundwater basins.

Low impact development and green infrastructure are used interchangeably in this report, these terms refer to a decentralized approach to stormwater management that works to mimic the natural hydrology of the site by retaining precipitation on-site to the maximum extent practicable.

Green Infrastructure was originally a term used for municipalities during capital improvements projects to implement more natural features into the design and construction such as replacing curb and gutter with bioswales. Green Infrastructure is a decentralized approach to stormwater management that works to mimic the natural hydrology of the site by retaining precipitation to the maximum practicable extent on-site. Stormwater quality control measures that incorporate GI principles are placed throughout the site in small, discrete units and distributed near the source of impacts or at regional large-scale facilities, such as under parking lots and parks. Green Infrastructure strategies are designed to protect surface and groundwater quality, maintain the integrity of ecosystems, and preserve the physical integrity of receiving waters by managing stormwater runoff at or close to the source. To enhance pollutant removal and groundwater recharge benefits, improvements can be made beyond conventional stormwater quality control measures using Green Infrastructure strategies for any size project.

Green Infrastructure and Low Impact Development have melded together over the years. In this context, the terms are interchangeable with regional and distributed projects defined as projects that retain rainfall and stormwater runoff on-site (at end user locations) to infiltrate into and replenish local groundwater basins. Examples of stormwater recharge projects include green streets (see Figure MM04-1), park retrofits (see Figure MM04-2), permeable pavement, and bioswales (SCWC, 2018).

The groundwater sustainability plan (GSP) Regulations that specify components of GSPs prepared pursuant to the Sustainable Groundwater Management Act (SGMA) require that groundwater sustainability agencies (GSAs) provide explanations of project and management actions (23 CCR § 354.44). Nothing in these Monitoring Methods supersedes the GSP Requirements as related to the development and implementation of GSPs, alternatives to a GSP, coordination agreements, and annual reporting requirements under SGMA.

Figure MM04-1. Distributed Urban Stormwater Projects and Potential Benefits from Green Streets

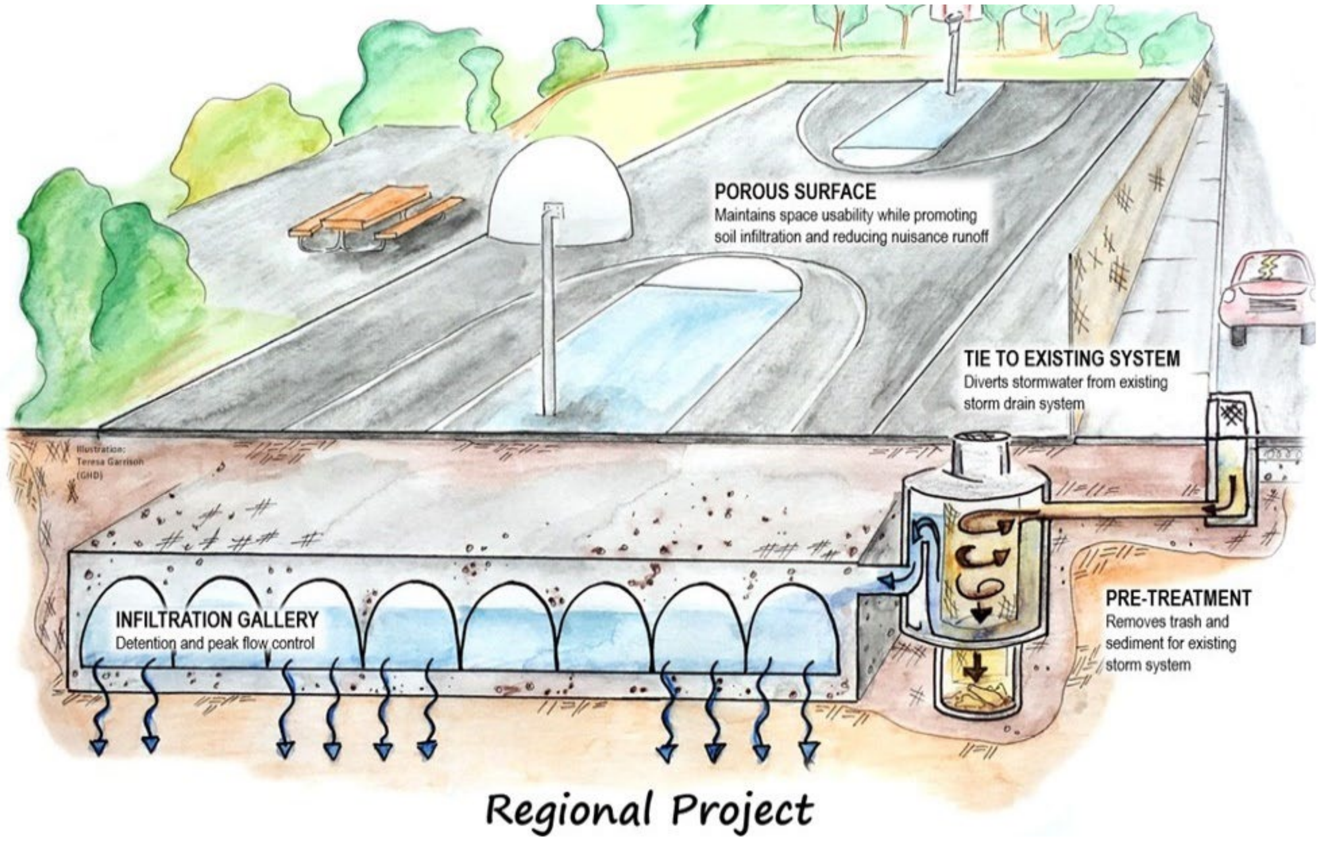

Figure MM04-2. Illustrative Example of a Regional Based Stormwater Project

Monitoring Objectives

Distributed and regional stormwater projects have the potential to recharge groundwater through infiltration and provide localized water quality treatment in the process. The objective is to identify stormwater projects that can be used to increase groundwater recharge, storage, and improve water quality. In areas where applicable, applying stormwater recharge can help with subsidence and seawater intrusion. Table MM04-1 below identifies the relative level of benefit of stormwater recharge projects on the six sustainability indicators included in SGMA.

Table MM04-1 Level of Benefit to the Six Sustainability Indicators Outlined in SGMA.

	Six Sustainability Indicators Outlined in SGMA	Applicability*
	Depleted Interconnected Surface Water	★
	Lowered Groundwater Levels	★★★
	Water Quality Degradation	★★★
	Subsidence	★
	Reduced Groundwater Storage	★★
	Seawater Intrusion	★

*Notes:
★★★ = Primary Benefit (High Applicability)
★★ = Secondary Benefit (Medium Applicability)
★ = Situational Benefit (Applicability dependent on Location, Site Characteristics, and Aquifer Condition)

Desired Outcomes or Benefits Resulting from Stormwater Recharge

Stormwater capture can increase water supplies in groundwater-dependent water systems, improve water quality, and provide local flood management during smaller rainfall events. Urban stormwater capture represents a significant opportunity to enhance community resiliency to climate change (Shimabuku et al. 2018). Additionally, green infrastructure has the potential to provide additional benefits, such as improved water quality, wildlife habitat, reduced urban temperatures, reduced energy use, and community spaces (Shimabuku et al., 2018; SCWC, 2018). Table MM04-2 shows the benefits of stormwater capture for groundwater sustainability, relative to background conditions.

Table MM04-2. Potential Benefits Resulting from Project / Action

	Potential Benefits on SGMA Sustainability Indicators	Benefit / Not Applicable	Description of Benefits
	Depleted interconnected surface water	Benefit	Increased groundwater and surface water interaction that benefits in-stream and riparian habitat for critical species and groundwater dependent ecosystems (if applicable).
	Lowered groundwater levels	Benefit	Increased groundwater levels and groundwater storage.
	Water quality degradation	Benefit	Improved receiving water bodies water quality.
	Subsidence	Benefit	Decreased land subsidence (if applicable).
	Reduced groundwater storage	Benefit	Increased seasonal storage of excess water and subsequent recovery.
	Seawater intrusion	Benefit	Decreased seawater intrusion (if applicable).

Potential Impacts

Stormwater recharge projects generally improve groundwater quality since stormwater facilities provide treatment through various means before stormwater is recharged. There is potential for urban constituents to provide a negate impact on groundwater quality. However, there is limited information existing on this potential. Additional data collection is needed to understand the relationship and data gaps. The risk of groundwater degradation can be reduced by appropriately designing stormwater facilities to provide water quality pre-treatment before infiltration. Potential impacts resulting from stormwater projects are shown in Table MM04-3.

Table MM04-3. Potential Impacts Resulting from Project / Action

Potential Impacts on SGMA Sustainability Indicators	Impact / Not Applicable	Mitigation Measures to Address Impacts
Depleted interconnected surface water	Not Applicable	
Lowered groundwater levels	Not Applicable	
Water quality degradation	Impact	The most effective approach to mitigate groundwater quality degradation from stormwater recharge is to provide treatment as part of the recharge facility. Most regulatory agencies require treatment of the 85th percentile storm, and minimum separation from the invert of a facility to the high groundwater table to encourage filtration within the unsaturated zone of the soil column.
Subsidence	Not Applicable	
Reduced groundwater storage	Not Applicable	
Seawater intrusion	Not Applicable	

Use and Limitations

Distributed and regional projects tend to have higher annual costs per acre-foot captured since they involve more infrastructure to capture smaller amounts of water (SCWC, 2018). For distributed and regional projects to be eligible for monitoring they should be large enough to justify the cost associated with the monitoring equipment. Smaller infiltration and recharge projects may not provide enough capture/recharge potential to justify the costs and these projects should be evaluated on a case-by-case basis to determine the overall applicability. In these cases, applying a distributed monitoring approach may be appropriate. This would entail monitoring at a few small sites that would represent and be applied on a community basis to estimate the benefits.

