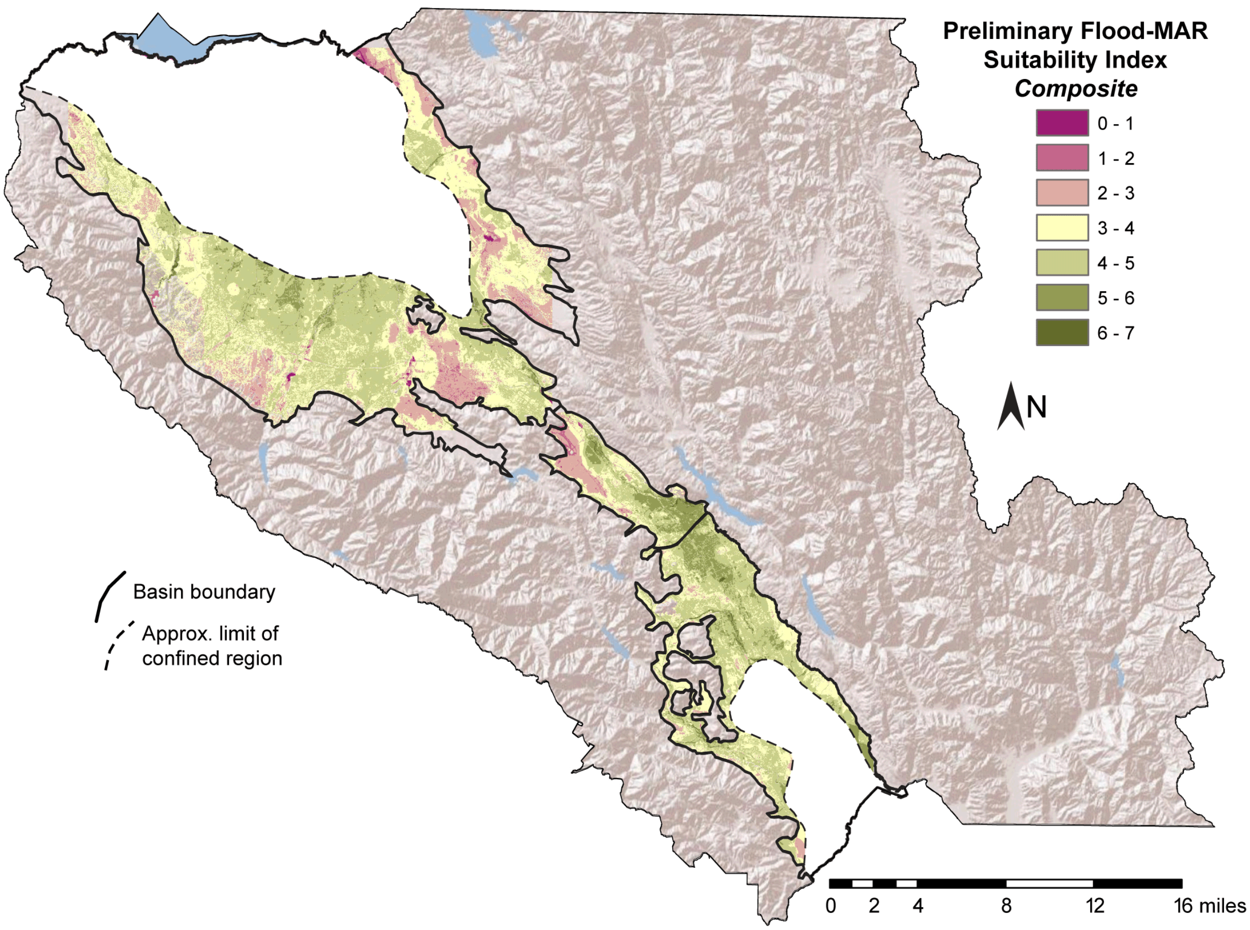
Pre-Feasibility Study for a Flood-MAR Program in the Santa Clara Valley Water District Service Area, Santa Clara County, CA



Water Resource Innovation Partnership (WRIP)

Award A4412X to the University of California (UC Water)

Final: 17 July 2023

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Executive Summary

Flood-managed aquifer recharge (Flood-MAR) collects and infiltrates high-magnitude or excess surface water flows on agricultural lands or other working or open landscapes. UC Water has partnered with Santa Clara Valley Water District (Valley Water) to explore the potential for implementing Flood-MAR in Valley Water's service area to support the augmentation of water supplies in Valley Water groundwater recharge zones.

This report provides both a high-level evaluation of options and considerations for Flood-MAR in Valley Water's service area and a mapping tool to support preliminary evaluation of potential Flood-MAR locations. The evaluation of options and considerations suggests that small, distributed recharge projects which collect and infiltrate local hillslope runoff from heavy rain events may be the most feasible types of Flood-MAR projects for Valley Water to focus on initially. Individually, these projects would contribute small water supply benefits relative to Valley Water's existing managed aquifer recharge (MAR) program. However, they could also help diversify Santa Clara County's water supplies, slow and infiltrate stormwater runoff, maintain or improve groundwater quality, and provide ecosystem benefits.

The report articulates key questions Valley Water will want to assess to determine whether Flood-MAR is legally, administratively, institutionally, and technically viable; identifies potential pathways for answering those questions; and provides recommendations for next steps for exploring Flood-MAR implementation in Valley Water's service area.

Options and considerations for a Flood-MAR program

We evaluated the potential for a programmatic approach to Flood-MAR, as compared to developing Flood-MAR through a series of one-off projects. A Flood-MAR program would support short- and long-term planning, information gathering, and evaluation and enable ongoing adjustment of both individual projects and Valley Water's Flood-MAR strategy. Because Valley Water may not have direct control of lands that present the best opportunities for Flood-MAR, a program could support effective implementation of projects on non-Valley Water property, including by providing appropriate incentive structures and oversight to ensure that Flood-MAR projects individually and collectively meet expectations. A programmatic structure would also support internal collaboration within Valley Water, foster economies of scale, leverage dispersed institutional expertise, and house institutional memory relevant to Flood-MAR.

Building an agency-scale Flood-MAR program at a large and complex agency like Valley Water would be a novel and ambitious approach. **Table ES-1** summarizes considerations for developing a Flood-MAR program within Valley Water and related questions, grouped into three main categories: (1) program goals and objectives, (2) internal program support, and (3) program functions. Some considerations are likely shared with other Valley Water programs, enabling Valley Water to straightforwardly leverage existing expertise in the Flood-MAR context, whereas other considerations will require innovation.

We examined three types of Flood-MAR projects and their potential viability in Valley Water's service area:

1) Flooding agricultural fields or other open space with high-magnitude streamflows,
2) Floodplain restoration, and

3) Distributed recharge projects that collect and infiltrate local hillslope runoff resulting from heavy precipitation events.

Given the geography, hydrology, and existing utilization of other types of MAR in Valley Water's service area, distributed recharge projects that collect and infiltrate hillslope runoff are likely the most promising type of Flood-MAR for Valley Water to focus on initially, allowing relatively rapid progress and implementation. Individual hillslope runoff projects are expected to provide lower volumes of recharge (tens to hundreds of acre-feet per year) than the large Flood-MAR projects (providing water supply benefits of thousands of acre-feet per year) that may be more feasible in other parts of California. Therefore, Flood-MAR would likely provide a relatively small additional water supply benefit compared to Valley Water's existing MAR program. However, Flood-MAR projects that collect and infiltrate hillslope runoff could also benefit Santa Clara County by diversifying water supplies, slowing and infiltrating stormwater runoff during major rain events, maintaining or improving groundwater quality, and supporting groundwater dependent ecosystems (including by increasing baseflow to rivers and streams).

Additional key points and findings include the following:

- Valley Water's existing MAR facilities already occupy many of the best recharge sites in Santa Clara County (County), and their recharge capacity exceeds the volume of water available for recharge from Valley Water's traditional sources in many years. However, the mapping tool discussed below indicates there may be areas suitable for Flood-MAR, pending further evaluation.
- If Valley Water pursues distributed Flood-MAR projects that collect and infiltrate local hillslope runoff, organizing Flood-MAR efforts at a programmatic level will likely be more efficient and effective than pursuing individual projects with less coordination.
- Valley Water could partner with other landowners and managers to develop Flood-MAR projects, a process it could facilitate with incentives.
- One potential model for providing incentives for Flood-MAR implementation is Recharge Net Metering (ReNeM), a rebate-based incentive structure developed through a collaborative effort in nearby Pajaro Valley. However, differences in the physical and institutional contexts of the two areas may affect the potential viability of a ReNeM-like incentive structure for Flood-MAR in Valley Water's service area. For example, groundwater production charges for agricultural water users are more than seven times higher in the Pajaro Valley (~$282 per AF) than in Valley Water's service area (~$37 per AF), reducing the potential motivational power of a rebate on those charges.
- Most permitting needs for Flood-MAR projects, summarized in **Table ES-2**, will likely be familiar to Valley Water because of its extensive experience with MAR implementation. However, Valley Water would need to decide how to address permitting needs for small Flood-MAR projects that are distributed across its service area on non-Valley Water property. Valley Water may be best positioned to pursue most permits and other regulatory approvals for such projects.
- It may make sense for Valley Water, rather than individual landowners, to apply for any necessary water right permits for Flood-MAR projects, including those on private land.

These institutional findings support, and are supported by, a Flood-MAR suitability mapping tool and related analysis.

Pre-feasibility analysis of surface and subsurface suitability for Flood-MAR

To support Valley Water in identifying the potential for Flood-MAR within its service area, UC Water also developed a mapping tool to identify areas that may be suitable for Flood-MAR, pending further evaluation. The mapping tool uses multi-criteria decision analysis (MCDA) with spatial data from the Valley Water service area to identify locations with multiple favorable conditions that could justify Flood-MAR development. MCDA is a decision-making approach that evaluates several factors (criteria) together to aid consideration of alternatives.

The mapping tool is based mainly on five data coverages (**Figure ES-1A**):

- Three data sets showing surface conditions throughout Santa Clara County: soil infiltration capacity, land use/land cover, and shallow geology; and
- Two data sets showing subsurface conditions within three groundwater management areas: vadose zone thickness (the depth of the unsaturated zone that extends from the land surface down to the groundwater table) and climate sensitivity of groundwater levels.

Other datasets incorporated as part of the mapping tool include surface slope, aquifer properties (as applied in regional groundwater models), water quality, locations of operating managed recharge systems, and areas designated as "open space." These and other datasets can be used to filter results from an initial screening (for example, removing sites that are too steep for infiltration for Flood-MAR) or can help prioritize potential project sites for field investigation.

Sites with the highest Flood-MAR suitability tend to be located where multiple criteria are satisfied: on old stream channels, on or near active (although often ephemeral) stream channels, and on other coarse Quaternary fluvial and alluvial deposits; where land is undeveloped, has low-intensity development, or is used for agricultural activities; where there is a vadose (unsaturated) zone 20-100 ft thick; and where there have been large differences in groundwater levels during dry climate periods compared to wet periods. Areas with potentially favorable Flood-MAR conditions are found throughout the project region, suggesting that some distribution of benefits may be possible, depending on additional considerations including design and construction costs, permitting, available water supplies, incentives for participation, and landowner interest.

The areas with the most favorable conditions for Flood-MAR, based on this pre-feasibility assessment, include (**Figure ES-1B**):

- Santa Clara Plain - along the western and southern margins of the basin, around and outside of the region generally dominated by confined conditions.
- Coyote Valley - along the southern and eastern half of the basin, particularly along active and old stream channels and other stream deposits.
- Llagas Subbasin - in the northern half and along the western margin of the subbasin, particularly where fluvial deposits cut across areas having finer soils.

This pre-feasibility assessment is designed to be used by Valley Water as a screening tool and guide, not as an absolute assessment upon which final decisions are based. There are multiple steps that Valley Water may find useful in advancing Flood-MAR efforts in this region, several of which could be advanced simultaneously or in close succession:

- Assess drainage areas and runoff generation to identify sites that may produce adequate hillslope runoff to support Flood-MAR projects that collect and infiltrated local hillslope runoff resulting from heavy precipitation events.
- Extend the MCDA by incorporating more existing datasets and/or by updating existing coverages or adding new coverages.
- Use the existing MCDA to identify potential field sites, advancing the effort towards quantitative feasibility assessment of specific project options.
- For potential Flood-MAR sites that pass a desktop analysis, conduct a field assessment to identify areas that prove to be more favorable based on observed, local conditions. Field assessment can include one or more of these approaches:
    - Conduct geophysical surveys using electrical, radar, and/or seismic methods and/or exploratory drilling to collect geotechnical data and/or continuous cores.
    - Monitor rainfall on site and in areas contributing to drainage, and potentially measure runoff if channelized flow occurs, to better understand local patterns and magnitudes, with comparison to historic records.
    - Sample local wells, with relatively high temporal and spatial resolution, to understand local groundwater quality and variability of quality.
    - Test local infiltration conditions at a plot to field scale.
    - Estimate project cost based on expected size, method to be used for collection/retention, and other engineering and institutional considerations.

A path forward

There is statewide consensus that enhancing recharge could benefit many parts of California, and there are working examples of successful Flood-MAR projects. This study looked at the preliminary feasibility of Flood-MAR within Santa Clara County for expanding the County's recharge capacity. Flood-MAR could be a useful complement to the variety of tools and methods Valley Water currently uses to manage resources for its large and heterogeneous service area. Advancing a Flood-MAR program could help Valley Water stay at the forefront of innovation and stewardship, contribute to resource resilience, and address future water management challenges. Valley Water's existing MAR systems provide an average of 90,000 acre-feet of recharge per year, and related pond sets have capacity to recharge 1,500 to 7,700 acre-feet per year. Flood-MAR projects that collect hillslope runoff in other parts of California generate <1,000 acre-feet per year of annual recharge per site; while smaller in magnitude, such projects could augment Valley Water's existing MAR program. Flood-MAR remains developmental in many ways, requiring creativity, care, and persistence to implement successfully.

In summary, our findings suggest both that a Flood-MAR program may be institutionally viable for Valley Water and that physical potential for Flood-MAR may exist within Valley Water's service area. We present a set of tools Valley Water can use and suggest other actions it can take to further investigate Flood-MAR feasibility. Positive indications of institutional viability and Flood-MAR suitability will be necessary at each stage to justify Valley Water's continued exploration of Flood-MAR. We find both at this pre-feasibility stage.

Table ES-1. Preliminary assessment of considerations for implementing a Flood-MAR program in Santa Clara County, assuming an initial focus on distributed recharge projects that collect hillslope runoff.