Due to the monitoring requirements needed, there are significant data gaps in understanding how the smaller distributed projects affect the overall groundwater conditions. Additional monitoring of these distributed projects is needed.

Results of stormwater recharge monitoring, using a monitoring network established during stormwater recharge facility construction, may indicate that insufficient data is being obtained to evaluate the effectiveness of the facility in relation to the established performance standards and/or that groundwater level rise or groundwater quality impacts may be of concern at or in the vicinity of the facility. These conditions can be addressed by developing and implementing a work plan to install additional monitoring equipment, adding critical monitoring points to obtain the desired data, as well as provide useful hydrogeologic information at targeted locations.

Permitting and Design Considerations

Under the Unites States Clean Water Act regulations, stormwater from **municipal separate storm sewers (MS4s)** was added to the list of discharges requiring permit coverage through the National Pollution Discharge Elimination System (NPDES). NPDES permits for both large and small MS4 areas, which vary regionally with respect to their requirements and allowances for reaching compliance and monitoring effectiveness, are the main driver for stormwater management in California. When an NPDES permit is issued, it specifies the effluent limitations for pollutants entering a receiving waterbody. It also establishes intervals for stormwater monitoring and water sampling; however, only at the receiving waterbody. In specific applications, the Regional Water Quality Control Board may require permitting for projects that link directly to groundwater aquifers.

Local permitting and regulations will play a role in the design of distributed and regional stormwater systems. Local agencies will have applied the MS4 requirements in various ways and may link treatment requirements into the design. Most local agencies do not require infiltration with the purpose of groundwater recharge, but infiltration is generally a highly encouraged method for stormwater management. Local agencies may require setback from supply wells and vertical setbacks from groundwater.

The following is a list of design considerations a project should consider for a stormwater recharge project approval:

- Measure capture and recharge
- Demonstrate how stored water recharges usable groundwater
- Possess the right to capture and recharge stormwater in the proposed project vicinity and not impact downstream users
- Captures a minimum of the **85th percentile (first flush) storm event**
- Provided water quality treatment, specifically for the first flush events
- Be located within urban water service area

Relationship to Other Methods

Stormwater is a source of water that can be used for groundwater recharge with various applications. All projects that divert water for recharge should check for water rights and limit downstream impacts.

Other Groundwater Recharge Monitoring Methods such as Aquifer Storage and Recovery (MM-01), Recharge Ponds (MM-02), and Flood-MAR (MM-03) are directly related and can use similar implementation approaches described in this Monitoring Method. Monitoring Methods for Groundwater and Surface Water Interactions (MM-07) and Groundwater Dependent Ecosystems (MM-10) can benefit from these projects. An indirect benefit from stormwater recharge can be the reduction of land subsidence in areas that experience rapidly dropping water levels, relating to the Subsidence Management Monitoring Method (MM-09).

KEY TERMS

Treatment and infiltration of the volume of runoff from the **85th percentile storm event** also called the first flush event.

Polluted stormwater runoff is commonly transported through **municipal separate storm sewer systems (MS4s)**, and then often discharged, untreated, into local water bodies.

An **MS4** is a conveyance or system of conveyances that is:

- owned by a state, city, town, village, or other public entity that discharges to waters of the U.S.,
- designed or used to collect or convey stormwater (e.g., storm drains, pipes, ditches),
- not a combined sewer, and
- not part of a sewage treatment plant, or publicly owned treatment works

Approach to Implementing Stormwater Recharge Monitoring

Stormwater infiltration projects deliver multiple benefits, such as water supply reliability, flood mitigation, groundwater recharge, habitat creation, and water quality improvements. Some of the main challenges with developing stormwater projects are related to costs, metering, data collection, and water supply yield. The relationship between stormwater capture and yield has not been extensively analyzed. In addition, most projects do not demonstrate a direct link to increased groundwater production or yield. This limits the ability to fully characterize stormwater capture project costs or to quantify the water supply benefit. Monitoring of stormwater projects has historically been limited, but monitoring is slowly being undertaken across different states as permitting agencies are starting to require more proof of treatment.

Justification

Achieving groundwater sustainability will require a multi-faceted approach. Distributed projects are usually designed for multiple benefits, with one of them being groundwater recharge. Distributed projects generally provide smaller capture volumes, yet meaningfully contribute to regional recharge if implemented on a broad scale. Additionally, because of their multiple benefits (e.g., water quality improvement, recreation, open space, and habitat restoration), there are ample partnership opportunities with other agencies that justify the importance of these projects for monitoring and review.

An analysis by the Pacific Institute, University of California, Santa Barbara (UCSB), and the Natural Resources Defense Council found that infiltration of runoff to recharge groundwater and rooftop rainwater capture in urbanized Southern California and the San Francisco Bay would provide an additional 420,000 to 630,000 acre-feet per year to local water supplies (Garrison, et al, 2014). This would represent approximately 5% to 8% of the average annual statewide urban water use.

Urban stormwater capture represents a significant opportunity to enhance community resiliency to climate change. With longer drought periods and heavier rainfall events becoming more common, effective urban stormwater capture provides an opportunity for addressing flood management and water quality impairments while also improving water supply reliability.

At a minimum, the monitoring methods for distributed and regional projects should measure the volume and quality of stormwater entering the facility. Most projects do not have flow monitoring in place because monitoring devices are expensive and/or there insufficient funding to support staff to collect metering data. This is a data gap that should be addressed to continue research and quantify the recharge benefits of stormwater.

Primary Monitoring

Local groundwater levels and groundwater quality are the primary monitoring needs for assessing benefits and impacts of distributed and regional stormwater projects. Individual monitoring for both distributed and regional systems can be challenging, and approaches where a representative stormwater facility is used and those rates applied to a larger community may be appropriate. The monitoring approaches for these parameters are discussed in detail in the step-by-step guide below.

Secondary Monitoring

The number of storms, volume of events, and percent of volume recharged to groundwater provide an understanding of recharge benefits of distributed and regional projects. Understanding groundwater recharge volume is the primary parameter to assess project effectiveness. Recharge volumes are generally assessed on an annual basis due to monthly variations in rainfall events.

Assessing the quality of the recharged water is also important, but more difficult to monitor as stormwater flow is event-based. However, periodic monitoring of water quality should be undertaken to understand the baseline water quality that is being recharged through the stormwater recharge systems.

Other Useful Monitoring

Stormwater facilities have a useful design life, generally based on the infiltration capacity of the underlying soil. Periodic checks on the soil infiltration rates can provide an understanding of the remaining useful life of the facility for groundwater recharge.

A Step-by-Step Guide to Applying Stormwater Recharge Method

Implementation of an appropriate and effective monitoring method for stormwater projects includes the following strategies and steps with references to relevant DWR's Best Management Practices (BMP) (DWR, 2016) for additional considerations and details:

1. **Project identification for groundwater recharge:** Identify the project, and if the project meets the criteria above to be monitored under the Stormwater Recharge Monitoring Method (MM-04). The underlaying hydrogeology will play an important part in understanding the ability for the project to provide beneficial groundwater recharge.
2. **Permitting:** Identify local agencies for NPDES MS4 permits or other regulations related to stormwater discharge permits. Work with the local agency design standards for stormwater control and treatment. NPDES MS4 permits will also set design standards based on the location of the project.
3. **Water rights:** Check and confirm the project proponent has access to water supply, such that other's water rights will not be infringed.
4. **System operations:** Step up an Operations and Maintenance / Monitoring Plan based on discharge permits, and primary, secondary, and/or additional monitoring requirements.

Primary Monitoring Method

1. **Safety plan:** All projects with fieldwork related activities should produce a Safety Plan. Planning for fieldwork and availability of access to the site, such as monitoring wells, is necessary to maintain project safety. Stormwater recharge projects may require a Safety Plan to address these and other potential safety concerns.
2. **Design a monitoring well network consistent with Groundwater Sustainability Plan Regulations and guidelines specified in DWR's BMP 2 Monitoring Networks and Identification of Data Gaps** (DWR, 2016)**:** Rely on existing wells and monitoring systems already in place. The monitoring network should be capable of capturing data on a sufficient temporal frequency and spatial distribution to demonstrate short-term, seasonal, and long-term trends. (Note that due to resolution associated with the groundwater monitoring wells, this may not be possible for any given location). For additional information, see the Recharge Ponds Monitoring Method (MM-02); however, given the generally smaller nature of stormwater recharge systems, not all the monitoring procedures presented in the Recharge Ponds Monitoring Method will be feasible. The economic feasibility of monitoring can play a role in the extent of monitoring that can be accomplished by the project proponent. The location of the monitoring network should be easily accessible such that gaining access to the site does not inhibit gathering and downloading data (refer to Step 1).
3. **Design a monitoring method for constituents of concern:** Based on the site and potential constituents of concern in the stormwater, various constituents may require monitoring. The parameters will generally be based on the local beneficial uses of the groundwater. Constituents of concern can include oil and greases, pH, turbidity, and fecal coliforms. Additional parameters may include metals, nitrates, salinity (or Total Dissolved Solids), toxicity, and radionuclides. Baseline monitoring of the constituents of concern should be performed prior to implementing any stormwater recharge project in order to identify any degradation to groundwater quality caused by the recharge project. The monitoring of the constituents of concern are separated into two systems:
    a. **Storm event water quality monitoring:** Monitoring of the stormwater runoff entering and exiting the system to monitor the treatment effectiveness of the facility.
    b. **Groundwater quality monitoring:** After storm events, groundwater quality for constituents of concern should be measured. The frequency should be dependent on the results, starting with monthly monitoring, and then reducing to annually at the conclusion of the wet season if constituent concentrations are not presenting a concern.
4. **Implement monitoring of monitoring wells:** Protocols for monitoring of groundwater levels and groundwater quality are addressed in DWR's BMP 1 Monitoring Protocols Standards and Sites (DWR, 2016). Conduct "baseline monitoring" in the monitoring wells prior to commencement of recharge operations to document groundwater levels and trends, and to characterize ambient groundwater quality and trends. While baseline monitoring for groundwater levels and quality should be conducted at a minimum prior to commencement of recharge operations, collecting baseline monitoring for at

least one year before recharge operations during prior seasonal low and seasonal high groundwater level periods is recommended. This would provide a more robust dataset to compare to project implementation data, should groundwater level or quality impacts occur.