PROGRAM GOALS AND OBJECTIVES	
What primary benefits are sought?	Enhancing water supply, advancing stakeholder engagement, and supporting climate change adaptation and resilience
What incidental benefits / co-benefits are sought, or would be desirable?	Reducing flood risk, preserving working landscapes, enhancing riparian habitat, maintaining / improving groundwater quality, and minimizing land subsidence potential
What negative impacts must be avoided?	Harm to fish/ecosystems, flooding, and property / infrastructure damage
What specific objectives would the program work towards in the short (and longer) term?	Developing appropriate incentive structures, legal / regulatory compliance support, and oversight for distributed projects
INTERNAL PROGRAM SUPPORT	
Where could the program reside in Valley Water?	Water Supply Planning and Conservation Unit (lead)
Who else would be involved internally?	Likely: staff from Groundwater Management Unit; Raw Water Operations Unit; Raw Water Field Operations & Pipeline Maintenance Unit; Hydrology, Hydraulics, and Geomorphology Unit; Watershed Policy and Planning Unit; Environmental Planning Unit; Financial Planning and Revenue Unit; Communications Unit; Treasury-Debt Management Unit; Office of the District Counsel; and related capital program design and implementation units
How would the program be funded?	Likely revenue from water charges, grant funding, and other appropriate Valley Water sources
PROGRAM FUNCTIONS	
1. Assessing source water options and availability	
When/where do high-magnitude flows occur in Valley Water's service area, and how are they expected to change in the future?	Hillslope runoff during heavy precipitation events, downstream of existing reservoirs and in unregulated watersheds (expected to increase in the future)
What flow / other requirements may affect the viability of potential source waters?	Valley Water's Fish and Aquatic Habitat Collaborative Effort (FAHCE) Program, Lake and Streambed Alteration Agreements (LSAAs), downstream water rights, fully appropriated stream system (FASS) designations, etc.
What storage / conveyance infrastructure would be needed to move potential source waters to potential recharge locations?	Ditches and culverts for collecting and conveying hillslope runoff to dedicated infiltration basins or lands, stream diversions for diverting flood water to off-stream lands
What legal permissions would be needed to access potential water sources?	Likely water right permits for capturing hillslope runoff, LSAAs and water rights for stream diversions, and related agreements with participating landowners / managers
2. Assessing areas suitable for recharge and recharge options	
What areas have moderate-to-high surface and subsurface suitability for Flood-MAR?	Areas with Flood-MAR Suitability Index ≥ 4 in the site-suitability tool (confirm through field investigation)

Which of these areas have compatible current land uses?	See site-suitability tool land use/land cover data set, other data to assess risks/benefits related to flooding, habitat, water quality
What are the water quality implications of recharging water in these areas?	Assess by comparing quality / contaminant profile data for potential source waters, soil / vadose zone, and groundwater
Which types of Flood-MAR projects, using which potential water sources, would be useful and feasible in these areas?	Initially, focus on distributed recharge projects that collect hillslope runoff and infiltrate it in dedicated recharge basins; but assess potential for other types of projects / water sources
3. External coordination and engagement needs	
Who owns and manages the land in potential recharge areas?	Private parties, especially growers, and other public agencies
Who holds or might be involved in acquiring water rights to potential water sources?	Valley Water may be best positioned to apply for water right permits from the State Water Resources Control Board (with landowner cooperation), especially to collect hillslope runoff
Who might be involved in acquiring other necessary permits and approvals?	Likely Valley Water (with cooperation from landowners, land managers, consultants, construction contractors, and others)
Who else might be interested in or be affected by Flood-MAR implementation?	Nearby landowners / tenants, downstream surface water users, domestic well users/groups, non-government organizations (NGOs), wildlife/other agencies
What partnerships, coordination, and other outreach/engagement will be needed to effectively implement / fund the program?	Potentially: private landowners/tenants, Santa Clara Valley Open Space Authority (OSA), Peninsula Open Space Trust (POST), Guadalupe-Coyote Resource Conservation District (GCRCD)
4. Incentives for Flood-MAR implementation on non-Valley Water property	
For what purposes might incentives be helpful or necessary?	To encourage recharge projects on non-Valley Water property.
What forms could incentives take?	Multiple options could be considered: direct payment, rebate, funding construction / land rental, and support for maintenance
What size / type of incentive may be needed to encourage sufficient participation?	Not clear; will require evaluation of interest, motivation, and other factors for potential program participants
How would incentives be administered?	Valley Water or a third-party certifier could administer incentives
5. Legal and regulatory compliance	
How would the program support / coordinate / fund permitting for Flood-MAR projects?	Valley Water may be better positioned to apply for water rights and other permits than individual landowners.
What level of environmental review would be required to support projects?	Projects may be eligible for CEQA suspension under Executive Order B-39-17 or Executive Order N-7-22.
What water rights would be needed to access potential water sources?	Temporary permits (180-day, 5-year) to support pilot efforts, standard permits for long-term operations.
What water quality permits / other approvals would projects need?	Potentially: NPDES Construction General Permit + Stormwater Pollution Prevention Plan, Section 404 permit, Section 401 Water Quality Certification
What species and ecosystem protections would affect projects?	Potentially: FAHCE, Lake and Streambed Alteration Agreements (LSAAs), CESA Incidental Take Permits, ESA Section 7 compliance
What cultural resources might be affected?	Depends on site (National Historic Preservation Act Section 106)

What other local, state, or federal permits or requirements might apply?	Santa Clara County Grading Permit, Valley Water District Act requirements
How would the program affect Valley Water's ability to meet its own statutory responsibilities and other legal obligations?	TBD — Would help meet SGMA requirements for sustainable groundwater management; projects could be selected to help meet FAHCE Settlement Agreement obligations
What funding sources are legally appropriate for Flood-MAR projects?	TBD — Would need to discuss with District Counsel's office and Finance
6. Tracking, oversight, evaluation, and adjustment	
How would the program provide effective oversight of Flood-MAR projects?	TBD — Would need to track project level recharge/infiltration effectiveness, water quality impacts, other benefits and risks
How would the program track its overall progress and effectiveness?	TBD — Would need to track program-level recharge/infiltration effectiveness, water quality impacts, other benefits and risks
What would happen if / when a project does not meet expectations?	TBD — Would need to require corrective measures when recharge is ineffective or the project creates substantial risks
How would the program learn / adjust?	TBD — Would need clear mechanisms for adaptive management

Table ES-2. Potential permitting and regulatory compliance needs for Flood-MAR projects

Category	Permit or approval	Agency	Applicability
Environmental review	CEQA compliance *Initial Study → (Mitigated) Negative Declaration or Environmental Impact Report*	Lead Agency	The project has the potential to affect the environment.
Water rights	Temporary water right permit *–180-day or 5-year*	State Water Resources Control Board: Division of Water Rights	The project involves temporary diversion and beneficial use of surface water (e.g., for pilot or while standard permit is pending).
	Standard water right permit	State Water Resources Control Board: Division of Water Rights	The project involves long-term diversion and beneficial use of surface water.
Water quality	CWA Section 401 Water Quality Certification	State Water Resource Control Board / Regional Water Quality Control Board	The project involves a federal permit or license for an activity that may result in a discharge of dredged or fill material into waters of the United States.
	CWA Section 404 Permit	U.S. Army Corps of Engineers	The project involves discharge of dredged or fill material into waters of the United States
	NPDES Construction General Permit + Storm Water Pollution Prevention Plan	State Water Resource Control Board / Regional Water Quality Control Board	The project disturbs one (1) or more acres of soil.
Species / ecosystems	Section 1602 Lake and Streambed Alteration Agreement (LSAA)	California Department of Fish and Wildlife	The project involves streambed alteration.
	CESA Section 2081 Incidental Take Permit	California Department of Fish and Wildlife	The project may affect state-listed species.
	ESA Section 7 compliance	U.S. Fish and Wildlife Service / National Marine Fisheries Service	The project involves a federal permit or license for an activity that may affect federally listed species.
Historic preservation	National Historic Preservation Act Section 106 compliance	State Office of Historic Preservation	The project involves construction near cultural resources.
Grading	Grading Permit	Santa Clara County	The project involves grading.

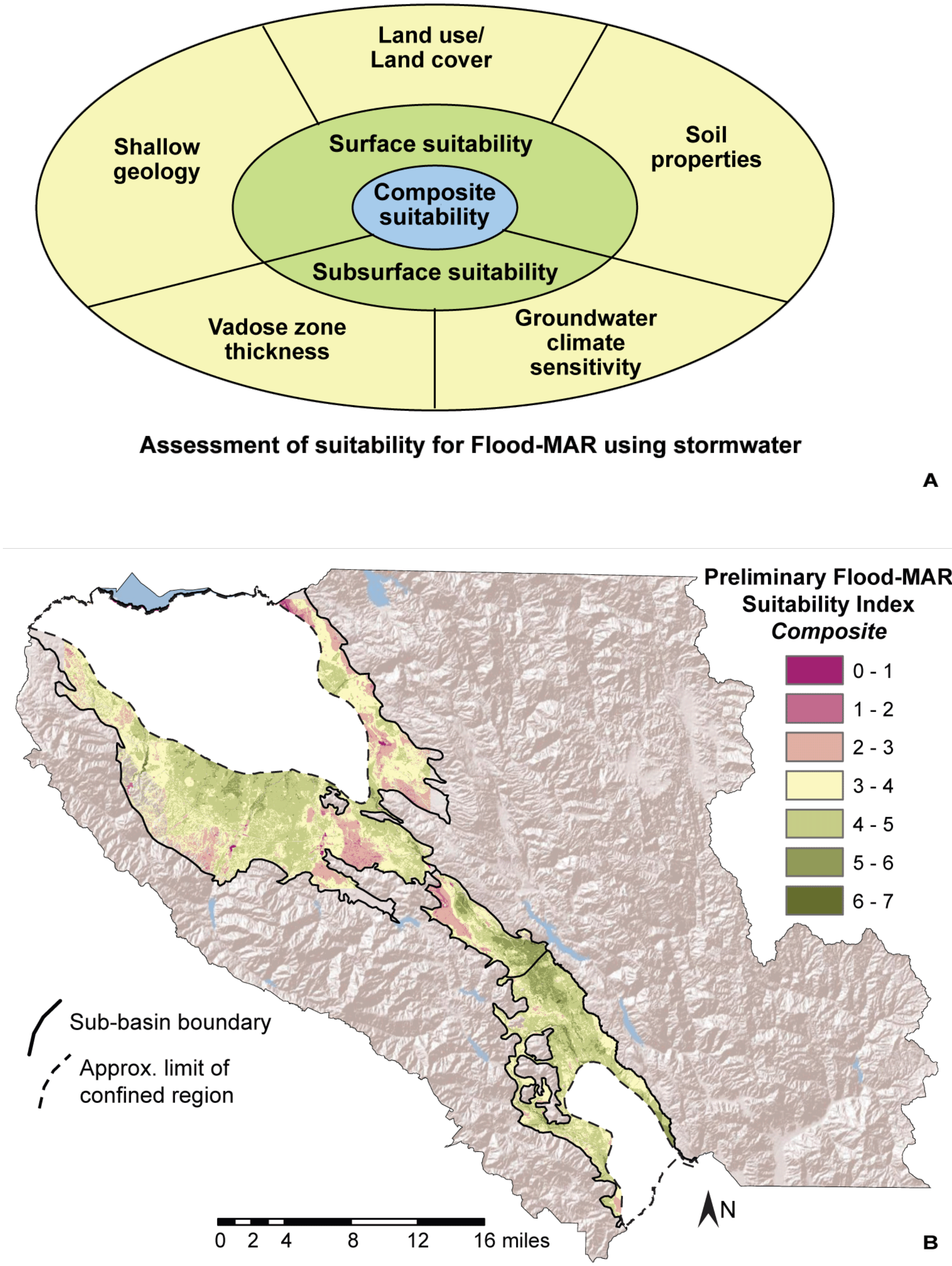

Figure ES-1. A. Overview of approach taken to combine factors for evaluation of suitability for Flood-MAR projects in Santa Clara County, using a geographic information system. The primary analysis used five factors, each weighted 20%. An alternative analysis added subsurface properties as used in regional groundwater models. **B.** Preliminary Flood-MAR suitability based on surface and subsurface factors, with values ≥4 indicating moderate to high suitability. White polygons with dashed boundaries denote areas having confined groundwater conditions.

Acknowledgements

This work was completed as part of the Water Resource Innovation Partnership (WRIP) between the University of California (UC) and Valley Water. UC participants are grateful to the many Valley Water personnel who contributed to this effort, including regular meetings and administrative oversight, review and preparation of datasets that were subsequently incorporated into the GIS, and Valley Water-UC workshops to exchange information, ideas, and opinions. The following individuals contributed to this effort, but UC personnel take responsibility for errors in fact or interpretation that may be found. We are especially grateful to S. Greene and J. Gurdak, who were primary technical and administrative leads, meeting with UC personnel on a regular basis, coordinating data delivery, explaining how Valley Water operates and introducing us to colleagues, discussing issues and interpretations in detail, and providing editorial guidance. K. Struve, A. Fulcher, B. Kassab, and E. Olson of Valley Water provided valuable technical and editorial feedback. V. de la Piedra helped to develop the WRIP and participated in numerous discussions, and C. Abuye and N. Murphy provided important data and editorial suggestions, and R. Harmon gave advice on data processing. Additionally, UC colleagues and Pajaro Valley Water Management Agency (PV Water) personnel shared insights and experiences that informed the report's findings. This work was supported by Valley Water (Contract #A4412X), the Gordon and Betty Moore Foundation (Award #9956), USDA/NIFA (Award #2021-67019-33595) and The Recharge Initiative (www.rechargeinitiative.org).

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I. Introduction

A. Background and motivation

Groundwater resources in California are increasingly stressed by rising demand, a changing climate, and shifting land use. Groundwater basins in central California are particularly vulnerable to growing groundwater demand and decreasing supply. Climate change is increasing both drought frequency and rainfall intensity. Urbanization and agricultural development tend to route water quickly off the landscape, limiting opportunities for infiltration and recharge, and long-term agricultural, industrial, and municipal needs are growing.

To help address these challenges, California's 2014 Sustainable Groundwater Management Act (SGMA) requires priority groundwater basins across the state to form groundwater sustainability agencies (GSAs), develop groundwater sustainability plans (GSPs), and implement practices to help maintain the supply and quality of water resources for coming generations. Santa Clara Valley Water District (Valley Water) is the GSA for the groundwater subbasins in Santa Clara County, which include the Santa Clara and Llagas subbasins. Both subbasins are listed as high priority by the Department of Water Resources (DWR). Valley Water has conjunctively managed groundwater and surface water in these basins for many decades.

The primary goal of this project is to explore the potential for implementation of flood-managed aquifer recharge (Flood-MAR) in Valley Water's service area to augment water supplies and provide additional benefits. In this report, we provide both a high-level evaluation of options and considerations for Flood-MAR in Valley Water's service area and a mapping tool to support preliminary evaluation of potentially suitable locations for Flood-MAR implementation. The report articulates key questions Valley Water will want to assess to determine whether a Flood-MAR program is legally, administratively, institutionally, and technically viable; identifies potential pathways for answering those questions; and provides recommended next steps for exploring Flood-MAR implementation in Valley Water's service area.