Secondary Monitoring Method

1. **Implement monitoring of water deliveries starting at commencement of recharge operations:** Monitoring for instantaneous flow rates should be as frequent as practicable, if conducted manually, and should be no less frequent than hourly, if measured electronically (data stored in a datalogger or web-based application). Measurements of total cumulative volume should be obtained commensurate with instantaneous flow rate measurements. Verify that the system is maintained for recharge as designed.

Other Useful Monitoring Method

1. **Implement monitoring of infiltration rates:** Use either the wetting cycle calculation method (volume infiltrated during wet weather) or falling-head method (rate of water level decline in a pond); for both methods, the water volume lost to evapotranspiration can be factored in. The frequency of monitoring will depend on the condition of the soil and observational assessment of the infiltration rates.

Data and Protocol - Fundamentals

For stormwater recharge projects to be eligible for monitoring they should be large enough, or a collection of enough small projects in a similar area to justify the cost associated with the monitoring equipment and labor. The projects should also be able to show that infiltrated water has the capacity to reach the groundwater based on hydrogeologic conditions. A conceptual model of the site, underlying geology, and groundwater conditions would be needed. Table MM04-4 provides an example of summary parameters to use in a monitoring report for stormwater recharge projects.

Table MM04-4. Example Data Monitoring Report (Generally Annually)

Annual Monitoring Report	
Number of storm events	XXX
Total stormwater volume Wet weather volume Dry weather volume	XXX AF Total XXX AF XXX AF
Total stormwater captured	XXX AF
Total stormwater that reaches pumping aquifer	XXX AF
Percent of capture that reaches pumping aquifer	XXX %
Groundwater Basin Recharged	XX Basin
Incurred Costs	$XXX

Data Analysis and Reporting

1. **Analyze monitoring data:** Monitoring data should be used to evaluate the effectiveness and performance, determine any limiting factors on performance, and identify options for improving performance if needed. This assessment also includes evaluating possible increasing concerns, as recharge continues, for causing unreasonable harm to nearby land or beneficial water uses and if/how recharge operations can be better managed to avoid significant risks.
2. **Prepare reports and manage data:** Includes compliance with regulatory and grant requirements and providing data to DWR, which is addressed in the Data Management and Monitoring Method (MM-12). Generally, data will be uploaded to the DWR system annually and progress on project implementation and monitoring will be provided in the annual report.

Key Protocols

The local NPDES MS4 permit specifies the effluent limitations for pollutants and establishes intervals for stormwater monitoring and water sampling at receiving waterbodies. **NPDES** MS4 permit requirements need to be followed for the type, location, frequency, and constituents sampled. For additional information see the NPDES Storm Water Sampling Guidance Document (EPA,1992).

In addition to sampling receiving water bodies for water quality trends, a clear method should be implemented to quantify water supply benefits. Typically, this can be done using a design storm event approach that a project will capture and forecasting how many of those full capture events will occur annually.

KEY TERMS

The **National Pollutant Discharge Elimination System (NPDES)** permit program addresses water pollution by regulating point sources that discharge pollutants to waters of the United States.

Drinking water standards are called **maximum contaminant levels (MCLs)**. MCLs are found in Title 22 of the California Code of Regulations.

Primary MCLs address health concerns. Esthetics such as taste and odor are addressed by secondary MCLs

State regulations addressing the treatment, storage, processing, or disposal of waste are contained in Title 27 of the California Code of Regulations. Waste discharges that can be exempted from requirements are issued **waste discharge requirements** and are regulated by the Waste Discharge Requirement Program

Data Standards

Groundwater, surface water, and water quality monitoring data should conform to the technical and reporting standards of the California Water Code (CWC) §352 et seq.

Groundwater elevation – Measurements should be recorded relative to a consistent vertical datum.

Groundwater quality – Concentrations of groundwater quality constituents of concern should be compared to **maximum contaminant levels (MCLs)** available from the California State Water Resources Control Board.

The sustainable management criteria in the regional Groundwater Sustainability Plan will help identify when groundwater recharge is needed to achieve sustainability and project benefits. Concentrations of groundwater quality constituents of concern should be compared to MCLs from the State Water Resources Control Board. NPDES permits or **waste discharge requirements** may be applicable to the project.

Examples of Stormwater Recharge Application

Altadena - Lake Avenue Green Improvement Project

Location: Lake Avenue in Altadena, California part of the Upper Los Angeles River

Year: 2021

Description and Relevance:

The project improves stormwater quality, increases water supply, and enhances the community through the installation of diversion structures, pretreatment devices, and drywells. The Project diverts, treats, and infiltrates the 85th percentile 24-hour volume storm event, approximately 14 acre-feet of urban and stormwater runoff from a 262-acre tributary area of primarily commercial and residential land uses. It is anticipated that 196 acre-feet of stormwater in an average rainfall year will be infiltrated into the Raymond Groundwater Basin. Monitoring of groundwater is based on procedures identified in the Lake Avenue Monitoring Plan.

To monitor the effectiveness of the system, a flow sensor and water quality auto-sampler were placed at the diversion structure and an additional flow sensor was placed at the discharge point. All data is collected using a telemetry system and sent to a web-based dashboard where it is stored and analyzed. The difference between the diverted flow and the outlet flow is used to define the event recharge. The sum of all events defines the annual capture. Water quality data from the auto-sampler are used to quantify the water quality benefit to receiving water bodies and to check for any potential groundwater quality impacts.

Links to Resources:

https://portal.safecleanwaterla.org/scw-reporting/map

Source References

Resources

Sampling Guidelines

The United States Environmental Protection Agency provides sampling guidelines for stormwater NPDES permits. Additional sampling requirements can be found in the region's specific NPDES discharge permit or MS4s, the link below provided a lookup tool for all regulated facilities under the State Water Resources Control Board.

https://www3.epa.gov/npdes/pubs/owm0093.pdf

https://ciwqs.waterboards.ca.gov/ciwqs/readOnly/CiwqsReportServlet?inCommand=reset&reportName=RegulatedFacility

Stormwater BMPs

Guidance document generated by the US Department of Transportation Federal Highway Administration for BMPs in the “Ultra-urban Setting”.

https://www.environment.fhwa.dot.gov/env_topics/water/ultraurban_bmp_rpt/index.aspx

Information on bioswales: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_029251.pdf

Methods for infiltration rate testing. Several methods exist, the selection of method should be based on project specifics and depth the project is proposing to infiltration into the soil.

References

California Department of Water Resources. 2016. *Best Management Practices for the Sustainable Management of Groundwater*, six-part series (BMP 1 Monitoring Protocols Standards and Sites, BMP 2 Monitoring Networks and Identification of Data Gaps, BMP 3 Hydrogeologic Conceptual Model, BMP 4 Water Budget, BMP 5 Modeling, and BMP 6 Sustainable Management Criteria DRAFT). Prepared for the Sustainable Groundwater Management Act, Water Code Section 10729(d). Viewed online at: https://water.ca.gov/Programs/Groundwater-Management/SGMA-Groundwater-Management/Best-Management-Practices-and-Guidance-Documents

Garrison N, Sahl J, Dugger A, and Wilkinson RP. 2014. *Stormwater Capture Potential in Urban Suburban California.* Issue Brief IB: 14-05-G. National Resources Defense Council and Pacific Institute.

Shimabuku, M, Diringer S, and Cooley H. 2018. *Stormwater capture in California: Innovative Policies and Funding Opportunities*. Oakland (CA): Pacific Institute. [Website]. Viewed online at: https://pacinst.org/wp-content/uploads/2018/07/Pacific-Institute-Stormwater-Capture-in-California.pdf.

Southern California Water Coalition. 2018. *Stormwater Capture: Enhancing Recharge and Direct Use through Data Collection. Southern California Water Coalition 2018 Whitepaper Update*. [Website]. Viewed online at: https://www.socalwater.org/wp-content/uploads/scwc-2018-stormwater-whitepaper_75220.pdf.

United States Department of Transportation Federal Highway Administration. 2022. *Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring*. [Website]. Viewed online at: https://www.environment.fhwa.dot.gov/env_topics/water/ultraurban_bmp_rpt/index.aspx.

United States Environmental Protection Agency. 1992. *NPDES Storm Water Sampling Guidance Document.* [Website]. Viewed online at: https://www3.epa.gov/npdes/pubs/owm0093.pdf.