B. What is Flood-MAR?

Boosting groundwater recharge can help California communities make the most of increasingly variable precipitation and surface water resources.[1] Managed aquifer recharge (**MAR**) is a strategy that can improve both the supply and quality of groundwater[2] by routing excess surface water into aquifers using a variety of techniques. MAR intentionally replenishes aquifers for later recovery and use or to achieve other benefits.[3] Today, MAR is playing a growing role in maintaining groundwater as an effective drought reserve and in slowing or reversing the effects of years of unsustainable groundwater pumping.[4] However, as climate change stretches the limits of California's surface water storage and conveyance systems, making MAR even more imperative, finding suitable sources of water for recharge can be challenging.

Therefore, water managers are increasingly looking for underutilized water sources to support recharge. High-magnitude surface water flows that result from heavy precipitation events, mostly during the wet season, are expected to increase with continued climate change.[5] In many stream systems, these flows remain unappropriated (not already spoken for under existing water rights). They have historically been considered a nuisance or hazard, rather than a potentially useful water source. Therefore, most existing water infrastructure was not designed to retain these flows. They occur less frequently, sometimes with little warning, and capturing and storing sudden large volumes of water in surface reservoirs can be difficult and risky.

Flood-MAR aims to prepare for—and capitalize on—opportunities to collect and infiltrate high-magnitude surface water flows. **Box 1** explains how the State of California defines Flood-MAR. Essentially, Flood-MAR is multi-benefit MAR that can aid in flood-risk reduction and involves agricultural lands or other working landscapes. This broad definition encompasses a wide range of recharge-related activities, including flooding agricultural fields with high-magnitude streamflows during the wet season, floodplain restoration, and distributed recharge projects that collect and infiltrate hillslope runoff during heavy rainfall events.

Box 1. Flood-MAR defined

The California Department of Water Resources (DWR) defines Flood-MAR as "an integrated and voluntary resource management strategy that uses flood water resulting from, or in anticipation of, rainfall or snow melt for managed aquifer recharge…on agricultural lands and working landscapes."[6] DWR described the contours of Flood-MAR more fully in a 2018 white paper,[7] including the following key details:

- **Flood-MAR uses "flood water"** — DWR's conception of "flood water" includes both (1) "high flows resulting from the largest annual precipitation...or snowmelt events typically during the winter and spring" and (2) "flows released from flood control reservoirs ahead of rain or snowmelt to evacuate additional flood control space" when those flows are "above regulatory instream flow requirements." "Flood water" is a broad category that potentially encompasses non-urban stormwater. In fact, DWR describes Flood-MAR as "similar in concept to [urban] stormwater capture and reuse programs currently employed in many areas across the State."
- **Flood-MAR involves agricultural lands or working landscapes** — "Flood-MAR focuses on the ability to use direct spreading on large acreages of active agricultural land, fallowed land, working landscapes, dedicated recharge basins (new or existing), or open space. For active farmland, recharge water is anticipated to be applied during the non-irrigation season, using existing or additional irrigation equipment or conveyance facilities." DWR notes that working landscapes that may be suitable for Flood-MAR include, but are not limited to, "refuges, floodplains, and flood bypasses."
- **Flood-MAR can be implemented at multiple scales** — "Flood-MAR can be implemented at multiple scales, from individual landowners diverting flood water with existing infrastructure, to using extensive detention/recharge areas and modernizing flood protection infrastructure/operations."
- **Flood-MAR is an integrated, multi-benefit adaptation strategy** — Flood-MAR involves "better integration of flood and groundwater management" and is inherently "multi-benefit—providing flood risk reduction, drought preparedness, aquifer replenishment, ecosystem enhancement, and other potential benefits." As a result, Flood-MAR is a promising adaptation strategy that can "help address two of the most challenging elements of future climate changes: more flashy/intense flood flows, and longer/deeper droughts." To fulfill this promise, DWR emphasizes the importance of proactive, strategic, and integrated planning across scales and jurisdictions to ensure that "California's water systems… are resilient to changing conditions and able to adapt nimbly and dynamically to stressors."

Flood-MAR can be designed and implemented to achieve a range of desirable benefits like enhancing water supply, reducing flood risk, preserving working landscapes, improving water quality, and mitigating land subsidence.[8] The actual benefits achieved will differ from project to project and will depend on the Flood-MAR approach employed, as well as a host of other site- and project-specific factors.

C. Valley Water's setting and interest in exploring Flood-MAR

Valley Water is responsible for providing clean water, flood protection, and stewardship of streams for more than 2 million residents of Santa Clara County (**Figure I-1**). Water supplies in Valley Water's service area include groundwater, local and imported surface water, and recycled water. Groundwater pumping accounts for about 40% of water use, and groundwater levels are managed through a MAR program that recharges local and imported surface water supplies. Hydrologic conditions, water resource needs, and considerations for developing projects to enhance water supplies and other resources vary across the service area.

Although Valley Water already has an extensive MAR program, it is interested in understanding the potential for Flood-MAR to enhance water supply and water-supply resilience in Santa Clara County. Valley Water maintains 102 groundwater recharge ponds comprising 285 acres and 98 miles of controlled instream recharge (**Figure I-2**).[9] These recharge facilities have a total potential recharge capacity of about 143,500 acre-feet per year (AFY), although the actual amount recharged rarely approaches this maximum.[10] Valley Water's service area includes three groundwater management areas. In the northern part of Santa Clara County, the Santa Clara Subbasin consists of the Santa Clara Plain and Coyote Valley groundwater management areas; to the south lies the Llagas Subbasin, another groundwater management area (**Figure I-1**). This report refers to the three groundwater management areas as: the Santa Clara Plain, Coyote Valley, and Llagas Subbasin. Between 2010 and 2019, Valley Water's MAR program recharged an average of 88,500 AFY of imported and local surface water, including 53,000 AFY in the Santa Clara Plain principal aquifer, 13,500 AFY in the Coyote Valley, and 22,000 AFY in the Llagas subbasin.[11]

Valley Water defines four primary benefit zones (**Figure I-1B**): designated regions where the agency replenishes groundwater, monitors conditions, and protects groundwater from pollutants. Valley Water collects a groundwater production charge from owners and operators of groundwater wells in the benefit zones to fund agency activities that protect and replenish groundwater supplies.[12] The charge is based on the amount of groundwater pumped and the purpose of use (agricultural or non-agricultural). For fiscal year 2022–2023, agricultural groundwater production charges are $36.85 per AF in all benefit zones, whereas non-agricultural groundwater production charges, depending on the groundwater charge zone, range from $368.50 to $1,724.00 per AF.[13]

Despite a long history of major investments in improving water supply reliability, Valley Water faces water supply challenges during extended droughts, which are expected to become more frequent and intense with continued climate change.[14] Both imported and local surface water supplies are becoming less reliable as increasing precipitation extremes —wet and dry— test the limits of existing surface water storage and conveyance systems. Meanwhile, rising temperatures and a thirstier atmosphere are increasing the amount of water necessary to meet the same evapotranspiration needs and increasing reservoir evaporation, exacerbating short- and long-term imbalances between water supply and water demand.

To help meet these challenges, Valley Water has commenced planning efforts to pursue a "no regrets" package of water conservation and local stormwater collection and recharge projects it hopes will reduce county-wide water demand by ~10,000 AFY while increasing available water supplies by ~1,000 AFY by 2040.[15] This package could include Flood-MAR. Indeed, among the potential projects discussed in Valley Water's Water Supply Master Plan are "[f]looding or recharge on South County agricultural parcels during the winter months" targeted to increase supply by approximately 1,000 AFY.[16]

Flood-MAR projects on non-Valley Water land could expand recharge, enhancing water supply in Santa Clara County. Valley Water's existing MAR projects already occupy most of the best recharge sites on Valley Water property, and their recharge capacity generally exceeds the volume of water available for recharge from Valley Water's traditional sources during most years. However, there may be areas under private ownership, or under other public agencies' management jurisdictions, that may be suitable for recharge to take advantage of surface supplies from storms during all year types that are not currently accessible.

Flood-MAR also has the potential to help Valley Water meet other important responsibilities and goals. Depending on the type of project and sites selected, potential incidental or co-benefits of Flood-MAR may include:

- Supporting climate change adaptation,
- Increasing meaningful stakeholder engagement,
- Reducing flood risk,
- Maintaining or improving groundwater quality (especially where nitrate/ salts are a concern),
- Preserving working landscapes,
- Strengthening surface water-groundwater connections by raising groundwater levels in the vicinity of streams (and therefore baseflow),
- Enhancing groundwater dependent ecosystems, potentially including riparian habitat, and
- Minimizing the potential for resumed land subsidence in the Santa Clara Plain.

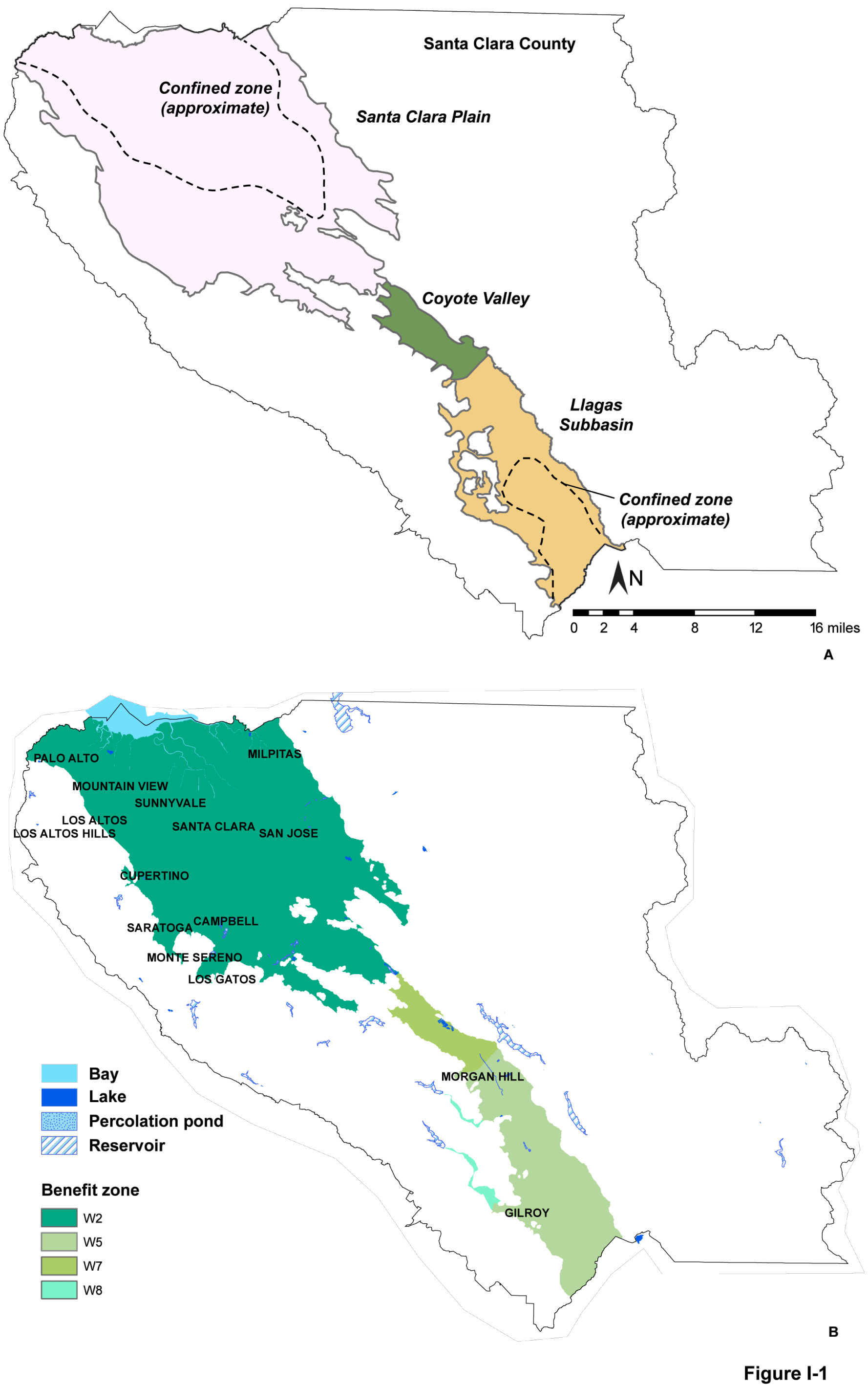


Figure I-1. Regional map, project area, basins, benefit zones, subregions and features.

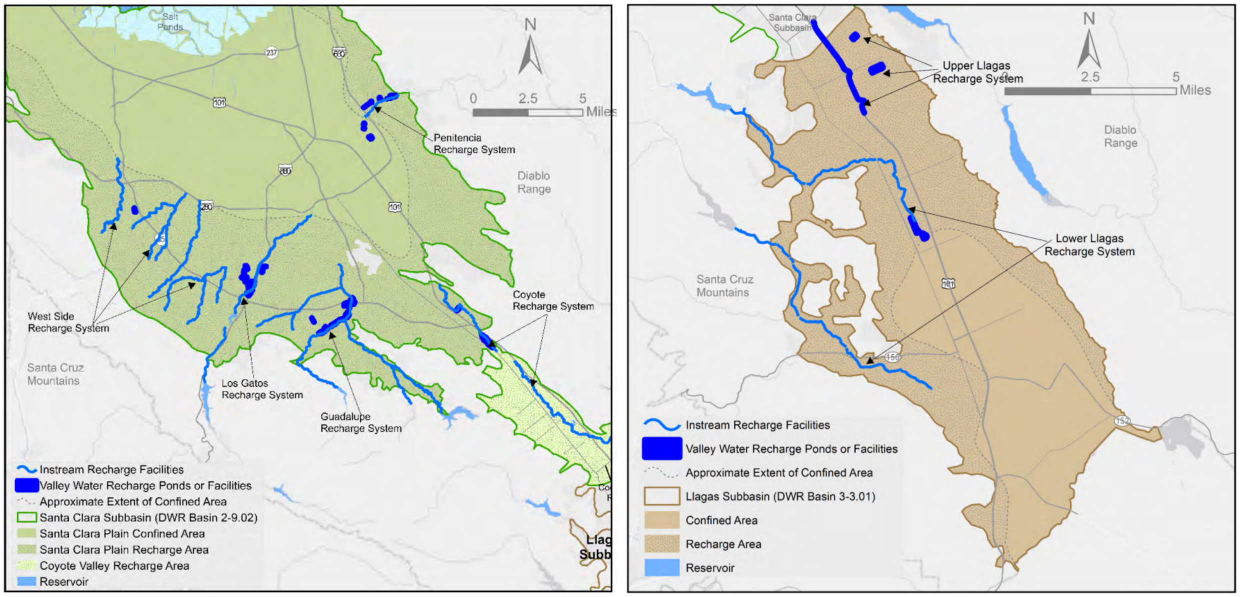


Figure I-2. Existing MAR facilities in the Santa Clara Subbasin, including the Coyote Valley, on the left, and the Llagas Subbasin, on the right.[17]

D. Project components and general approach

The Water Resource Innovation Partnership (WRIP) between Valley Water and a team of water researchers from the University of California (UC Water) has completed a pre-feasibility assessment of opportunities to develop a Flood-MAR program to help augment and diversify Valley Water's managed recharge program while generating additional benefits for the region.

The WRIP included two tasks. Task 1 was a high-level analysis of institutional, economic, management, legal, and policy considerations for a potential Flood-MAR program in Valley Water's service area. Part II of this report describes the results of that high-level analysis. Task 2 comprised spatial data compilation, interpretation, and analysis to assess where Flood-MAR objectives might be accomplished. The results of this work are summarized in Part III of this report. In addition to this report, our deliverables include a functional geographic information system (GIS) -based tool that can help Valley Water identify promising Flood-MAR sites for further evaluation and support the next stages in feasibility assessment, including evaluating costs, permitting, and other factors related to developing and operating a new program.

Valley Water is rich in data, knowledge, and expertise in groundwater management, including MAR. The WRIP is intended to supplement Valley Water's many capabilities by building capacity and stimulating innovative thinking that can help Valley Water continue to secure and sustain water resources for Santa Clara County into the future.

II. Options and considerations for a Potential Flood-MAR Program

A. Utility of a Flood-MAR program

A Flood-MAR program could be designed to strategically and adaptively steer Flood-MAR efforts in Santa Clara County. Identifying and prioritizing the best opportunities for Flood-MAR will require coordinated consideration of Flood-MAR options, potential collaborators, funding possibilities, and incentives.

For the purposes of this report, we make a distinction between *programs* and *projects*. We define a project as an individual MAR installation such as a defined infiltration basin, along with the defined set of actions that are necessary to successfully implement such an installation, such as planning, design, and permitting. In contrast, we define a program as the institutional umbrella under which a range of related projects could be carried out.

A Flood-MAR program could support short- and long-term planning, information gathering, evaluation, and adjustment. It could guide a modular or phased approach to Flood-MAR implementation that, for example, initially prioritizes certain project types or co-benefits. Because Valley Water may not have direct control of lands that present the best opportunities for Flood-MAR, a program could support effective implementation of projects on non-Valley Water property, including by providing appropriate incentive structures, outreach, and oversight to ensure that Flood-MAR projects individually and collectively meet expectations. A programmatic structure would also support internal collaboration within Valley Water, facilitate outreach and other forms of public engagement around Flood-MAR, foster economies of scale, leverage dispersed institutional expertise, and house institutional memory relevant to Flood-MAR.

To inform potential development of a Flood-MAR program at Valley Water, we use the remainder of Part II to outline three different approaches to Flood-MAR, discuss considerations for developing a Flood-MAR program, and summarize key takeaways regarding options and considerations for Flood-MAR.

B. Three approaches considered for Flood-MAR

We examined three types of Flood-MAR projects and their potential viability in Valley Water's service area:

1) Flooding agricultural fields or other open space with high-magnitude streamflows,
2) Floodplain restoration, and
3) Distributed recharge projects that collect and infiltrate local hillslope runoff resulting from heavy precipitation events.

1. Flooding agricultural fields

Flooding agricultural fields with high-magnitude streamflows, either local or imported, may be the most widely known approach to Flood-MAR. This approach is a subset of agricultural managed aquifer recharge (Ag-MAR)— "intentionally flooding fallow, dormant, or active cropland when excess surface water is available."[18] Ag-MAR is the focus of significant ongoing research[19] and is seen as a key tool for addressing unsustainable overdraft in some parts of California, particularly the Central Valley.

Risks to groundwater quality are generally higher for Ag-MAR than for other types of MAR. Ag-MAR has the potential to leach in-use and legacy contaminants (nitrogen, salts, etc.) from current agricultural practices and past agricultural use,[20] in addition to geogenic contaminants such as arsenic,[21] into the underlying groundwater. However, strategic Ag-MAR implementation can reduce water quality risks and even improve groundwater quality. For example, Ag-MAR implementation can prioritize sites where crops had low nitrogen needs, there is low to medium historical nitrogen loading, growers are currently using best practices for managing salts and applying fertilizers and other chemicals, and it is possible to recharge large volumes of relatively clean, high-magnitude flood flows.[22] Where groundwater quality is poor, high-volume Ag-MAR has the potential to actively improve groundwater quality through dilution. Care should be taken to meaningfully include those who could be affected by Ag-MAR in decision making processes. This includes communities that rely on shallow drinking water wells that could benefit from higher groundwater levels or experience negative impacts, such as short- or long-term water quality degradation.[23]

Whether this type of Flood-MAR would be feasible or cost effective in Santa Clara County is unclear. It would rely on diverting high flows from streams and moving that water to appropriate agricultural fields. However, the State currently considers many of the streams in Santa Clara County to be “fully appropriated” (see **Box 2**), which could make establishing new water rights to divert high flows from those streams challenging. Furthermore, Valley Water already has surface storage reservoirs and MAR facilities associated with the County’s most productive watersheds that may be able to accept some high flows.

To better understand the potential utility of this Flood-MAR approach in its service area, Valley Water could explore how often and where unappropriated high streamflows occur within its service area. Depending on the location of a potential Ag-MAR site relative to the source of high streamflows and existing conveyance infrastructure, new permanent or temporary infrastructure may be needed to convey water to it.[24] Existing infrastructure that could, in theory, be used to support Ag-MAR may have limited capacity to carry flood flows, since such infrastructure was generally designed to move and distribute water under more moderate flow conditions to meet irrigation demands. On the other hand, due to the intermittent nature of water availability, it may be cost-effective for some Ag-MAR implementers whose property is close to a source of high flows to rely in part on temporary infrastructure and rented equipment.

Example: Terranova Ranch and the larger McMullin On-Farm Flood Capture Expansion Project (McMullin) increase conveyance capacity from the Kings River to farmland, grazing land, and fallow land in an effort to grapple with flooding during times of excess water, augment groundwater recharge and in-lieu recharge across the region, and address the impacts of climate change.[25] Terranova and McMullin target both private and public properties where economic productivity won’t be negatively impacted by temporary flood conditions.[26] As a pilot study, Terranova diverted roughly 14 AF per day to 1,000 acres of farmland growing tomatoes, wine grapes, alfalfa, pistachios, olives, walnuts, and almonds, though McMullin plans to expand the program's capacity to divert roughly 1,000 AF per day to more than 15,000 acres.[27] Terranova’s estimated costs for the pilot were $36 per AF.[28]

2. Floodplain restoration

Another approach to Flood-MAR is floodplain restoration. Whereas the other two approaches we discuss here involve actively diverting high flows, floodplain restoration projects take a different tack. When portions of artificial levees—constructed to keep flood water out of the floodplain—are removed or set back, high flows can once again access these areas, bringing sediment, nutrients, and water that help to rebuild lost ecosystem function.

Floodplain restoration projects can have a broad suite of potential benefits, including for riparian ecosystems and habitat, and may help reduce downstream flooding. Due to the relatively unconstrained nature of water flow into areas where levees have been removed, it may not be possible to measure the volume of water spread or infiltrated. However, measurements of groundwater levels in nearby wells can be used to derive estimates and demonstrate benefits.

A key consideration for this approach for Valley Water is that much of Santa Clara County is densely populated, so there may be limited areas in which this approach could be used. Valley Water could explore whether there are areas in the County where levees currently exist, levee breaches or setbacks would likely have recharge benefits, and floodplain restoration efforts would be unlikely to exacerbate local flood impacts.

Example: The Lower Cosumnes River Floodplain Restoration Project in the eastern Sacramento-San Joaquin Delta alters or removes levees to reintroduce natural flooding regimes and promote habitat restoration and enhancement, though the program previously used active management measures like wetland construction and hand-planting of native plant species.[29] Although recharge is not its primary goal, the 50,000-acre, landscape-scale public-private partnership (initiated by The Nature Conservancy in 1985) slows and detains floodwaters, allowing them to infiltrate and augment groundwater.[30]

3. Distributed recharge projects that collect hillslope runoff

A third approach to Flood-MAR is developing an array of relatively small (~100–1,000 AFY) recharge projects, each collecting drainage from 100s to 1,000s of acres, that collect and infiltrate local stormwater in locations that are especially well suited for recharge. Targeted incentives may be especially important for this Flood-MAR approach. For example, a program in the Pajaro Valley incentivizes individual landowners and Pajaro Valley Water Management Agency (PV Water) to support projects that collect some of the hillslope runoff from significant precipitation events and route it through ditches, culverts, and a sediment detention basin before the runoff flows into a dedicated infiltration basin.

Given the geography, hydrology, and existing utilization of other types of MAR in Valley Water's service area, distributed recharge projects that collect hillslope runoff are likely the most promising type of Flood-MAR for Valley Water to focus on initially. This approach would complement Valley Water's existing MAR program by tapping a currently underutilized water source and expanding recharge efforts on lands owned and managed by others. Routing hillslope runoff from heavy precipitation events into local, dedicated infiltration basins would enable site-appropriate design and the ability to incorporate soil amendments tailored to best protect or enhance groundwater quality. As we note in **Part III.D**, Valley Water could assess potential water supplies for this Flood-MAR approach by assessing drainage areas and estimating runoff to identify especially promising areas for implementation within its service area.

Example: PV Water operates a recharge net metering (ReNeM) program that uses performance-based financial incentives to encourage groundwater recharge at individual project sites, typically on private property. Specifically, the program uses ditches and canals to divert hillslope runoff generated by heavy precipitation events to infiltration basins where the collected runoff can help recharge groundwater.[31] PV Water initiated its ReNeM program as a pilot study in 2016 and made the program permanent in 2021.[32] The agency aims to scale the program to eventually infiltrate approximately 1,000 AFY; together, the three currently deployed projects collectively infiltrate about one-third of this volume. **Figure II-1** shows the infiltration basin for one of these projects.

Figure II-1. Hillslope-runoff collection and infiltration project at Bokariza-Drobac Ranch, showing the 4.3 acre infiltration basin during dry conditions (top) and wet conditions (bottom). Photo credit: A. Fisher (UCSC).

C. Considerations for developing a Flood-MAR program

If Valley Water decides to pursue Flood-MAR, establishing a Flood-MAR program would be helpful for coordinating, prioritizing, and ensuring effective implementation of Flood-MAR projects regardless of the type, scale, or number of projects envisioned. A Flood-MAR program could be especially critical for providing the incentive structure and oversight necessary to support the Flood-MAR approach we have identified as most promising for early implementation in Valley Water's service area: distributed recharge projects that collect hillslope runoff.

Below, we discuss considerations for developing a Flood-MAR program within Valley Water and related questions, grouped into three main categories:

1) program goals and objectives,
2) internal program support, and
3) program functions.

Note that many considerations overlap with or influence one another. Additionally, some considerations are likely shared with other Valley Water programs, enabling Valley Water to straightforwardly leverage that existing expertise in the Flood-MAR context. Other considerations may be largely uncharted territory, creating the opportunity for state-level leadership and innovation by Valley Water.

1. Program goals and objectives

A Flood-MAR program's goals inform all other aspects of the program, including what types of projects, scales of recharge, recharge locations, partnerships, and incentive structures are likely to be necessary or helpful. Goals should be based on the benefits sought, or that would be desirable, as well as the negative impacts it needs to avoid. In addition to broad goals, a Flood-MAR program needs specific objectives. For example, initial objectives for Valley Water might include identifying program design features and functions that would support an early focus on distributed recharge projects that collect hillslope runoff. We summarize key questions associated with program goals and objectives—and our preliminary assessment of answers for Valley Water—in **Table II-1**.

Table II-1. Preliminary assessment of considerations related to goals and objectives for a potential Flood-MAR program in Santa Clara County, assuming an initial focus on distributed recharge projects that collect hillslope runoff.

PROGRAM GOALS AND OBJECTIVES	
What primary benefits are sought?	Enhancing water supply, advancing stakeholder engagement, and supporting climate change adaptation and resilience
What incidental benefits / co-benefits are sought, or would be desirable?	Reducing flood risk, preserving working landscapes, enhancing riparian habitat, maintaining / improving groundwater quality, and minimizing land subsidence potential
What negative impacts must be avoided?	Harm to fish/ecosystems, flooding, and property / infrastructure damage
What specific objectives would the program work towards in the short (and longer) term?	Developing appropriate incentive structures, legal / regulatory compliance support, and oversight for distributed projects

2. Internal program support

Developing and operating a Flood-MAR program requires sufficient internal program support. We summarize key considerations related to internal program support in **Table II-2**, noting our preliminary assessment of these considerations for Valley Water.

Where a Flood-MAR program is housed within an agency will influence the program's goals, functions, and design. This will be especially true in large agencies whose subcomponents are compartmentalized, with relatively distinct, well-defined functions, funding streams, and boundaries. Valley Water is such an agency. Based on discussions with staff, a Flood-MAR program would likely be spearheaded by the Water Supply Planning and Conservation Unit, within the Water Supply Division of its Water Utility business area. This placement reflects Flood-MAR's potential to enhance water supply. Other units would likely provide support, as summarized in **Table II-2**.

The program could be funded with revenue from water charges, supplemented by grants from agencies such as California's Department of Water Resources and the U.S. Department of Agriculture's Natural Resources Conservation Service. If a Flood-MAR program proves feasible from a water supply lens, Valley Water might consider prioritizing projects likely to generate multiple benefits. For example, some Flood-MAR projects could also help meet Watersheds goals and responsibilities by enhancing habitat. Multi-benefit projects might make program operations, program decision making, and project permitting more complex, but it could also enhance opportunities to secure external funding.

Table II-2. Preliminary assessment of considerations related to internal program support for a potential Flood-MAR program in Santa Clara County, assuming an initial focus on distributed recharge projects that collect hillslope runoff.

INTERNAL PROGRAM SUPPORT	
Where could the program reside in Valley Water?	Water Supply Planning and Conservation Unit (lead)
Who else would be involved internally?	Likely: staff from Groundwater Management Unit; Raw Water Operations Unit; Raw Water Field Operations & Pipeline Maintenance Unit; Hydrology, Hydraulics, and Geomorphology Unit; Watershed Policy and Planning Unit; Environmental Planning Unit; Financial Planning and Revenue Unit; Communications Unit; Treasury-Debt Management Unit; Office of the District Counsel; and related capital program design and implementation units
How would the program be funded?	Likely revenue from water charges, grant funding, and other appropriate Valley Water sources

3. Program functions

A Flood-MAR program needs to perform a range of functions to enable coordinated and effective project implementation. In **Table II-3**, we summarize key considerations related to program functions and our preliminary assessment of these considerations for Valley Water, organized into 6 main categories: (1) assessing source water options and availability, (2) assessing areas suitable for recharge and recharge options, (3) external coordination and engagement needs, (4) incentives for Flood-MAR implementation on land not owned by Valley

Water, (5) legal and regulatory compliance, and (6) tracking, oversight, evaluation, and adjustment. We highlight several considerations in more depth below.

Table II-3. Preliminary assessment of considerations related to program functions for a potential Flood-MAR program in Santa Clara County, assuming an initial focus on distributed recharge projects that collect hillslope runoff.