Indirect Potable Reuse (IPR) Monitoring Method
MONITORING METHOD [MM-05]

MONITORING METHOD [MM-05]

Indirect Potable Reuse (IPR) Monitoring Method

Project / Action Type	Indirect Potable Reuse (IPR) projects use highly purified recycled water to recharge aquifers for water supply augmentation.
Similar / Related Project Types	IPR would be implemented in conjunction with recharge projects such as Aquifer Storage and Recovery or Recharge Ponds. IPR may support sustainability indicators such as interconnected surface water, seawater intrusion, and subsidence, as well as potentially support groundwater dependent ecosystems.
Metric	Groundwater levels. Groundwater storage. Applicable water quality constituents.
Measurement Unit	Groundwater levels measured in feet in a consistent vertical datum. Recharge/demand volumes in acre-feet. Concentration or measurement of applicable groundwater quality constituents (typically mg/L), specifically Title 22 requirements from the California Code of Regulations.
Beneficial User	Municipal and domestic water supply (MUN) Industrial service supply (IND) Industrial process supply (PROC) Agricultural water supply (AGR) Groundwater recharge (GWR)

Indirect Potable Reuse Overview

Indirect potable reuse (IPR) is the planned use of highly treated recycled water to augment drinking water supplies (Rodriguez et al. 2009). There are two types of IPR projects defined by the State Water Resources Control Board (SWRCB): groundwater replenishment reuse projects, and surface water source augmentation projects (SWRCB, 2021). This Monitoring Method focuses on groundwater replenishment reuse applications. The purpose of this Monitoring Method is to provide recommendations for monitoring and reporting to assess the effectiveness of IPR projects.

IPR projects use advanced treated water as the source of water to recharge aquifers. A groundwater replenishment reuse project involves the planned use of recycled municipal wastewater that is operated for the purpose of replenishing a groundwater basin designated in the Water Quality Control Plan (as defined in Water Code section 13050[j]) for use as a source of municipal and domestic water supply. Groundwater replenishment projects could be done with surface application, where the recharge water is applied to an infiltrating area (like a pond), or with subsurface application, where the recharge water is applied by other means (SWRCB, 2021).

The groundwater sustainability plan (GSP) Regulations that specify components of GSPs prepared pursuant to the Sustainable Groundwater Management Act (SGMA) require that groundwater sustainability agencies (GSAs) provide explanations of project and management actions (23 CCR § 354.44). Nothing in these Monitoring Methods supersedes the GSP Requirements as related to the development and implementation of GSPs, alternatives to a GSP, coordination agreements, and annual reporting requirements under SGMA.

California's Code of Regulations **Title 22** refers to state guidelines for how treated and recycled water is discharged and used.

Monitoring Objectives

IPR projects enable the reuse of existing water supplies to recharge groundwater via injection or ponds. Monitoring the specific groundwater components allows the project proponents to determine if the project is providing the intended benefits, or if it is causing any impacts to nearby beneficial users. Monitoring of IPR projects also is required for compliance with **Title 22** permitting. This Monitoring Method provides guidance for monitoring groundwater quality impacts related to using advanced treated recycled water as a source water for groundwater replenishment projects. The applicability of IPR projects to the six sustainability indicators outlined in SGMA is presented in Table MM05-1.

Table MM05-1. Level of Benefit to the Six Sustainability Indicators Outlined SGMA

	Six Sustainability Indicators Outlined in SGMA	Applicability*
	Depleted Interconnected Surface Water	★
	Lowered Groundwater Levels	★★
	Water Quality Degradation	★
	Subsidence	★★
	Reduced Groundwater Storage	★★★
	Seawater Intrusion	★★

*Notes:
★★★ = Primary Benefit (High Applicability)
★★ = Secondary Benefit (Medium Applicability)
★ = Situational Benefit (Applicability dependent on Location, Site Characteristics, and Aquifer Condition)

Desired Outcomes or Benefits Resulting from IPR

Meeting sustainability objectives related to groundwater recharge without causing undesirable results for groundwater quality. The IPR project can improve sustainability indicators as a result of raising groundwater levels. Table MM05-2 shows the benefits from IPR projects for groundwater sustainability, relative to ambient conditions.

Table MM05-2. Potential Benefits Resulting from Project / Action

	Potential Benefits on SGMA Sustainability Indicators	Benefit / Not Applicable	Description of Benefits
	Depleted interconnected surface water	Benefit	Raising groundwater levels can help reduce surface water to groundwater or increase flow from groundwater to surface water.
	Lowered groundwater levels	Benefit	Raising groundwater levels will help the reduction of supply related to low groundwater levels.
	Water quality degradation	Not Applicable	
	Subsidence	Benefit	Raising groundwater levels can help maintain pore pressures in clays to prevent lowering of ground surface.
	Reduced groundwater storage	Benefit	Groundwater replenishment and water banking through IPR can be extracted during periods when water availability is low.
	Seawater intrusion	Benefit	Decrease or prevent seawater intrusion into freshwater aquifers by providing an alternative water supply.

Potential Impacts

As IPR projects introduce a new source of water to groundwater aquifers, the primary concern for potential impact is towards groundwater quality degradation. IPR projects should generally improve groundwater quality since water used for recharge undergoes advanced treatment. However, there is some potential for groundwater quality impacts related to leaching of applied, legacy, or natural constituents in soil or due to treatment process failures. Potential impacts resulting from IPR are shown in Table MM05-3.

Table MM05-3. Potential Impacts Resulting from Project / Action

	Potential Impacts on SGMA Sustainability Indicators	Impact / Not Applicable	Mitigation Measures to Address Impacts
	Depleted interconnected surface water	Not Applicable	
	Lowered groundwater levels	Not Applicable	
	Water quality degradation	Impact	Title 22 requirements for monitoring of treatment processes and required monitoring of water quality entering and within the aquifer should prevent and mitigate water quality concerns.
	Subsidence	Not Applicable	
	Reduced groundwater storage	Not Applicable	
	Seawater intrusion	Not Applicable	

Use and Limitations

The primary challenges of the IPR monitoring methods are cost and land availability for installing new monitoring wells to meet IPR regulations. These challenges must be met to permit the IPR project.

Results of monitoring using the monitoring network established during facility construction may indicate that insufficient data are being obtained to evaluate the effectiveness of the IPR project in relation to the established performance standards. Groundwater quality impacts may be of concern at or in the vicinity of the facility. These conditions can be addressed by developing and implementing a work plan to install additional monitoring wells, which would provide helpful hydrogeologic information at targeted locations and additional critical monitoring points.

Permitting and Design Considerations

IPR projects are regulated as **groundwater replenishment reuse projects (GRRP)** in Title 22, Division 4, Chapter 3 of the California Code of Regulations by State Water Resources Control Board Division of Drinking Water with permitting by the Regional Water Quality Control Board (RWQCB) and consultation with the California Department of Health. Article 5.1 of Chapter 3 provides regulations for surface application (recharge ponds) and Article 5.2 provides regulations for subsurface application, like Aquifer Storage and Recovery projects. Beyond regulating advanced treated water quality and requiring that treatment procedures comply with approved processes, the regulations for GRRP include monitoring for groundwater quality constituents at specific locations and monitoring to evaluate underground retention time of advanced treated water. IPR projects will need to comply with the GRRP regulations, and project proponents should report on compliance to grant administrators, including documentation from regulating agencies.

Groundwater Replenishment Reuse Projects (GRRP) are IPR based projects focused on groundwater recharge and replenishment with advanced treated water.

Since IPR projects could potentially cause significant environmental impacts, they require preparation of a project Environmental Impact Report to comply with the California Environmental Quality Act. The Environmental Impact Report will include an evaluation of impacts on hydrology resources, including groundwater and surface water resources. The Environmental Impact Report may include mitigation measures that require the project proponent to monitor for groundwater and surface water impacts during project operation. The project proponent should report on the implementation of mitigation measures that monitor for potential operational hydrology impacts.

Relationship to Other Monitoring Methods

Monitoring for sustainability benefits from IPR will be consistent with other Groundwater Recharge Projects Monitoring Methods including Aquifer Storage and Recovery (MM-01) and Recharge Ponds (MM-02). ISR projects may also monitoring for specific sustainability indicators as outlined in the Monitoring Methods for Groundwater and Surface Water Interactions (MM-07), Seawater Intrusion Management (MM-08), Subsidence Management (MM-09), and Groundwater Dependent Ecosystems (MM-10) if applicable.

Approach to Implementing Indirect Potable Reuse Monitoring

IPR is one approach being used for groundwater sustainability projects to increase groundwater recharge, reuse existing water supplies, reduce waste discharge, and prevent undesirable results such as seawater intrusion and subsidence. IPR uses wastewater that has undergone advanced treatment (typically microfiltration, reverse osmosis, and ultraviolet light-based advanced oxidation). The advanced treated water is used to augment groundwater storage via injection or surface spreading in recharge ponds or basins. As sustainability benefits should be monitored based on Monitoring Methods for the applicable groundwater recharge project type and sustainability indicators and considerations expected to benefit, this method describes monitoring for groundwater quality impacts from IPR.

The primary concern about IPR projects is that the introduction of a new water source to the groundwater aquifer could impact water quality. Although the source of water is designed to be highly purified and generally expected to improve groundwater quality, adverse groundwater quality impacts could occur due to treatment failures or geochemical reactions between the purified water and aquifer sediments.