PROGRAM FUNCTIONS	
1. Assessing source water options and availability	
When/where do high-magnitude flows occur in Valley Water's service area, and how are they expected to change in the future?	Hillslope runoff during heavy precipitation events, downstream of existing reservoirs and in unregulated watersheds (expected to increase in the future)
What flow / other requirements may affect the viability of potential source waters?	Valley Water's Fish and Aquatic Habitat Collaborative Effort (FAHCE) Program, Lake and Streambed Alteration Agreements (LSAAs), downstream water rights, fully appropriated stream system (FASS) designations, etc.
What storage / conveyance infrastructure would be needed to move potential source waters to potential recharge locations?	Ditches and culverts for collecting and conveying hillslope runoff to dedicated infiltration basins or lands, stream diversions for diverting flood water to off-stream lands
What legal permissions would be needed to access potential water sources?	Likely water right permits for capturing hillslope runoff, LSAAs and water rights for stream diversions, and related agreements with participating landowners / managers
2. Assessing areas suitable for recharge and recharge options	
What areas have moderate-to-high surface and subsurface suitability for Flood-MAR?	Areas with Flood-MAR Suitability Index ≥ 4 in the site-suitability tool (confirm through field investigation)
Which of these areas have compatible current land uses?	See site-suitability tool land use/land cover data set, other data to assess risks/benefits related to flooding, habitat, water quality
What are the water quality implications of recharging water in these areas?	Assess by comparing quality / contaminant profile data for potential source waters, soil / vadose zone, and groundwater
Which types of Flood-MAR projects, using which potential water sources, would be useful and feasible in these areas?	Initially, focus on distributed recharge projects that collect hillslope runoff and infiltrate it in dedicated recharge basins; but assess potential for other types of projects / water sources
3. External coordination and engagement needs	
Who owns and manages the land in potential recharge areas?	Private parties, especially growers, and other public agencies
Who holds or might be involved in acquiring water rights to potential water sources?	Valley Water may be best positioned to apply for water right permits from the State Water Resources Control Board (with landowner cooperation), especially to collect hillslope runoff
Who might be involved in acquiring other necessary permits and approvals?	Likely Valley Water (with cooperation from landowners, land managers, consultants, construction contractors, and others)
Who else might be interested in or be affected by Flood-MAR implementation?	Nearby landowners / tenants, downstream surface water users, domestic well users/groups, non-government organizations (NGOs), wildlife/other agencies

What partnerships, coordination, and other outreach/engagement will be needed to effectively implement / fund the program?	Potentially: private landowners/tenants, Santa Clara Valley Open Space Authority (OSA), Peninsula Open Space Trust (POST), Guadalupe-Coyote Resource Conservation District (GCRCD)
4. Incentives for Flood-MAR implementation on non-Valley Water property	
For what purposes might incentives be helpful or necessary?	To encourage recharge projects on non-Valley Water property.
What forms could incentives take?	Multiple options could be considered: direct payment, rebate, funding construction / land rental, and support for maintenance
What size / type of incentive may be needed to encourage sufficient participation?	Not clear; will require evaluation of interest, motivation, and other factors for potential program participants
How would incentives be administered?	Valley Water or a third-party certifier could administer incentives
5. Legal and regulatory compliance	
How would the program support / coordinate / fund permitting for Flood-MAR projects?	Valley Water may be better positioned to apply for water rights and other permits than individual landowners.
What level of environmental review would be required to support projects?	Projects may be eligible for CEQA suspension under Executive Order B-39-17 or Executive Order N-7-22.
What water rights would be needed to access potential water sources?	Temporary permits (180-day, 5-year) to support pilot efforts, standard permits for long-term operations.
What water quality permits / other approvals would projects need?	Potentially: NPDES Construction General Permit + Stormwater Pollution Prevention Plan, Section 404 permit, Section 401 Water Quality Certification
What species and ecosystem protections would affect projects?	Potentially: FAHCE, Lake and Streambed Alteration Agreements (LSAAs), CESA Incidental Take Permits, ESA Section 7 compliance
What cultural resources might be affected?	Depends on site (National Historic Preservation Act Section 106)
What other local, state, or federal permits or requirements might apply?	Santa Clara County Grading Permit, Valley Water District Act requirements
How would the program affect Valley Water's ability to meet its own statutory responsibilities and other legal obligations?	TBD — Would help meet SGMA requirements for sustainable groundwater management; projects could be selected to help meet FAHCE Settlement Agreement obligations
What funding sources are legally appropriate for Flood-MAR projects?	TBD — Would need to discuss with District Counsel's office and Finance
6. Tracking, oversight, evaluation, and adjustment	
How would the program provide effective oversight of Flood-MAR projects?	TBD — Would need to track project level recharge/infiltration effectiveness, water quality impacts, other benefits and risks
How would the program track its overall progress and effectiveness?	TBD — Would need to track program-level recharge/infiltration effectiveness, water quality impacts, other benefits and risks
What would happen if / when a project does not meet expectations?	TBD — Would need to require corrective measures when recharge is ineffective or the project creates substantial risks
How would the program learn / adjust?	TBD — Would need clear mechanisms for adaptive management

a. Considerations related to water rights for recharge

One important function of a Flood-MAR program would be to identify the legal clearances, such as a water right permit, needed to divert a potential water source and how best to approach obtaining those clearances for individual projects.

Acquiring a water right permit to divert and use high-magnitude stream flows (or hillslope runoff) for groundwater recharge is not necessarily easy or straightforward. First, the State Water Resources Control Board (State Water Board) simply has less experience considering permit applications that seek to divert sporadic flood flows or to recharge any source of water in order to serve non-extractive beneficial uses, such as reducing the development of "undesirable results" under SGMA[33] (like significant and unreasonable land subsidence, seawater intrusion, degradation of water quality, or depletion of interconnected surface waters). Likewise, GSAs and other local water management agencies across the state have little experience to date applying for water right permits like these. Additionally, the regulatory landscape is changing in real time as the Governor directs the State Water Board and other agencies to expedite permitting of recharge projects to "maximize the extent to which winter precipitation recharges underground aquifers."[34]

The California Legislature and the State Water Board have both taken steps in recent years to try to better support water right permitting for these types of projects. In 2019, the Legislature added a five-year temporary permit option (in addition to the existing 180-day temporary permit option)[35] as a bridge to a standard permit, and the State Water Board developed a streamlined administrative process for those pursuing a standard permit to divert water for recharge during "high flow conditions" or "imminent threat" of flooding,[36] summarized in **Table II-4**.[37] Both options are open only to groundwater sustainability agencies or other "local agencies" under SGMA, and each defines slimmed down requirements for water availability analysis (used to demonstrate that water is available to be appropriated; see also **Box 2** regarding fully appropriated stream systems) that are nonetheless intended to provide adequate protection for fish and other wildlife and other water users. To help potential MAR proponents understand permitting options and requirements associated with water rights for recharge, the State Water Board created several webpages,[38] including one that lists all applications for temporary permits for underground storage received since 2016,[39] and fact sheets. One fact sheet discusses the distinctions between flood-control projects that result in incidental recharge—which do not require a water right—and other recharge activities—which do.[40] A second fact sheet explains what California's requirement for "beneficial use" means in the context of water rights for recharge and provides guidance on demonstrating / accounting for different beneficial uses of recharged water.[41]

Despite these efforts, important issues related to water right permitting for recharge projects remain unclear, creating stumbling blocks for those trying to implement certain types of recharge projects. To date, only two applications have been submitted for 5-year temporary permits.[42] Both identify extractive beneficial uses (agricultural irrigation). One, submitted on August 24, 2022, was approved on January 11, 2023,[43] while the other application, submitted on November 16, 2022, is still pending as of February 21, 2023.[44] Because, to date, few entities have sought to include non-extractive uses in their water right applications (or to pursue entirely non-extractive beneficial uses), it is not clear how an applicant might demonstrate that the beneficial use is accruing or what level of proof the State Water Board will expect an applicant to provide.

Similarly, to date, there are no examples of applications to support a small recharge project that collects and infiltrates hillslope runoff, including those in the Pajaro Valley. Therefore, it is unclear what the State Water Board will require of successful applicants for such projects and whether there might be circumstances under which a water right would not be needed to implement this type of project.

We expect greater clarity to emerge as more Flood-MAR project proponents submit, and the State Water Board responds to, water right permit applications that address a wider range of water source characteristics and post-recharge purposes of use.

Table II-4. Comparison of traditional permit options and newer permit options (outlined with a heavy black line) tailored to support groundwater recharge projects under SGMA.[45]

	Temporary Permits		**Standard Permits**	
Permit pathway	**Temporary Permit** (urgent need)	**Temporary Permit for Diversion to Underground Storage**	**Streamlined Permit for Groundwater Recharge**	**Standard Permit**
Authority	Water Code §§ 1425–1431	Water Code §§ 1433–1433.6	Administrative adjustment to standard permit process	Water Code §§ 1375–1410.2
Duration	Up to 180 days *(revocable; no priority)*	Up to 5 years *(revocable; no priority)*	Permanent authorization *(secures a priority date)*	Permanent authorization *(secures a priority date)*
Eligibility	"Any person" demonstrating "an urgent need to divert and use [surface] water" for beneficial use	A GSA (or other "local agency" under SGMA) proposing "diversion of surface water to underground storage for beneficial use that advances the sustainability goal of a groundwater basin"	A GSA (or other "local agency" under SGMA) proposing diversions of high flows between Dec. 1 and Mar. 31 to underground storage for beneficial use	"Any person" proposing to divert and use surface water for beneficial use
Water availability analysis	Simplified	Simplified *(simplified analysis OK if diversion would occur only when flow exceeds flood stage)*	Streamlined *(availability assumed when defined "high flow conditions" or "imminent threat of flood conditions" exist)*	Standard *(must demonstrate reasonable likelihood water is available to appropriate)*
CEQA review	Required *(unless suspended by executive order)*	Must be completed before applying	Must be completed before applying	Required
Required findings	• No injury to other legal water users • No unreasonable effects on fish/wildlife • In the public interest • Urgent need	• No injury to other legal water users • No unreasonable effects on fish/wildlife • In the public interest • Consistent with GSP, if applicable	• No injury to other legal water users • No unreasonable effects on fish/wildlife • In the public interest	• No injury to other legal water users • No unreasonable effects on fish/wildlife • In the public interest
Guidance on "Best Use"	For pilot projects *or when applicants need to get a diversion authorized quickly*	As a bridge to get a recharge project up and running while a streamlined / standard application is in process	For qualifying recharge projects seeking permanent authorization	For permanent recharge projects that don't qualify under the streamlined pathway

Box 2. Fully appropriated stream systems and new water right permits

Another set of challenges arises if the proposed water source is part of a fully appropriated stream system (FASS). Stream systems that have been designated as fully appropriated year round are generally off limits for new water rights.[46] Additionally, an application won't be accepted if it proposes to divert water from a seasonally fully appropriated stream during the season it is deemed fully appropriated. A water right applicant can request the State Water Board to revise its FASS determination through a petition process that requires an additional $10,000 fee and can take several years to complete before a related permit application can be processed.[47] In Santa Clara County, the portion of Uvas Creek upstream of Uvas Dam, Moody Gulch, and Alamitos Creek have been declared fully appropriated year round, while Casey Gulch Creek, Coyote River, Guadalupe Creek, and the remainder of Uvas Creek have been declared fully appropriated seasonally.[48]

We anticipate that Valley Water, rather than individual landowners, is better positioned to apply for water right permits that may be necessary for Flood-MAR projects on non-Valley Water property. First, Valley Water has extensive experience applying for and managing water rights and the expertise and resources needed to do so efficiently. Second, the water right permitting options that are tailored to MAR are only available to GSAs or other local water agencies under SGMA. Third, CEQA is currently suspended for local or state agencies seeking certain temporary permits for capturing water from high-runoff events for local recharge. Finally, having Valley Water apply for the permit helps to assure that project goals remain aligned with the overall Flood-MAR program and priorities.[49]

b. Considerations related to Recharge Net Metering incentives

Valley Water could support Flood-MAR implementation in its service area by directly constructing and maintaining Flood-MAR projects on land it owns or acquires, collaborating on projects sited on other agencies' lands, and/or creating incentives for others to implement Flood-MAR projects on non-Valley Water land.

Recharge net metering (ReNeM) is an incentive structure that encourages distributed groundwater recharge at individual project sites located on private or public land by compensating rechargers for project performance—the net increase in infiltration associated with the project's operation.[50] This compensation is intended to offset the operation, maintenance, and opportunity costs rechargers incur as a result of maintaining hillslope runoff collection systems and infiltration basins on their properties. Under PV Water's ReNeM program, incentives are structured as partial rebates against groundwater production charges (known as groundwater augmentation charges) based on the volume of water infiltrated on an annual basis. At present, all recharge projects operated through ReNeM were developed for resource benefit (non-regulatory) purposes.

For a ReNeM program to successfully support a cooperative partnership between parties, it is crucial that the parties share a mutual understanding of the incentive structure and agreement. This includes establishing a mutually-agreed upon manner for determining the incentive payment[51]—in the case of ReNeM, an agreed-upon valuation of the water that is infiltrated. Valley Water could support this mutual understanding in several ways. A contract between participants or similar tool can establish a list of expectations and understandings that support a trustworthy and reliable partnership. Ideally, this tool would also detail the understood method for arbitrating requested changes to the program or program disputes. This tool should also clarify the method for establishing the incentive amount—in the case of ReNeM, a means of establishing the amount of water infiltrated in order to calculate the payment amount.

One avenue for building trust in a ReNeM program is by incorporating a third-party certifier (TPC) who is delegated key responsibilities in order to minimize conflict and demonstrate the trustworthiness of the program. In the case of ReNeM, the TPC could be responsible for (or contribute to) ensuring the reliability of the measurements upon which payments to rechargers are predicated, overseeing incentive payments to rechargers, evaluating program performance, preparing reports, and determining when adjustments are needed. To ensure the TPC builds trust into the program, the TPC entity must have both the expertise and the capacity necessary to carry out the responsibilities it has been delegated.

Though incentivizing private participation in Flood-MAR seems promising in concept, it is not without challenges that Valley Water would need to navigate successfully. For example, differences in the physical and institutional contexts of PV Water and Valley Water may affect the potential viability of a ReNeM-like incentive structure for Flood-MAR in Valley Water's service area. Most importantly, groundwater production charges for agricultural water users are more than seven times higher in the Pajaro Valley ($282 per AF[52]) than in Valley Water's service area (~$37 per AF[53]), reducing the potential motivational power of a rebate on those charges. Another useful comparison is the cost of incentive compared to the next potential water source.

c. Considerations related to legal and regulatory compliance for small, distributed recharge projects

To be effective, a Flood-MAR program would likely need to support and coordinate permitting for individual Flood-MAR projects. Most Flood-MAR projects will require permits or other approvals from multiple local, state, and/or federal agencies. **Table II-3** summarizes many of these permitting and approval requirements, and **Table II-5** provides additional information about when they might come into play.