Justification

To achieve the GSP sustainability goal, an IPR project needs to show that it does not cause undesirable results for groundwater quality even as it provides the benefits of groundwater recharge (increased groundwater in storage and reductions in groundwater level declines). SGMA defines the groundwater quality sustainability indicator to ensure the groundwater management, including the implementation of projects and actions, does not result in significant and unreasonable groundwater quality impacts.

This Monitoring Method does not describe all groundwater monitoring required by the GRRP regulations and instead considers groundwater monitoring to evaluate undesirable results as primary monitoring. For example, the GRRP regulations provide requirements, such as **tracer studies**, to monitor groundwater to estimate underground retention time. As this is monitoring to prevent potential impacts as opposed to monitoring actual impacts that could be undesirable results, this is not described in this method even though the project proponent will need to follow these requirements related to project permitting. Monitoring such as tracer studies are considered secondary monitoring for the purposes of evaluation of grant outcomes even though they are required by the GRRP regulations. The data from this secondary monitoring should be available for the Department of Water Resources (DWR) to obtain, if requested.

The method described here focuses on primary monitoring for observed impacts to groundwater quality that may lead to undesirable results. However, some of the requirements in the GRRP may overlap with the presented monitoring method.

Tracer studies inject a harmless constituent of known concentration into the subsurface which is monitored at downgradient locations.

They are used in the field to obtain information on the direction and velocity of the flow of groundwater and associated contaminants, and the presence of preferential flow paths.

A Step-by-Step Guide to Applying Indirect Potable Reuse Monitoring Method

1. **Safety plan:** All projects with fieldwork related activities should produce a Safety Plan. Planning for fieldwork and availability of access to the site, such as monitoring wells, is necessary to maintain project safety. IPR projects may require a Safety Plan to address these and other potential safety concerns.
2. **Identify monitoring wells:** Identify monitoring wells used to meet GRRP regulations.

   Title 22 (Sections 60320.126 and.226) requires the following monitoring wells.

   a. One monitoring well located between the IPR recharge basin or well that is between two weeks and six months travel time from the recharge location and at least 30 days upgradient of the nearest drinking water well.
   b. The second monitoring well is required between the recharge location and the nearest downgradient drinking water well.

   Monitoring wells should be located in each aquifer recharged by IPR. Monitoring at wells identified by the project proponent in its Title 22 Engineering Report for meeting these regulations should be reported to DWR as part of this method. The location of the monitoring network should be easily accessible such that gaining access to the site does not inhibit gathering and downloading data (refer to Step 1).
3. **Identify Representative Monitoring Points (RMP):** Identify RMPs closest to IPR recharge location in aquifers recharged by IPR that are most likely to show groundwater quality impacts. Consistent with reporting requirements in the GRRP regulations (Title 22 Sections 601320.128 and .228), any RMPs that are within ten years travel time of the IPR recharge location should also be identified. Monitoring at these RMPs should be reported to DWR as part of the annual reports.
4. **Monitoring plan:** Implement monitoring plans described in IPR Project Title 22 Engineering Report and, if applicable, under the GSP for the region. These plans may describe the groundwater quality monitoring approach at the wells identified in Steps 1 and 2, including monitoring baseline conditions.
5. **Monitoring:** Sample wells quarterly. This is consistent with the sampling frequency required by GRRP regulations (Title 22 Sections 60320.126 and.226).

Data and Protocol - Fundamentals

GRRP regulations identify groundwater quality parameters to be monitored during operation of an IPR project as total nitrogen, nitrate, nitrite, contaminants with secondary maximum contaminant limits, and any other contaminants specified by Division of Drinking Water or RWQCB. Table MM05-4 presents an example list of flow and water quality monitoring that may be required under Order from Waste Discharge Requirements and Water Reclamation Requirements. These constituents should be monitored at all monitoring wells identified to meet GRRP regulations and permitting requirements. In addition, constituents identified in the GSP with water quality sustainable management criteria should be monitored at IPR monitoring wells.

Table MM05-4. Example Groundwater Data Monitoring Report (Generally Quarterly)

Sample Location	Parameter	Units	Sample Type	Min Sampling Frequency	Value
ALL	Total flow	MGD or Acre Feet	Recorder	continuous	XX
MM-XX	Water level elevation	Feet	---	quarterly	XX
	Total Residual Chlorine	mg/L	grab	quarterly	XX
	TOC	mg/L	grab	quarterly	XX
	Total Coliform	MPN/ 100 mL	grab	quarterly	XX
	BOD5	mg/L	grab	annually	XX
	Oil and grease	mg/L	grab	annually	XX
	Nitrate-N	mg/L	grab	quarterly	XX

Nitrite-N	mg/L	grab	quarterly	XX
Total Nitrogen	mg/L	grab	quarterly	XX
Total Dissolved Solids	mg/L	grab	quarterly	XX
Sulfate	mg/L	grab	quarterly	XX
Chloride	mg/L	grab	quarterly	XX
Boron	mg/L	grab	quarterly	XX
Odor	TON	grab	quarterly	XX
Color	CU	grab	quarterly	XX
Total Suspended Solids	mg/L	grab	quarterly	XX
Turbidity	NTU	grab	quarterly	XX
Foaming Agents	mg/L	grab	quarterly	XX
Specific Conductance	µmhos/cm	grab	quarterly	XX
Corrosivity	LSI	grab	quarterly	XX
Silver	µg/L	grab	quarterly	XX
Iron	µg/L	grab	quarterly	XX
Zinc	µg/L	grab	quarterly	XX
Aluminum	µg/L	grab	quarterly	XX
Manganese	µg/L	grab	quarterly	XX
Copper	µg/L	grab	quarterly	XX
MTBE	µg/L	grab	quarterly	XX
Thiobencarb	µg/L	grab	quarterly	XX
Fluoride	µg/L	grab	quarterly	XX
Other Inorganics with Primary MCLs	µg/L	grab	quarterly	XX
Other Regulated Organics	µg/L	grab	quarterly	XX
Other Constituents/parameters with Secondary MCLs	µg/L	grab	quarterly	XX
Disinfection Byproducts	µg/L	grab	quarterly	XX
Radioactivity	pCi/L	grab	quarterly	XX
Other General Physical and General Minerals	µg/L	grab	quarterly	XX
Other Constituents with Notification Levels	µg/L	grab	annually	XX
Remaining Priority Pollutants	µg/L	grab	quarterly	XX
Identified constituents of emerging concern	µg/L	grab	quarterly	XX

Data Analysis and Reporting

1. **Evaluate data vs. water quality objectives.** Water quality data should be evaluated against maximum contaminant levels for constituents listed in the Title 22 Engineering Report and the GSP. Exceedances may lead to suspension of operation of the IPR project until corrective actions are implemented, or the project proponent can show that exceedances were not caused by the IPR project.
2. **Report data annually to DWR**. Data collected as part of this method will be reported in the Title 22 Annual Report and the GSP Annual Report. For grant compliance, the data can be referenced and summarized to document whether there are groundwater quality impacts from the IPR project and whether the IPR project is contributing to groundwater quality undesirable results. This summary should be included in the larger report to DWR describing the recharge benefits of the IPR project as described in other Monitoring Methods.

Data Standards

Precision and accuracy of water quality sampling should facilitate comparison with water quality objectives. For example, GRRP regulations include a confirmation sampling trigger related to concentrations at 80% of the maximum contaminant limits for nitrate, nitrite, and nitrogen so data precision and accuracy should be able to distinguish above and below the trigger. Data standards will vary by constituent as Division of Drinking Water, RWQCB, or the GSP may require monitoring additional constituents such as arsenic, perfluoroalkyl substances (referred to as PFAS) or other constituents of emerging concern.

Key Protocols

There are several protocols that an IPR project will need to follow:

- DWR's Best Management Practice 1 Monitoring Protocols Standards and Sites - describes protocols for measuring groundwater quality to assist in the establishment of consistent data collection procedures and processes (DWR, 2016)
- Water Quality Sampling Protocol Described in GSP
- California Department of Toxic Substances Control, Representative Sampling of Groundwater for Hazardous Substances Guidance Manual for Groundwater Investigations
- USGS National Field Manual for the Collection of the Water-Quality Data

Example of Indirect Potable Reuse Application

Orange County Water District Groundwater Replenishment System

Location: North and Central Orange County, California

Year: 2008-Present

Description and Relevance:

Orange County Water District (OCWD) operates the Groundwater Replenishment System (GWRS) that performs advanced treatment of wastewater from Orange County Sanitation District and recharges the Orange County Groundwater Basin with high quality water. The Advanced Water Purification Facility of

Figure MM05-1. Advanced Water Purification Facility UV/AOP System. (Orange County Water District, 2021a).

Figure MM05-2. Groundwater Replenishment System Location Map. (Orange County Water District, 2021a)

GWRS is designed to produce up to 100 million gallons per day. IPR occurs with recharge at the Anaheim Forebay spreading basins, injection wells at the Talbert Seawater Intrusion Barrier, and injection wells for the Mid-Basin Injection Project. Each recharge facility includes a network of monitoring wells to meet groundwater monitoring requirements of Title 22 GRRP regulations and the project permit as described in the Santa Ana RWQCB Monitoring and Reporting Program No. R8-2004-002.

OCWD is planning the final expansion of the GWRS to increase production up to 130 million gallons per day and add recharge at four (4) additional surface sites. The Title 22 Engineering Report for the final expansion describes monitoring and reporting for the final expansion that is based on the current Santa Ana RWQCB Monitoring and Reporting Program and therefore consistent with monitoring groundwater quality impacts from an IPR project as described in this method.

OCWD is also the Groundwater Sustainability Agency that manages the OCWD Management Area of the Orange County Groundwater Basin where the GWRS is located. In its definition of sustainability under SGMA, OCWD defines significant and unreasonable degradation of water quality for the OCWD Management Area as "*degradation of groundwater quality attributable to groundwater production or recharge practices in the OCWD Management Area and to the extent that a significant volume of groundwater becomes unusable for its designated beneficial uses*" (OCWD, Basin 8-1 Alterative: OCWD Management Area, 2017). This definition is consistent with this method to evaluate whether recharge via IPR contributes to undesirable results for groundwater quality.

Links to Resources:

https://www.ocwd.com/media/9897/2020-gwrs-annual-report-appendices-1.pdf

https://www.ocwd.com/media/10211/gwrsfe-title-22-engineering-report.pdf

https://www.ocwd.com/media/4918/basin-8-1-alternative-final-report-1.pdf

Water Replenishment District - Dominguez Gap Barrier Project

Location: Los Angeles, CA

Year: 2006-Present

Description and Relevance:

The Water Replenishment District of Southern California installed 56 injections wells to impede seawater intrusion into the coastal aquifer and to provide potable water for domestic wells. The Project involves the delivery of recycled water from the City of Los Angeles Department of Public Works - Bureau of Sanitation Terminal Island Water Reclamation Plant/Advanced Water Treatment Facility to the Dominguez Gap Barrier. The Water Replenishment District measures and tracks groundwater levels and quality conditions, evaluates potential impact of recycled water on groundwater, and identifies potential problems at monitoring wells before recycled water arrives at any downgradient drinking water wells. An extensive tracer study was performed between February 2006 through the fall of 2010 to determine the extent of travel and movement of the injected recycled water through the aquifers. This study confirmed that adequate mixing and additional blending of recycled water occurs. This project will ultimately receive 9.5 million gallons per day of advanced treated wastewater, which will enable the expansion of the existing infrastructure to include a Second Barrier Connection.

Links to Resources: https://www.wrd.org/sites/pr/files/WRD 2021 ESR - May %28FINAL%29.pdf

Source References

California Department of Toxic Substances Control. 2008. *Representative Sampling of Groundwater for Hazardous Substances Guidance Manual for Groundwater Investigations*.

California Department of Water Resources. 2016. *Best Management Practices for the Sustainable Management of Groundwater, six-part series (BMP 1 Monitoring Protocols Standards and Sites, BMP 2 Monitoring Networks and Identification of Data Gaps, BMP 3 Hydrogeologic Conceptual Model, BMP 4 Water Budget, BMP 5 Modeling, and BMP 6 Sustainable Management Criteria DRAFT).* Sacramento (CA): California Department of Water Resources. California Natural Resources Agency. [Website] Viewed online at: https://water.ca.gov/Programs/Groundwater-Management/SGMA-Groundwater-Management/Best-Management-Practices-and-Guidance-Documents.

California State Water Resources Control Board. 2018. *Water Recycling Criteria, Title 22, Division 4, Chapter 3, California Code of Regulations*. Sacramento (CA): State Water Resources Control Board.

——. 2021. *Indirect Potable Reuse Information.* Sacramento (CA). California Water Boards. [Website]. Viewed online at: https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/indirect-potable-reuse.html#:~:text=Indirect%20Potable%20Reuse%20Information&text=Indirect%20Potable%20Reuse%20(IPR)%20is,Source%20Augmentation%20Projects%20(SWSAP).

Rodriguez C, Van Buynder P, Lugg R, Blair P, Devine B, Cook A, and Weinstein P. 2009. *Indirect potable reuse: a sustainable water supply alternative*. International journal of environmental research and public health, 6(3), 1174–1209. [Website]. Viewed online at: https://doi.org/10.3390/ijerph6031174.

State Water Resources Control Board. 2018. *SWRCB, Resolution 2018-0057, “Water Quality Control Policy for Recycled Water, Title 23 “Waters”, Division 3 “SWRCB and RWQCBs”, Chapter 22 “State Policy for Water Quality Control”.*

United States Geological Survey. 2006. *National Field Manual for the Collection of the Water-Quality Data*. Viewed online at: http://pubs.water.usgs.gov/twri9A

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Groundwater Quality Improvement Monitoring Method

MONITORING METHOD [MM-06]

MONITORING METHOD [MM-06]

Groundwater Quality Improvement Monitoring Method

Project / Action Type	Groundwater Quality Improvement projects that use aquifer remediation or clean-up to improve accessibility to groundwater resources for different beneficial uses.
Similar / Related Project Types	Groundwater Recharge projects that help improve water quality by recharging high quality surface water and diluting existing groundwater constituents of concern.
Metric	Site specific; contaminant concentration (inorganic chemicals, organic chemicals, disinfectants and by-products, microorganisms, radionuclides), general water quality parameters (pH, salinity, turbidity, hardness, temperature, oxidation reduction potential). Applicable water quality constituents (situationally). Groundwater Dependent Ecosystems (situationally).
Measurement Unit	Concentration or measurement of applicable groundwater quality constituents (typically mg/L), may include, inorganic chemicals, organic chemicals, disinfectants and by-products, microorganisms, radionuclides, pH, salinity, turbidity, hardness, temperature, oxidation reduction potential or any other applicable constituent of concern.
Beneficial User	Municipal and domestic water supply (MUN) Industrial service supply (IND) Industrial process supply (PROC) Agricultural water supply (AGR) Freshwater replenishment to surface waters (FRSH) (situationally)

Groundwater Quality Improvement Overview

Groundwater quality issues can limit local water supply availability for beneficial use. In areas with existing groundwater quality issues, groundwater remedies may be implemented to restore groundwater quality to beneficial uses, which would improve accessibility to the groundwater source previously impaired, minimize further migration of impacted groundwater, reduce contaminant concentrations, and protect human health and the environment from exposure to contaminants.

In general, some of the following **groundwater quality remediation projects** may be implemented to improve water quality: pump and treat, groundwater recirculation between extraction and injection wells with amendments for in situ remediations, permeable reactive barriers, enhanced in situ biodegradation or chemical oxidation injections, thermal reduction, soil vapor extraction, and excavation of contaminant sources.

GROUNDWATER REMEDIATION PROJECT TYPES TO IMPROVE WATER QUALITY
Pump and Treat – Groundwater is pumped from wells to an above-ground treatment system that removes the contaminants.
In situ remediation - Term meaning "in place" or in the natural or original position, such as the treatment of groundwater in the subsurface.
Permeable reactive barriers - A permeable wall or vertical zone containing reactive media, oriented to intercept and remediate a contaminant plume as groundwater migrates the zone.
Enhanced in situ biodegradation – The use of microorganisms to degrade contaminants in place with the goal of producing harmless chemicals as end products.
Chemical oxidation injections - In situ remediation technology for groundwater or soil where strong oxidants are injected or mechanically mixed into the treatment zone to promote destructive abiotic degradation reactions.
Thermal remediation (or thermal reduction) - In situ remediation technology for groundwater where energy is injected into the subsurface to mobilize and recover volatile and semi-volatile organic contaminants. This method commonly utilizes steam-enhanced extraction, electrical-resistance heating, or thermal-conductive heating to remediate contaminants from source zones.
Soil vapor extraction - A physical treatment process for in situ remediation of volatile contaminants in vadose zone (unsaturated) soils.
Excavation of contaminated sources – a method of removing contaminated material from a site involves digging it up for "ex situ" (above-ground) treatment or for disposal in a landfill.

The groundwater sustainability plan (GSP) Regulations that specify components of GSPs prepared pursuant to the Sustainable Groundwater Management Act (SGMA) require that groundwater sustainability agencies (GSAs) provide explanations of project and management actions (23 CCR § 354.44). Nothing in these Monitoring Methods supersedes the GSP Requirements as related to the development and implementation of GSPs, alternatives to a GSP, coordination agreements, and annual reporting requirements under SGMA.

Monitoring Objectives

The processes affecting groundwater quality vary widely and depend on many factors, including hydrogeology, local aquifer conditions, and human activities related to land use. When implementing projects and actions, supplemental characterization may be needed to improve the understanding of local aquifer conditions in areas with existing groundwater contamination or in areas where active remedial operations are ongoing. This Monitoring Method provides guidance for monitoring the effectiveness of groundwater remedies to improve groundwater resources and how ongoing remedial actions may affect the implementation of other unrelated projects and actions. The applicability of water quality-based projects to the sustainability indicators outlined in SGMA is presented in Table MM06-1.

Table MM06-1. Level of Benefit to the Six Sustainability Indicators Outlined in SGMA

	Six Sustainability Indicators Outlined in SGMA	Applicability*
	Depleted Interconnected Surface Water	
	Lowered Groundwater Levels	★
	Water Quality Degradation	★★★
	Subsidence	
	Reduced Groundwater Storage	★★
	Seawater Intrusion	★

*Notes:

★★★ = Primary Benefit (High Applicability)

★★ = Secondary Benefit (Medium Applicability)

★ = Situational Benefit (Applicability dependent on Location, Site Characteristics, and Aquifer Condition)

Desired Outcomes or Benefits Resulting from Groundwater Quality Improvement

The implementation of effective groundwater remedial actions has the potential to improve impaired groundwater resources and benefit a water resource management plan's ability to achieve sustainability within a basin. During planning of other projects or actions, consideration of existing groundwater quality issues can prevent the potential for exacerbation or spreading of existing groundwater contamination. The main outcome of this type of project is to allow for the use of a groundwater source that may not have been useable previously and improve supply of groundwater as shown in Table MM06-2.