This support and coordination role would be especially important for smaller, distributed projects that collect hillslope runoff, since individual rechargers may lack the resources and bandwidth to identify and address all regulatory requirements on their own. In particular, Valley Water has—and would further build—essential institutional knowledge that could both aid individual project development and contribute to economies of scale. Therefore, Valley Water may be better positioned than individual landowners to apply for the regulatory approvals needed for particular projects. Additionally, Valley Water can explore possibilities for addressing some regulatory requirements (such as environmental review) on a programmatic-level for similar projects (such as distributed stormwater recharge projects implemented under a ReNeM-like incentive structure).

Table II-5. Potential permitting and regulatory compliance needs for Flood-MAR projects.

Category	Permit or approval	Agency	Applicability
Environmental review	CEQA compliance *Initial Study → (Mitigated) Negative Declaration or Environmental Impact Report*	Lead Agency	The project has the potential to affect the environment.
Water rights	Temporary water right permit *–180-day or 5-year*	State Water Resources Control Board: Division of Water Rights	The project involves temporary diversion and beneficial use of surface water (e.g., for pilot or while standard permit is pending.
	Standard water right permit	State Water Resources Control Board: Division of Water Rights	The project involves long-term diversion and beneficial use of surface water.
Water quality	CWA Section 401 Water Quality Certification	State Water Resource Control Board / Regional Water Quality Control Board	The project involves a federal permit or license for an activity that may result in a discharge of dredged or fill material into waters of the United States.
	CWA Section 404 Permit	U.S. Army Corps of Engineers	The project involves discharge of dredged or fill material into waters of the United States
	NPDES Construction General Permit + Storm Water Pollution Prevention Plan	State Water Resource Control Board / Regional Water Quality Control Board	The project disturbs 1 or more acres of soil.
Species / ecosystems	Section 1602 Lake and Streambed Alteration Agreement (LSAA)	California Department of Fish and Wildlife	The project involves streambed alteration.
	CESA Section 2081 Incidental Take Permit	California Department of Fish and Wildlife	The project may affect state-listed species.
	ESA Section 7 compliance	U.S. Fish and Wildlife Service / National Marine Fisheries Service	The project involves a federal permit or license for an activity that may affect federally listed species.
Historic preservation	National Historic Preservation Act Section 106 compliance	State Office of Historic Preservation	The project involves construction near cultural resources.
Grading	Grading Permit	Santa Clara County	Project involves grading

D. Key takeaways regarding options and considerations

In Part II, we discussed the utility of a Flood-MAR program, described three approaches to Flood-MAR, and summarized considerations for developing a Flood-MAR program, which we have distilled into **Tables II-1, II-2, and II-3**. Below, we highlight key takeaways for Valley Water.

- Valley Water's existing MAR facilities already occupy many of the best recharge sites in Santa Clara County (County), and their recharge capacity exceeds the volume of water available for recharge from Valley Water's traditional sources in many years. However, the mapping tool discussed below indicates there may be areas suitable for Flood-MAR, pending further evaluation.

- If Valley Water pursues distributed Flood-MAR projects that collect and infiltrate local hillslope runoff, organizing Flood-MAR efforts at a programmatic level will likely be more efficient and effective than pursuing individual projects with less coordination.

- Valley Water could partner with other landowners and managers to develop Flood-MAR projects, a process it could facilitate with incentives.

- One potential model for providing incentives for Flood-MAR implementation is Recharge Net Metering (ReNeM), a rebate-based incentive structure developed through a collaborative effort in nearby Pajaro Valley. However, differences in the physical and institutional contexts of the two areas may affect the potential viability of a ReNeM-like incentive structure for Flood-MAR in Valley Water's service area. For example, groundwater production charges for agricultural water users are more than seven times higher in the Pajaro Valley (~$282 per AF) than in Valley Water's service area (~$37 per AF), reducing the potential motivational power of a rebate on those charges.

- Most permitting needs for Flood-MAR projects, summarized in **Table ES-2**, will likely be familiar to Valley Water because of its extensive experience with MAR implementation. However, Valley Water would need to decide how to address permitting needs for small Flood-MAR projects that are distributed across its service area on non-Valley Water property. Valley Water may be best positioned to pursue most permits and other regulatory approvals for such projects.

- It may make sense for Valley Water, rather than individual landowners, to apply for any necessary water right permits for Flood-MAR projects, including those on private land.

Considerable work is still needed to develop and implement a successful Flood-MAR program at Valley Water. Flood-MAR remains developmental in many ways, and Valley Water could continue to evaluate whether a Flood-MAR program could help increase water resilience in its service area, in part supported by the Flood-MAR suitability mapping tool discussed in the next section of this report.

III. Pre-feasibility Analysis of Surface and Subsurface Suitability for Flood-MAR

A primary goal of this project is to assess sites where there may be good opportunities to improve groundwater resources using Flood-MAR in Santa Clara County, particularly distributed locations that could host recharge systems supplied by local stormwater collection. The methods used in this study have been applied in other regions,[54] but this report presents results of the first regional effort to map suitability for Flood-MAR in Santa Clara County. Results of this work have direct implications for this region, and may serve as a template for other parts of the state and country, where planning and implementation of new groundwater projects are expected to be increasingly common and important in coming years.

A. Data and Methods

1. Multicriteria decision analysis (MCDA) for Flood-MAR suitability

A Geographic Information System (GIS) is a computer-based mapping and analysis system, combining a geospatial database that uses a variety of data types and formats, visualization tools for displaying datasets, and scripting tools for modifying and combining datasets to generate new data coverages. The use of a GIS for spatial assessment of Flood-MAR suitability through multicriteria decision analysis (MCDA) is well established in the technical literature (**Fig. III-1**).[55] Individual datasets are acquired and imported into the GIS in digital format, with adjustments made as needed to the geographic projection, resolution, data gaps or errors, and/or units of measurement and display. Each dataset used as part of the formal analysis is called a "***factor***." Each factor includes spatial data in either real-world units (e.g., ft/day for infiltration capacity) or categories (e.g., row crops or moderate urban development for land use/land cover). An assessment is made as to how each factor varies across the study region, and a classification scale is developed for simplified representation of the data, known as a "***rating***." Once all the factors of interest are rated, multiple factors are combined according to their importance ("***weight***") to generate a spatial suitability "***index***," helping to identify locations where there is alignment of properties that are the most favorable for the processes or activities of interest (**Fig. III-1A**). Note that factors could be developed that are either positive or negative with respect to feasibility, using a particular method, and some could be used to filter potential project regions or focus on specific subregions. These issues are discussed later when data are presented.

For the current project to assess suitability for Flood-MAR, we divided the assessment into two general classes of coverages: *surface* and *subsurface* (**Fig. III-IB**). Surface coverages included parameters the soil infiltration capacity, land use/land cover, and the nature of shallow geologic units, found at the surface or below soils. These datasets are available for the full study region, although, as described later, considerable processing was required to put them in suitable formats. Subsurface coverages included hydrogeologic parameters such as geometry (lateral extent, thickness) of aquifers and confining layers, vadose zone thickness (distance from the ground surface to top of groundwater) and the climate sensitivity of groundwater levels to inter-annual variations. We also explored use of transmissive and storage properties within uppermost aquifer units (as applied in groundwater models), but as described later, these were not incorporated into the MCDA as delivered. Subsurface factor coverages were available mainly within spatially defined groundwater management areas.

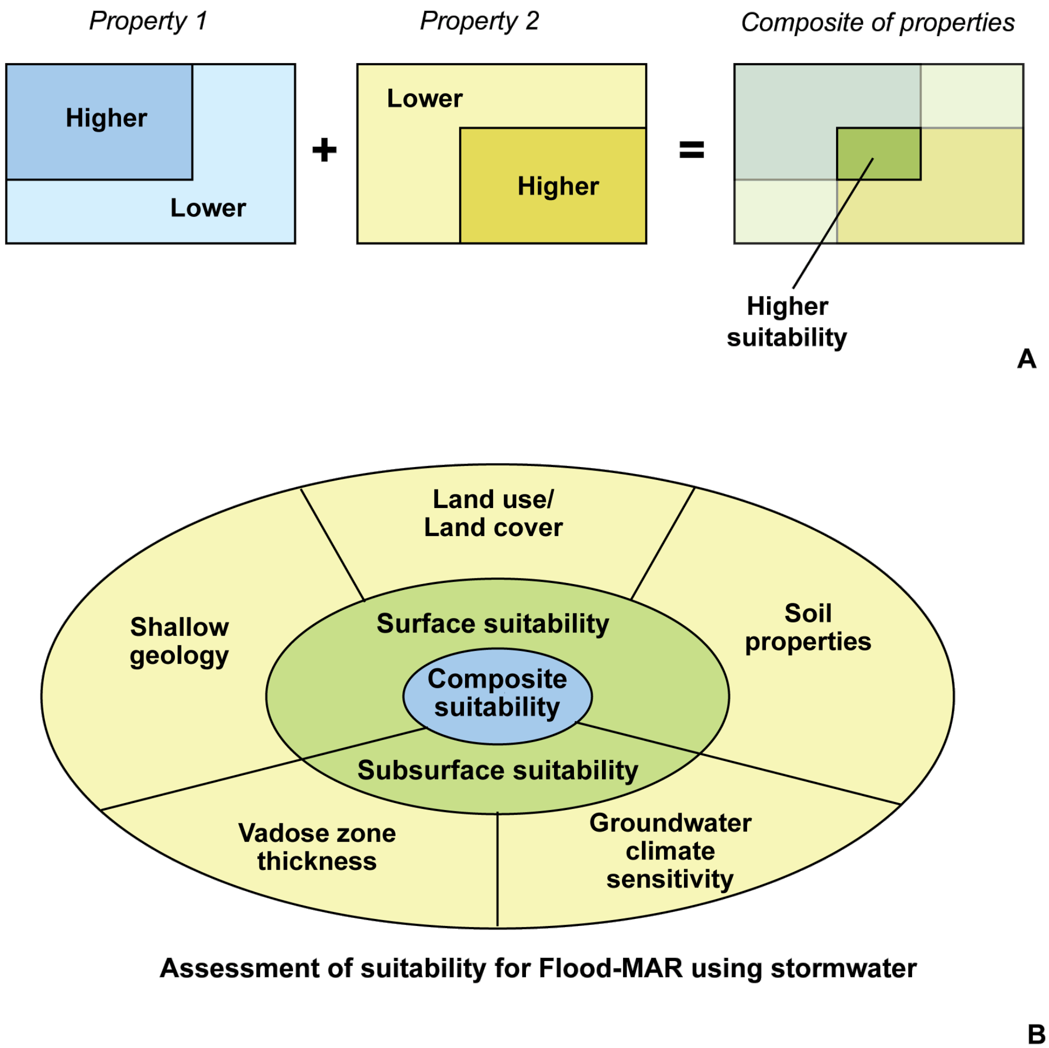


Figure III-1. Selected concepts applied for this study. **A.** Overview of general approach taken using a geographic information system (GIS), with independent factors rated on the basis of perceived suitability for Flood-MAR, then combined to identify areas with a higher or lower suitability index. **B.** Cartoon illustrating primary factors and weights as applied for this study. Individual surface and subsurface factors were weighted equally in primary analysis, although additional factors and weights were also tested, as discussed in text. Weights can be adjusted as desired using the GIS project to recalculate suitability indices.

This project uses existing GIS data coverages to efficiently develop new datasets, maps, interpretations, and recommendations. Many GIS datasets were available when this project began, so we focused first on evaluation of these coverages, identifying gaps or other problems, and determining what additional work can be justified in support of improving the Flood-MAR suitability assessment, rather than investing extensive effort before potential benefits are clear. We revisit this issue later in this report.

In order to combine disparate data types for classifying Flood-MAR suitability with MCDA, we used the following workflow:

- Factor datasets, polygons delineating spatial regions, and point data were acquired and documented, then imported into a draft (working) GIS project for evaluation. Data that were selected for use with the main GIS project were reprojected and/or regridded, if needed, to assure consistency with project standards and to align values with those from other factor datasets. For this project, a 1/9-arc-second digital elevation model (DEM) with ~10 ft x 10 ft resolution was selected as the spatial template; all subsequent datasets were reprojected and/or regridded so that values would align with pixels comprising the DEM.

- Some data incorporated into the main project were in vector form, comprising shapes or factor values at individual points, although most of the data subjected to quantitative assessment through MCDA were applied as raster data. Shapes were used mainly to define project subareas or to focus investigation and interpretation, e.g., parcel maps indicating open space or otherwise accessible properties.

- Factors used quantitatively as part of MCDA for Flood-MAR suitability were rated on an integer scale with eight levels: 0 to 7, where 0 indicates *poor suitability* and 7 indicates *excellent suitability*. Ratings were assigned independently for each factor, based on consideration of the nature of the data (quantitative or categorical) and the distribution of values/categories in a spatial sense and within a probability density function (PDF, aka, *histogram*). In general, we sought to have intermediate values on each rating scale (3 to 4) apply for conditions that were "acceptable" or "satisfactory" for Flood-MAR, with higher values (5 to 7) being *good* to *excellent* and lower values (0 to 2) being *poor to fair*. Ratings were also assigned with an eye towards showing the diversity of conditions. Criteria used to assign ratings are specific to each factor, as discussed later in this report, and maps and histograms of assigned factor ratings are shown.

- Factors were analyzed initially as part of separate surface and subsurface assessments, with factor weights (fractional values, $0 < W_f < 1$) assigned based on the inferred importance of each factor and confidence in data accuracy (**Figure III-1B**). For assessment of Flood-MAR suitability based on surface factors, we used ratings for soil infiltration capacity, shallow geology, and land use/land cover, with each factor weighted equally ($W_{f\text{-surface}} = 0.33$ for each). For assessment of Flood-MAR suitability based on subsurface factors, we assigned equal weights to vadose zone thickness and climate sensitivity of groundwater levels ($W_{f\text{-subsurface}} = 0.50$). We also tested incorporation of transmissivity and storage values from shallow aquifer layers (as applied in groundwater models) weighting these at half the value of other subsurface factors. Independent consideration of surface and subsurface data resulted in generation of two Flood-MAR suitability index maps: surface and subsurface.

- Surface and subsurface Flood-MAR suitability indices were combined to create a map of composite Flood-MAR suitability, with each of five total factors weighted evenly ($W_{f\text{-composite}} = 0.20$) (**Figure III-1A**). As discussed in more detail below, there is no standard or rigorous basis for assigning relative weights to different factors, so as an initial analysis, we chose equal weighting, reasoning that the initial set of five factors were all fundamentally important for siting Flood-MAR projects. That said, relative weighting can be adjusted in the future and used to generate new maps, and variations in weighting of factors or indices could be applied to different sites based on local conditions, preferred mode of MAR (infiltration basin, flood plain inundation, etc.). The working GIS project can be updated and/or augmented to include or exclude data as desired, based on what makes sense for particular goals and subareas of the Valley Water service area.