Table MM06-2. Potential Benefits Resulting from Project / Action

	Potential Benefits on SGMA Sustainability Indicators	Benefit / Not Applicable	Description of Benefits
	Depleted interconnected surface water	Not Applicable	
	Lowered groundwater levels	Not Applicable	
	Water quality degradation	Benefit	Source water quality that is better than ambient groundwater quality can improve groundwater quality through dilution. For example, Flood-MAR recharge may lower nitrate and salinity concentrations in degraded groundwater to concentrations below acceptable levels for beneficial use.
	Subsidence	Not Applicable	
	Reduced groundwater storage	Not Applicable	
	Seawater intrusion	Not Applicable	

Potential Impacts

Groundwater remediation is intended to remove or degrade contaminants in an aquifer; however, active remediation approaches have the potential to further degrade groundwater or have other unintended consequences when implemented. Actions and projects implemented in areas where soil or groundwater is degraded may exacerbate or spread existing contamination. Application of in situ chemicals, other injection solutions, or permeable reactive barriers are often designed to change the oxidation-reduction state of the aquifer. This change in geochemical conditions can induce target contaminant degradation but also can mobilize naturally occurring metals like arsenic, selenium, and hexavalent chromium, which may not have been a water quality issue prior to remediation. Long-term extraction and treatment can lower groundwater levels, which has numerous potential impacts on all sustainability indicators. Potential impacts on the SGMA sustainability indicators resulting from groundwater quality improvement projects are shown in Table MM06-3.

There are also mechanisms for water quality degradation from water supply projects and actions:

Managed Aquifer Recharge – With managed aquifer recharge projects, there is some potential for groundwater quality degradation from mobilization and flushing of chemical constituents (whether applied, such as from previous agricultural land use, legacy contamination, or naturally-occurring minerals in the pre-recharge vadose zone).

- **Recharge ponds** – If the chemistry of infiltrating water is different from that of the native groundwater (for example, when using recycled water through IPR), geochemical changes may occur during infiltration. Infiltration may alter the shallow water levels and cause the water table to fluctuate. Fluctuations in the water table resulting in wetting and dewatering of shallow vadose zone sediments and may also induce changes in geochemistry.
- **Injection wells** –During direct injection, differences in recharge water chemistry and native groundwater chemistry can cause adverse interactions. These changes are likely to be more abrupt compared to other recharge processes. The use of injection wells may alter the groundwater flow regime and cause faster transport between different zones within the aquifer.
- **Flood-managed aquifer recharge (Flood-MAR)** - Flood-MAR usually involves the use of floodwater for recharge on agricultural lands. Generally, projects are implemented in areas with access to surface water, so similar water sources have previously been introduced to the aquifer, making abrupt changes to geochemical conditions unlikely. However, agricultural areas may have legacy contaminant sources in soil, especially from past agricultural practices, that are a potential source of contamination during recharge events.

Changes in Pumping – Changing the timing, magnitude, and/or spatial distribution of pumping may mobilize chemical constituents and degrade water quality.

- **Water Trading** - Trading programs may change the volume and use of groundwater supplies, affecting return flows, magnitude and timing of pumping, and contaminant loading. Increasing pumping in an area with poor water quality may cause the migration of contaminants. Increased water use by a user with higher contaminant loading may result in higher contaminant concentration in return flows.
- **New Pumping** – Pumping from new wells may increase the vertical and lateral movement of groundwater, resulting in transport of contaminants or changes in geochemistry that may induce contaminant mobilization. Pumping in new regions of an aquifer may also cause water levels to fluctuate, resulting in changes to geochemical conditions.
- **Retiring Wells** - Inactive wells may act as conduits for groundwater, allowing shallow groundwater of poorer quality to migrate vertically and degrade deeper **hydrostratigraphic zones**. Therefore, it is important to properly decommission wells that are no longer in use.

The **hydrostratigraphic zone** refers to a geologic area consisting of a body of rock having considerable lateral extent and composing a reasonably distinct hydrologic system.

Table MM06-3. Potential Impacts Resulting from Project / Action

	Potential Impacts on SGMA Sustainability Indicators	Impact / Not Applicable	Mitigation Measures to Address Impacts
	Depleted interconnected surface water	Not Applicable	
	Lowered groundwater levels	Impact	Aggressive and/or sustained remedial groundwater extraction for prolonged periods is expected to lower groundwater levels locally. Mitigate impacts by extracting at lowest rates to still achieve sufficient contaminant plume capture. Deliver treated water for groundwater recharge. Consider other beneficial reuses of treated water or in lieu exchanges of treated water for reduced groundwater pumping.
	Water quality degradation	Impact	Monitor remediation projects and implement mitigation measures to address unintended consequences including mobilization of contaminants from recharge projects, changes to pumping regime, geochemical reactions, or other remediation by-products.
	Subsidence	Not Applicable	
	Reduced groundwater storage	Not Applicable	
	Seawater intrusion	Not Applicable	

Use and Limitations

Groundwater remediation for beneficial use may be impractical, not cost effective, or otherwise infeasible. Emerging contaminants are continuously being identified, and regulatory standards are occasionally revised, so that in the future, a remediated site could have concentrations of a new or emerging contaminant above regulatory standards, even if it is considered suitable for beneficial use under the current regulatory limits.

Working with responsible parties to monitor the remedial actions can be a challenge and should be considered in the project design, implementation, and monitoring approaches.

Groundwater quality monitoring cannot easily be automated; therefore, it is relatively expensive compared to monitoring more passive properties such as groundwater levels. Results of monitoring using the monitoring network established during project development may indicate that insufficient data are being obtained to evaluate the effectiveness of the project in relation to the established performance standards and/or that groundwater level rise or groundwater quality impacts may be of concern at or in the vicinity of the facility. These conditions can be addressed by developing and implementing a work plan to install additional monitoring wells and/or vadose zone piezometers, which would provide useful hydrogeologic information at targeted locations, as well as providing additional critical monitoring points.

Permitting and Design Considerations

Local permitting and regulations can play a role in the design requirements for a project and the expected water quality. Water quality project permitting and design can be based on the objectives of the specific project including, the project location, intended use of project water, and the potential impacts the project could have on groundwater. The Regional Water Quality Control Board (RWQCB) and State Water Resources Control Board (SWRCB) Division of Drinking Water can be involved with decision making regarding the use of contaminated or remediated water sources, especially where uses for drinking water beneficial use. RWQCB **Basin Plan** and SWRCB Antidegradation Policy should be considered when planning most groundwater quality improvement or recharge projects. Basin Plans generally have identified constituents of concern and set limits for acceptable concentration limits for various beneficial uses. Depending on the project, proponents may need to conduct an **antidegradation analysis** to understand the influence the project might have on water quality relative to the existing groundwater conditions. The water quality may be governed differently, depending upon the application and location of the project.

KEY TERMS

An **antidegradation analysis** is an assessment of proposed water uses relative to the SWRCB Antidegradation Policy

Basin Plans are management plans with specific requirements for the 9 RWQCB regions.

Water quality objectives may also be identified in a region's Groundwater Sustainability Plan, and a project proponent should investigate if there are any applicable management criteria identified under the Groundwater Sustainability Plan.

Relationship to Other Monitoring Methods

The Groundwater Recharge Projects Monitoring Methods including Aquifer Storage and Recovery (MM-01), Recharge Ponds (MM-02), Flood-MAR (MM-03), Stormwater Recharge (MM-04), and Indirect Potable Reuse (MM-05) are related as all of these can either improve or degrade groundwater quality depending on the water sources used for recharge, natural characteristics of the aquifer, and project implementation approach. The Seawater Intrusion Management Monitoring Method (MM-08) is related because it causes groundwater quality degradation.

Approach to Implementing Groundwater Quality Improvement Monitoring Method

If a project is being considered in an aquifer with existing contamination, planning and evaluation is needed to ensure that undesired results do not occur. It may be possible to design a project or action to provide groundwater quality improvements. Understanding hydrogeologic and geochemical conditions is critical to anticipating whether the project may improve groundwater quality or potentially create impacts to previously uncontaminated portions of the aquifer. The potential to reinject treated water into the aquifer instead of discharging back to a stream or other surface water body, should be carefully considered and monitored.

Justification

A monitoring network is needed for water quality improvement projects that are capable of tracking compliance with regulatory thresholds. Where groundwater impacts are known to exist, networks may have already been established under the direction of other agencies. In some cases, Groundwater Sustainability Agencies or other project proponents may have to install additional monitor wells to supplement existing monitoring networks, to better track the effects of the remedial action in a portion of the aquifer.