- The map of Flood-MAR suitability using surface data was updated prior to combining with the subsurface assessment to exclude areas with slopes that exceed some reasonable threshold (as discussed later), based on the understanding that the first Flood-MAR projects that might be considered during future work may involve a dedicated infiltration basin supplied with excess stormwater runoff from nearby hillslopes (the Flood-MAR approach identified as initially most promising in **Part II**). The engineering challenges of building a Flood-MAR infiltration basin on a steep slope are likely to outweigh any perceived advantages offered by good surface or subsurface conditions. It makes sense to focus first on areas where construction and operation is easier and cheaper. The use of slope as a factor to exclude parts of the study area is an example of application of a *filter*, independent of the rated factors used to calculate Flood-MAR suitability indices. Later in this report we discuss how additional filters could be applied to help focus site evaluation.

- Additional maps were generated to highlight subregions of the project area and additional factors that could be of particular interest, including open space, the spatial extent of Valley Water's groundwater benefit zones, and water quality data. As discussed below, these factors were not used in the quantitative calculation of Flood-MAR suitability indices because these could be considered to be positive or negative characteristics, depending on the nature of project scope, type, funding, and other characteristics. It may be preferred to view these factors as *overlays* on maps showing a Flood-MAR suitability index, as a means to highlight or exclude specific project options. And as with application of filters, additional overlays could be added to the digital GIS project in the future, as new data become available or additional issues are found to be useful for this purpose.

2. GIS development, data sources, and datasets

a. Creation and structure of a Flood-MAR suitability GIS

Geographic information system work for this project was completed using *ArcGIS*, Version 10.7 (released December 2018), commercial software that is widely used for environmental resource assessment, run on the *Windows 10* operating system. A copy of the project was saved in version 10.4 format for distribution, to assure compatibility with systems and software in current use by Valley Water. The GIS created for this project uses a geographic coordinate system (GCS) based on the North American Datum, 1983, California Zone 3. Incoming data that used a different GCS were regridded and/or reprojected to be compatible with the standard GCS. Data are plotted in State Plane Coordinates in units of feet.

In the context of the discussion in this section, a "GIS project" comprises an ArcGIS file ending with the .mxd extension that, when opened, displays one or more data layers linked to a geodatabase. When this project was completed, it was transferred to Valley Water as a Map Package, a self-contained and compressed folder and file structure with a .mpk extension. This GIS project contains symbology, a map layout, organized and nested data layers, and other components as needed to make the project self-contained and usable on a computer system other than the one on which it was created. To facilitate this, the GIS project developed and delivered for this Flood-MAR suitability assessment (VWMAR104.mpk) was set up so that (a) folder and file locations are specified relative to the main project file (rather than with absolute file paths), and (b) the project uses a single geodatabase that travels with the rest of the files and data in a dedicated folder (VW.gdb). Of course, the computer on which the project is opened must have a suitable version of *ArcGIS* installed, with compatible *ArcGIS* settings, have associated *Windows 10* files installed, etc.

The project team compiled and reviewed a large number of documents that were available on the Valley Water website or made available by Valley Water collaborators, then created an initial listing of potentially useful data. Some of data coverages were immediately available on the Valley Water website or other websites organized and maintained by federal, state, or regional agencies or other groups; we started work with these data and coverages. Metadata concerning incoming data was collected in a *GoogleSheet* (*WRIP-GIS_IncomingArchive_Metadata*), to aid in tracking file status and potential utility:

> https://docs.google.com/spreadsheets/d/1JIMUDHgKZLWLiAWLklJ59SMlikV_qDnoYvfQCYK9pAA/edit#gid=0

All incoming datasets were placed initially in a dedicated *IncomingArchive* folder on the UCSC Hydrogeology data server (a redundant RAID 1+0, with data mirroring and striping), secured behind a firewall and backed up regularly. These incoming data were preserved without editing, so that we could reopen them later to check status and verify earlier decisions.

Any of these files that required additional steps for assessment (e.g., reprojection, clipping, and/or numerical manipulation) were subsequently copied to a working folder (*ScratchShared*), which contains numerous files, subfolders, and informal projects. Neither this working folder nor the *IncomingArchive* folder are considered to be part of the main project, which is located in a separate folder (*VW_MAR_Proj*) on the UCSC server.

As GIS data were acquired, they were imported into one or more temporary (working) GIS projects for assessment in informal "scratch" GIS projects. Simply importing a GIS data coverage can result in generation of new files, so we were careful to do this outside the *IncomingArchive* folder. If data were considered to be useful for the main project, they were exported from the working project into a dedicated folder/file structure for the main project, including renaming as needed (using *ArcCatalog*) so that folders and files would be readily identifiable and named in a consistent way. Files subsequently imported into the main project are listed on a dedicated *GoogleSheet* of metadata, *WRIP-GIS_MainProject_Metadata*,

> https://docs.google.com/spreadsheets/d/1vjHjco1cknS8gmZcEhFzcMVLbTc3dD0csiXQ2kFebKk/edit#gid=1052823668

Individual datasets in the main project are nested in a series of folders and subfolders by category, including short and descriptive names that are also used in naming data layers in the project itself, e.g., 01_ProjAreas, 05_DEM, 10_Soils, etc. Each of these folders contains either a single set of *ArcGIS* files needed to comprise a data layer, or (more often) a series of files and subfolders that are needed in support of one or more data layers, each with one or more datasets. The metadata *GoogleSheet* contains two tabs, one each for *Data Folders* and *Data Files*, including details concerning sources and formats. An overview of data categories and types used in the main GIS project is presented in **Table III-1**.

Table III-1. Main data types and sources used for this project.

Surface	Data Source [a]
Soil infiltration capacity	SSURGO
Land use/Land cover	NLCD
Geology	USGS
Subsurface	
Vadose zone thickness	Valley Water
Aquifer transmissivity	Valley Water
Aquifer storage	Valley Water
Sensitivity of water levels to climate	Valley Water
Filter	
Slope	USGS
Applications	
Selected open space areas	SCV-OSA, Valley Water
Groundwater benefit zones	Valley Water
Water quality (TDS and nutrients)	Valley Water

[a] SSURGO = Soil Survey Geographic Database, USDA/NRCS
NLCD = National Land Cover Database
USGS = United States Geological Survey
SCV-OSA = Santa Clara Valley, Open Space Authority
Additional metadata for data sources available here:
https://docs.google.com/spreadsheets/d/1vjHjco1cknS8gmZcEhFzcMVLbTc3dD0csiXQ2kFebKk/edit#gid=0

b. Datasets used in project

i. Project Area polygons and features

The full project area is Santa Clara County, but most groundwater resources are found in the Santa Clara Plain, Coyote Valley, and Llagas Subbasin (**Figure I-1**). The Santa Clara Plain is more urbanized, although there are population centers in Coyote Valley and the Llagas Subbasin as well. In general, Coyote Valley and the Llagas Subbasin have considerable land areas in agricultural production and designated as undeveloped. Groundwater flow directions are generally from the NNW to SSE in the Llagas Subbasin, and from SSE to NNW in Coyote Valley and the Santa Clara Plain; of course there are local gradients and flow patterns in association with variations in stratigraphy, recharge, and pumping.

Valley Water defines a series of groundwater "benefit zones" that roughly correspond to the following groundwater management areas: W2 (Santa Clara Plain), W7 (Coyote Valley), and W5 and W8 (Llagas Subbasin) (**Figure I-1**). Valley Water has identified regions in the Santa Clara Plain and Llagas Subbasin where groundwater conditions are generally confined, meaning that there are fine-grained layers forming the top of important aquifer units, limiting local recharge into underlying, principal aquifers. The limits of confined conditions were mapped decades ago and appear on numerous Valley Water documents, as well as figures shown in this report. Other important hydrologic features included in the main GIS project created as part of this study include water bodies and channels, particularly losing stream reaches and the locations of operating percolation basins.

ii. Land surface elevation (DEMs)

We used a USGS digital elevation model (DEM) as the basis for the full project, with pixel dimensions and locations forming a template for incorporation of all additional raster data (**Figure III-2**). The selected DEM uses the NAD83 datum, has resolution of 1/9-arc-second, equivalent in the project area to ~10 ft x 10 ft, and has complete coverage across Santa Clara County. This resolution is fine enough to allow relatively detailed assessment, without creating excessive computational or visualization burdens. We also incorporated a 1/3-arc-second DEM in the project, which can be useful for displays of the full project area because it renders more quickly than the finer DEM.

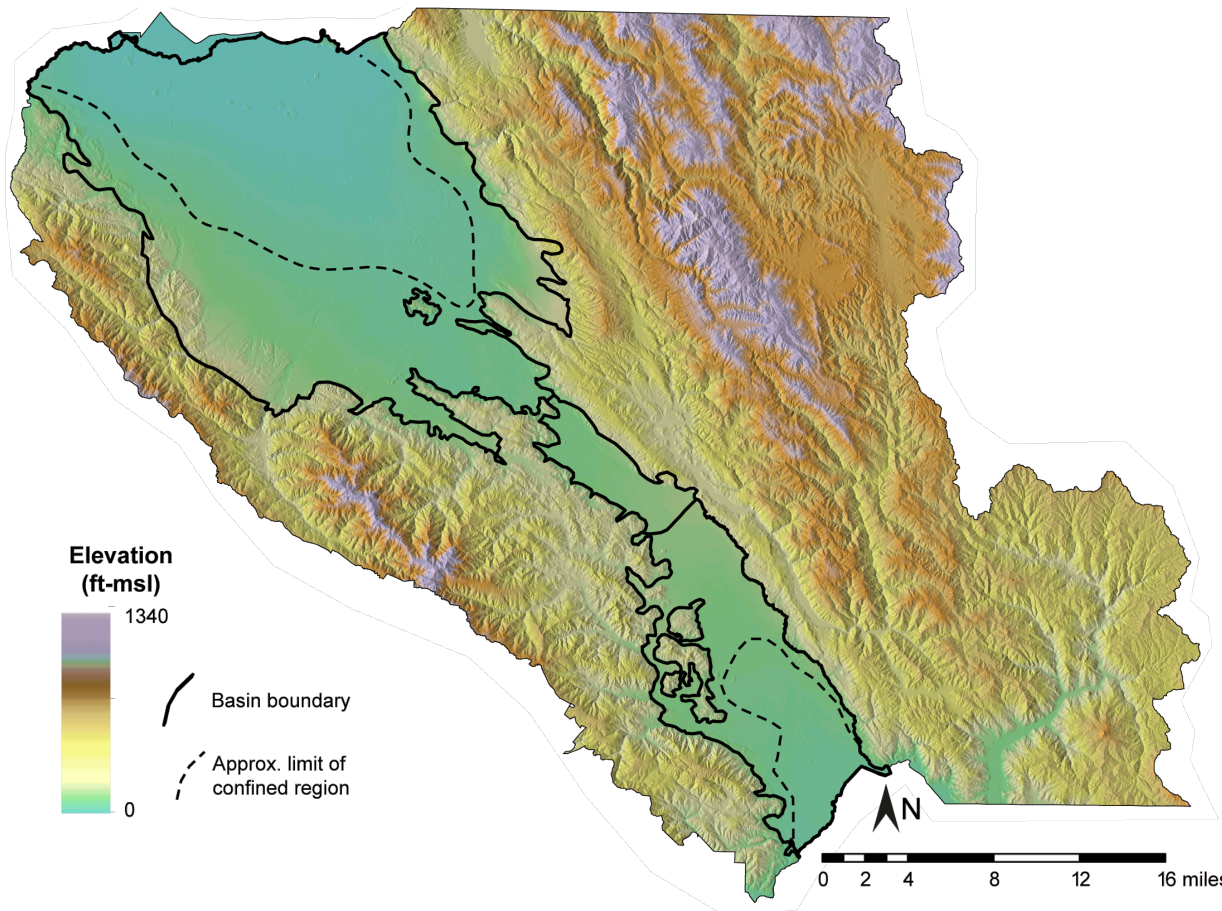


Figure III-2. Hill-shade digital elevation model of full project area (Santa Clara County), showing groundwater subbasins and approximate limits of confined regions.

A hill-shade DEM illustrates variations in slopes in Santa Clara County, emphasizing that primary aquifers that are the focus of this study are located mainly below valley floors and define the Santa Clara Plain, Coyote Valley, and Llagas Subbasin (**Figure III-2**). That said, there local areas with steep slopes, especially near basin edges and where stratigraphically deeper geological units penetrate through the valley fill deposits.

iii. Infiltration capacity

Soil information was extracted from the NRCS SSURGO database[56] and processed for plotting (**Figure III-3**). Infiltration capacity is not provided as a simple spatial coverage in the SSURGO database. Instead, polygons are defined for a wide variety of map unit symbol codes (MUSYM), and for each code there is information on the thickness of individual soil layers and their typical properties, including each layers' saturated hydraulic conductivity. The latter usually appears as a range of values, often extending across 1–2 orders of magnitude. Thus considerable manipulation of SSURGO data was required to generate a map of soil infiltration capacity for use in Flood-MAR suitability analysis.