A Step-by-Step Guide to Applying Groundwater Quality Improvements Monitoring Method

Implementation of an effective monitoring method to assess project benefits or impacts includes the following:

1. **Determine oversight agency for known groundwater impacts or existing remedial operations:** California Water Code guidelines designate the SWRCB and RWQCB as the principal state agencies with responsibility for the coordination and control of water quality for groundwater. However, depending on the source and nature of the water quality impacts, other federal, state, and local agencies may have jurisdiction over clean-up efforts.
   - If a significant groundwater quality issue is managed under the regulatory oversight of the SWRCB or RWQCB, the project proponent should confer with that agency and seek to confirm a reasonable plan to address the groundwater quality issue. Other agencies with regulatory responsibility for groundwater quality may include the United States Environmental Protection Agency, and different state agencies, including the California Department of Pesticide Regulation, Department of Conservation's Division of Oil, Gas, and Geothermal Resources, and Department of Toxic Substances Control. Counties and cities also may have regulatory authority over some issues pertaining to local groundwater quality.
   - If a significant groundwater quality issue has been identified and is not clearly under the purview of another agency, the project proponent should confer with SWRCB, RWQCB, or other appropriate staff, and affected parties, to determine a reasonable plan to address the issue.
2. **Develop a conceptual site model for the impacted site:** A site-specific conceptual site model may be developed based on the available hydrogeologic and geochemical data. The conceptual site model provides a basis for decision-making that evolves as investigations progress.
3. **Safety plan:** All projects with fieldwork related activities should produce a Safety Plan. Planning for fieldwork and availability of access to the site, such as monitoring wells, is necessary to maintain project safety. Groundwater quality improvement projects may require a Safety Plan to address these and other potential safety concerns.
4. **Design a monitoring well network consistent with guidelines and Groundwater Sustainability Plan Regulations specified in the Department of Water Resources (DWR) Best Management Practice (BMP) 2 Monitoring Networks and Identification of Data Gaps (DWR, 2016):** A water quality monitoring network should be capable of capturing data on a sufficient temporal frequency and spatial distribution to demonstrate short-term, seasonal, and long-term trends in basin conditions for relevant constituents of concern. A monitoring network can be designed and implemented to sufficiently track compliance with water quality standards, as well as provide enough detail to track project implementation and be able to assess potential impacts on beneficial users. The location of the monitoring network should be easily accessible such that gaining access to the site does not inhibit gathering and downloading data (refer to Step 1).
   - Determine the number of wells to evaluate and document the contaminant types, contaminant concentrations, and lateral and vertical distribution of contaminants. The number and location of wells will depend on site-specific factors, including groundwater flow direction and gradient, hydrostratigraphy, and the identified water-bearing zones. The number of contaminant sources on a site, the properties of contaminants, and the extent of groundwater contamination also will affect decisions regarding the number of wells needed and how the wells are spaced.
   - At a minimum, a monitoring network should include wells in the following locations in relation to the site and contaminant plume:
     - Upgradient to provide background water quality
     - Within a plume to identify the distribution of contaminant concentrations
     - At either side of the plume to define the lateral extent of contamination
     - At the downgradient edge of the plume to monitor its migration
     - Clusters installed at different depths in a contaminated, water-bearing zone to identify the vertical extent of contamination
     - In underlying water-bearing zones to identify the presence or absence of contamination

  - Drinking water supply wells (domestic, public supply, and small water system wells) that may be impacted by contamination
- Monitoring network wells should ideally be dedicated groundwater monitoring wells with known construction information. The selection of wells can be aquifer-specific and wells that are screened across more than one aquifer should be avoided where possible. If existing wells are used, the screened intervals should be known to interpret and utilize the water level or water quality data collected from those wells. Monitoring wells should be drilled and installed in accordance with DWR Bulletin 74-81 and 74-90.

5. **Implement groundwater monitoring program:** Protocols for monitoring groundwater levels and groundwater quality are addressed in DWR's BMP 1 Monitoring Protocols Standards and Sites (DWR, 2016). Selected notable considerations for implementation of a groundwater monitoring program include the following:
   - All monitoring should be conducted in such a manner to produce reliable, consistent, high-quality, and defendable data.
   - A Quality Assurance Program Plan, Sampling and Analysis Plan, and/or Quality Assurance Project Plan can be developed, where applicable, to establish data quality objectives for data measurement, sampling procedures, sample and document custody procedures, laboratory analytical methods, data validation protocol, and reporting procedures.
   - To assess the potential effects a project may have on water quality, monitoring should be conducted prior to the start of project operations to establish baseline conditions. While baseline monitoring should be conducted at a minimum prior to commencement of recharge projects, collecting baseline monitoring for at least one year before recharge operations would provide a more robust dataset to compare to project implementation data should groundwater quality impacts occur.
   - The frequency of groundwater quality monitoring may be based on the hydrogeologic conditions of the project area. For new monitoring wells, it is recommended that sampling be conducted at least quarterly for a minimum of one (1) year to establish water quality trends and track seasonal variations. Semi-annual or annual monitoring may be sufficient once water quality trends have been established.

Data and Protocols - Fundamentals

The effectiveness of a groundwater quality remedy and resulting groundwater quality improvement can be assessed using wells installed specifically for monitoring. Table MM06-4 provides an example list of monitoring parameters that can be used in reporting and understanding the effects of a project in a quantifiable way over time. The primary monitoring requirements and tools include the following:

- Groundwater levels are measured to evaluate groundwater flow directions and gradients; primary monitoring points are monitoring wells. Primary tools for measuring groundwater levels include electrical sounders and pressure transducers installed in the monitoring wells and piezometers as outlined in DWR's BMP 1 Monitoring Protocols Standards and Sites (DWR, 2016); the use of dataloggers in association with pressure transducers allows automated collection of water level measurements at frequent intervals.

- Groundwater sampling is conducted to evaluate groundwater quality and monitor mobilization of chemical constituents. Primary tools for sampling groundwater include dedicated or temporary pumps installed in the monitoring wells to purge and obtain representative groundwater samples for laboratory analyses, as indicated in DWR's BMP 1 Monitoring Protocols Standards and Sites (DWR, 2016).

Table MM06-4. Example Data Monitoring Report (Generally Annually)

Monitoring Reporting	
Total Groundwater Treated	XXX AF
Total Contaminants Removed	XXX tons
Average Groundwater Quality Constituent Change (list all identified, Recharge Area / Background)	+/- XXX mg/L / +/- XXX mg/L
Incurred Costs	$XXX

Data Analysis and Reporting

1. **Analyze monitoring data:** Results of the groundwater monitoring program should be used to evaluate potential water quality impacts or benefits, from project implementation.
2. **Prepare reports and manage data:** Results of groundwater quality monitoring BMP be reported in accordance with regulatory order requirements and/or grant requirements and provided to DWR for review. Data reporting and management procedures are addressed in the Data Management and Monitoring Method (MM-12).
3. **Expand or refine monitoring network adaptively**, as needed.

Data Standards

- Groundwater monitoring should be conducted in accordance with standard sampling and analytical protocols and documentation requirements to ensure groundwater monitoring data are collected, reviewed, and analyzed in a consistent manner and results are repeatable and defensible.
- Data collected should be machine readable, with pre-established fields of entry, to better allow data analytics.
- Concentration data should be compared to current regulatory standards. A variety of standards exist depending on toxicology and related policy. Common regulatory standards for comparing groundwater concentrations are the SWRCB primary and secondary maximum contaminant levels and notification levels, though some emerging contaminants are regulated under different entities such as the United State Environmental Protection Agency.

Key Protocols

The key protocols for groundwater quality monitoring can be found in the following:

- **DWR's BMP 1 Monitoring Protocols Standards and Sites (DWR, 2016) -** Describes protocols for measurement of groundwater levels and collection of groundwater samples for analysis to establish consistent data collection procedures.
- **DWR's BMP 2 Monitoring Networks and Identification of Data Gaps (DWR, 2016) -** Provides guidelines for establishing monitoring networks capable of providing sustainable indicator data of sufficient accuracy and quantity to demonstrate sustainable management in the basin and provides information on how to identify and resolve data gaps to reduce uncertainty.
- **California Department of Toxic Substances (2012): Guidelines for Planning and Implementing Groundwater Characterization of Contaminated Sites -** Presents a recommended approach to planning and conducting groundwater investigations, when planning and conducting site characterization activities.

Examples of Groundwater Quality Improvement Application

Name of Project: Regional Salinity Management

Location: Santa Ana Basin

Year: 1979-present

Description and Relevance:

The Santa Ana Watershed Basin Study addressed Santa Ana Watershed Project Authority's Regional Interceptor system, also known as the Inland Empire Interceptor Brine Line. The Brine Line was constructed to help manage the basin's water quality by exporting highly saline waters from the Inland Empire to a wastewater treatment plant in Orange County where the effluent is processed for ocean discharge. Like nearly all watersheds in arid climates, salt management is essential for water resource managers to ensure populations and ecosystems continue to thrive. The Brine Line, an important tool in managing inland groundwater basins, has allowed businesses with industrial processes that produce brine to move into and expand in the Inland Empire. Orange County also benefits from the Brine Line through the removal of salinity from the Santa Ana River, providing a reliable level of protection for its water quality and reducing the area's dependence upon imported water.

Links to Resources:
https://www.usbr.gov/watersmart/bsp/docs/finalreport/SantaAnaWatershed/SantaAnaBasinStudySummaryReport.pdf

https://www.wmwd.com/213/The-Solutions

Name of Project: San Gabriel Basin Groundwater Remediation

Location: San Gabriel Basin, LA County

Year: 1979-present

Description and Relevance:

After severe groundwater contamination was detected in the San Gabriel Basin a plan of action was needed. The Environmental Protection Agency designated four Superfund sites in the area and the San Gabriel Basin Water Quality Authority was formed to coordinate the clean-up efforts. Since its creation more than 28 years ago 1.8 million acre-feet of water and 196,000 pounds of contaminants have been treated, thus making the region less dependent upon imported water.

Links to Resources: https://wqa.com/wp-content/uploads/2021/12/2020-2021-Annual-Report.pdf

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