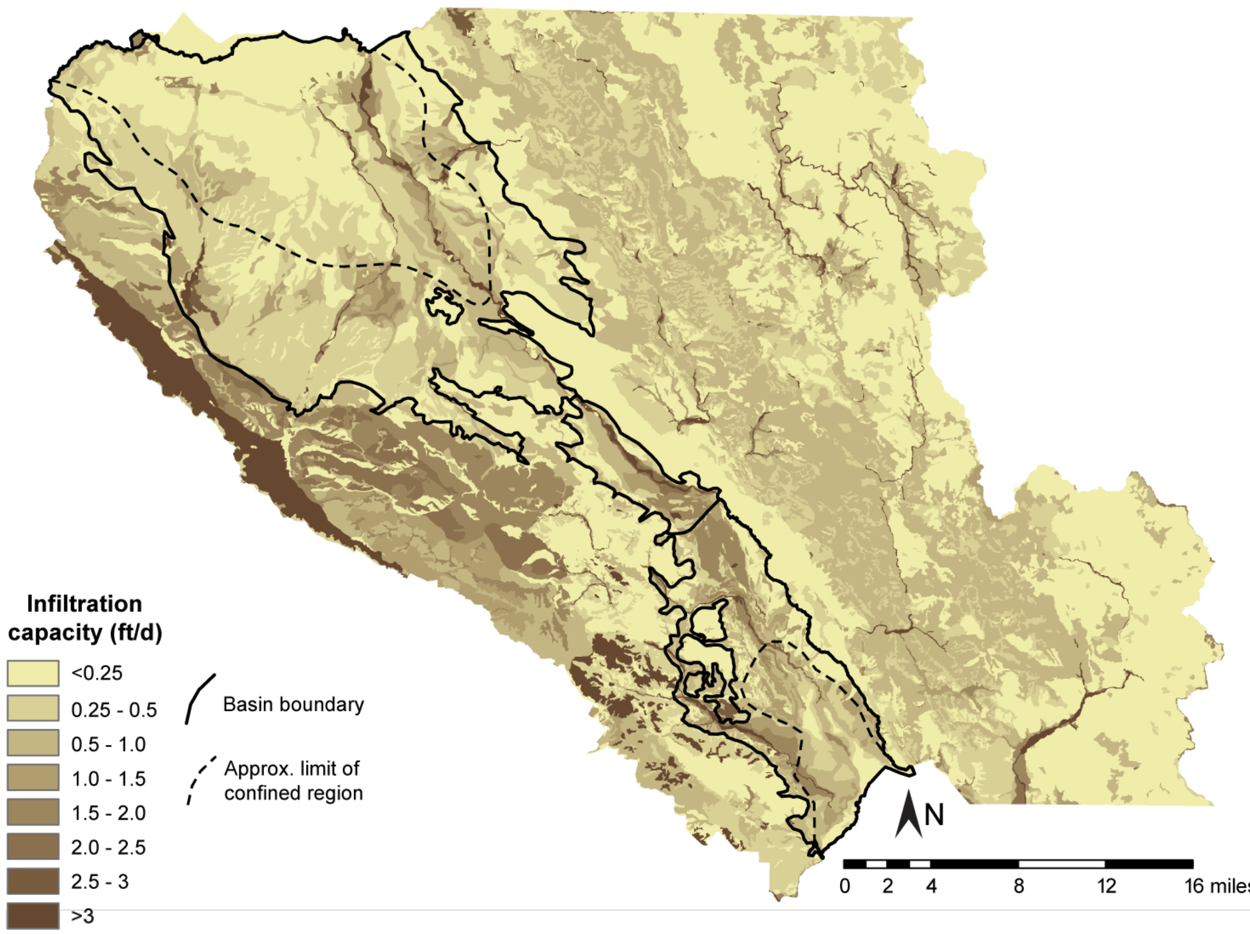


Figure III-3. Infiltration capacity of soils in study area, binned to highlight areas with most favorable properties for Flood-MAR. In general, Flood-MAR project sites should be identified in areas where infiltration rates are ≥0.5 ft/day. Higher rates are better for increasing water supply.

We extracted data for each soil type represented in Santa Clara County and linked these to soil polygons. For each soil type, we took the arithmetic mean of saturated conductivity listed for each soil horizon, then calculated the harmonic mean of layer values, accounting for both differences in properties and the thickness reported for each soil layer:

$$IC_E = \frac{\sum_{i=1}^{n} d_i}{\sum_{i=1}^{n} \left(\frac{d_i}{\overline{K}_i} \right)} \quad (1)$$

where IC_E = soil infiltration capacity (ft/day), d_i = layer thickness (ft), and $\overline{K_i}$ = arithmetic mean of the range of conductivity values reported for individual layers (ft/day). This approach allowed for a wide range of soil properties to be represented, while giving more importance for vertical infiltration to layers having the lowest (limiting) infiltration capacity. This approach also recognizes that, within each soil polygon, more infiltration is likely to occur where conditions are most favorable. Soil IC_E values were converted to units noted above during compilation and processing, then rasterized. The resulting map is interpreted as representing the infiltration capacity of shallow soils, and is available for the full project region (**Figure III-3**).

iv. Land use/land cover

We considered numerous datasets that define land use/land cover (LULC) across the project region, and decided to work mainly with the 2019 National Land Cover Dataset (NLCD, https://www.mrlc.gov/data/nlcd-2019-land-cover-conus) (**Figure III-4**). This dataset offers several advantages compared to other options. First, this is a well-established data product generated for the full continental United States by the U.S. Geological Survey in collaboration with regional partners, applying standardized methods and incorporating data from 2001-19. The NLCD includes the full project region, rather than leaving gaps that would require patching (with a different classification scheme), has the same resolution as the DEM used as the raster template for GIS work (after regridding to align pixels), and uses a self-consistent set of LULC designations with sufficient granularity for the present application. For example, the NLCD includes four designations for "developed" land, ranging from high intensity to open space, distinguishes between deciduous, evergreen, and mixed forests, and has distinct classifications for cultivated crops and hay/pasture. Areas designated as cultivated crops could be updated with an overlay that includes classifications based on crop type or land practices, if desired, but we did not attempt this for the initial suitability analysis for several reasons.

Some earlier studies using MCDA for recharge suitability analysis have favored specific crops on the basis of associated soils types, perceived economic value, or application of fertilizers or nutrients.[57] However, cropping datasets have incomplete coverage for the project area (which covers all of Santa Clara County). The accuracy of various data products is a concern, but coarser classification means that LULC designations are more likely to be correct than for more detailed assignment of practices. In addition, cropping data is not necessarily indicative of farming practices, e.g., distinguishing between conventional, organic, or dry-farming techniques. We have a separate data coverage for soil properties, so linking crops to infiltration would involve "double-counting" soil properties (e.g., rice is grown frequently where soils are hydrophobic). In some areas, crops are rotated annually or more frequently, so no single snapshot will be indicative of "typical" conditions during some designated time period, and the extent and reliability of available data is highly variable across the region. Indeed, many more detailed cropping datasets are not well documented, so the sources and reliability of data are unknown.

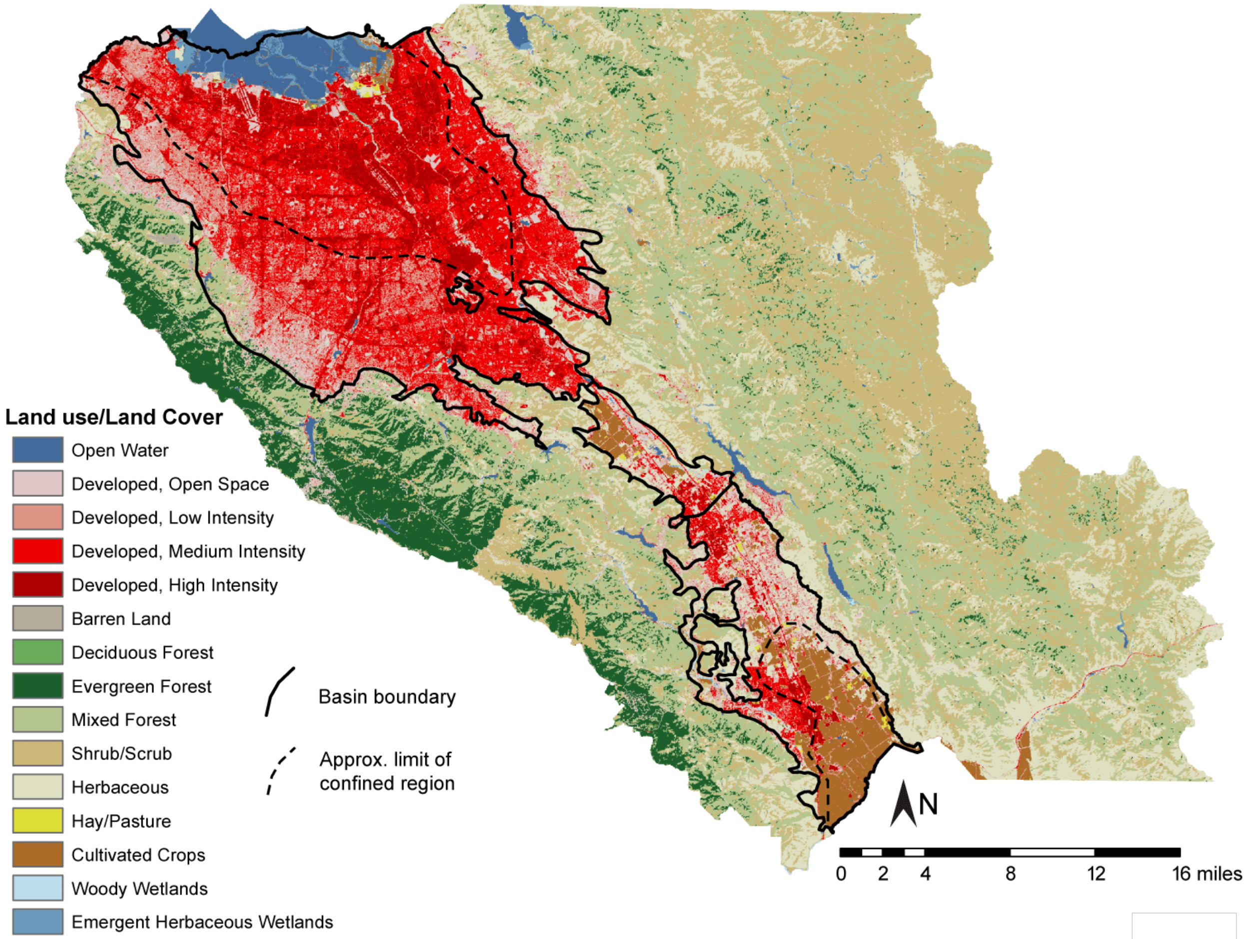


Figure III-4. Land use/land cover in the study area, based on categories in the National Land Cover Dataset.

As discussed later in the section on rating of datasets, we did not wish to apply a rating system that would favor particular crops, for reasons noted above and because how one rates individual crops depends on a series of potentially useful but ultimately arbitrary classifications. For example, one could consider some perennial vine or tree crops to be either favorable or contraindicated for Flood-MAR projects, because the plants will or will not tolerate inundation (depends on MAR operations as well as soils and crop species). Similarly, one could decide that a lower value crop is more favorable for Flood-MAR because a grower removing that land from production in favor of MAR might seem more likely, but in practice these are decisions made by individuals and companies on the basis of many considerations. We note that a more granular cropping coverage could be overlain as a replacement for selected NLCD designations (e.g., cultivated crops could be divided into a finer classification), if desired.

v. Geology

Regional geology maps for the study region were combined to develop a composite coverage, using a geodatabase downloaded from the USGS. In the context of this study, *Geology* refers to 72 formations or other lithologic units or designations identified with specific codes (**Figure III-5**). For Quaternary deposits that are found near the surface in most of the designated groundwater basin areas, we used a compilation of datasets created by *Whitter et al.* (2006)[58] and digitized by

Wentworth et al. (2006),[59] defining 55 "type names." For areas with older geological units, data was obtained from the USGS State Geologic Map Compilation (SGMC) geodatabase,[60] including 13 formations ranging in age from Eocene to Mesozoic, and four Quaternary units. Where the latter was also represented by Quaternary deposits in the *Wentworth et al.* (2006) compilation, the latter designations superseded those from the statewide compilation.

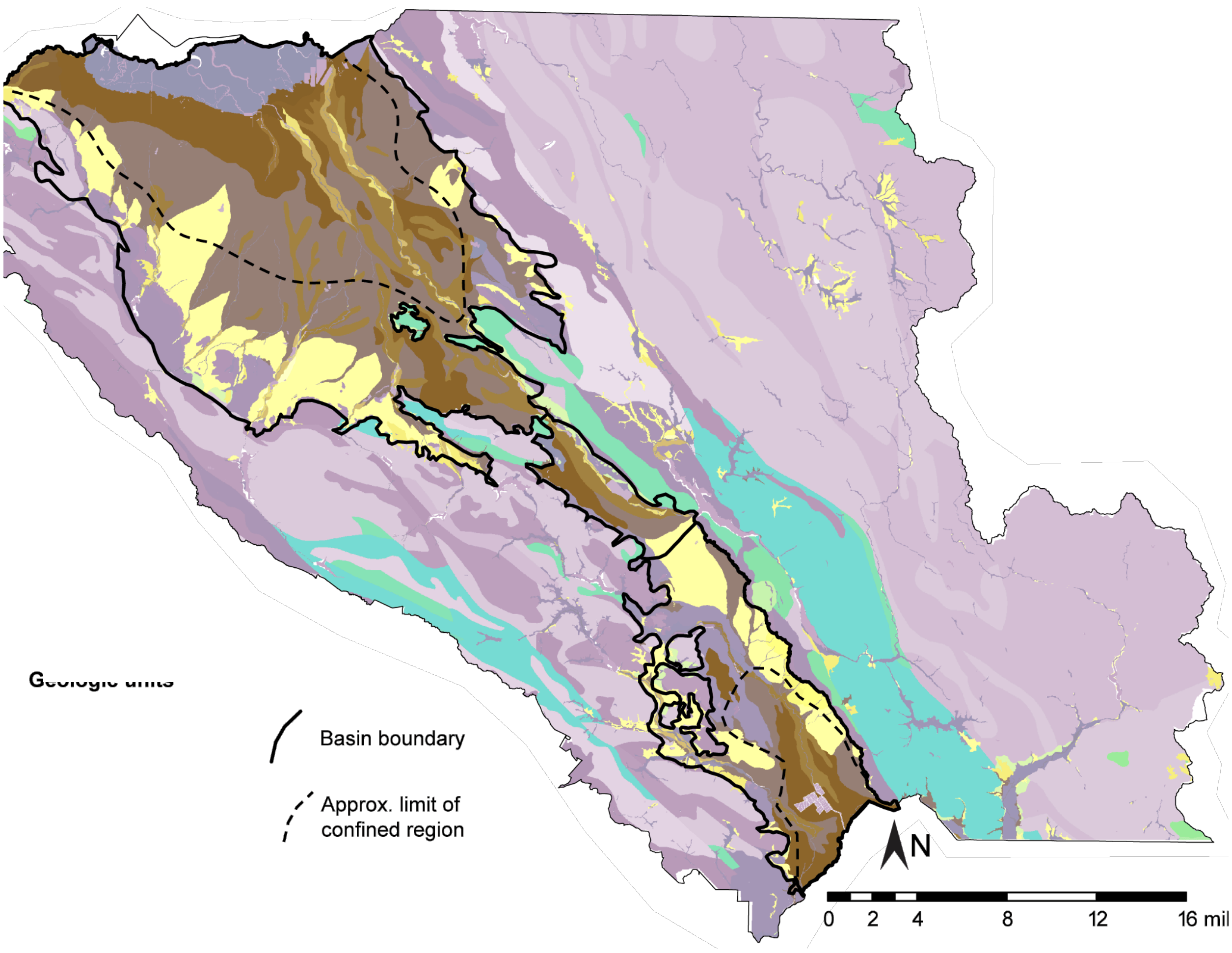


Figure III-5. Geologic units mapped across study area, including 72 distinct lithologies and other classifications. A full listing is included in metadata, but in general, areas with lithologies most conducive to Flood-MAR activities are coarse Quaternary deposits, including areas colored buff-tan to brown to dark lavender.

In general, Quaternary deposits comprise the primary aquifer units in the three groundwater management areas, but particularly at basin edges, older units may be interlayered with younger deposits and therefore could be important for Flood-MAR suitability assessment. Basin edges, where alluvial and fluvial units may pinch out against bedrock deposits, are often locations of "mountain front" recharge because primary aquifer units are sometimes exposed ("daylighted") in these areas. In contrast, areas closer to valley centers often contain wetland or estuarine deposits that are fine grained and can result in development of confined conditions in underlying aquifers. Thus the lateral edges of the groundwater basins are of particular interest for assessing Flood-MAR suitability.

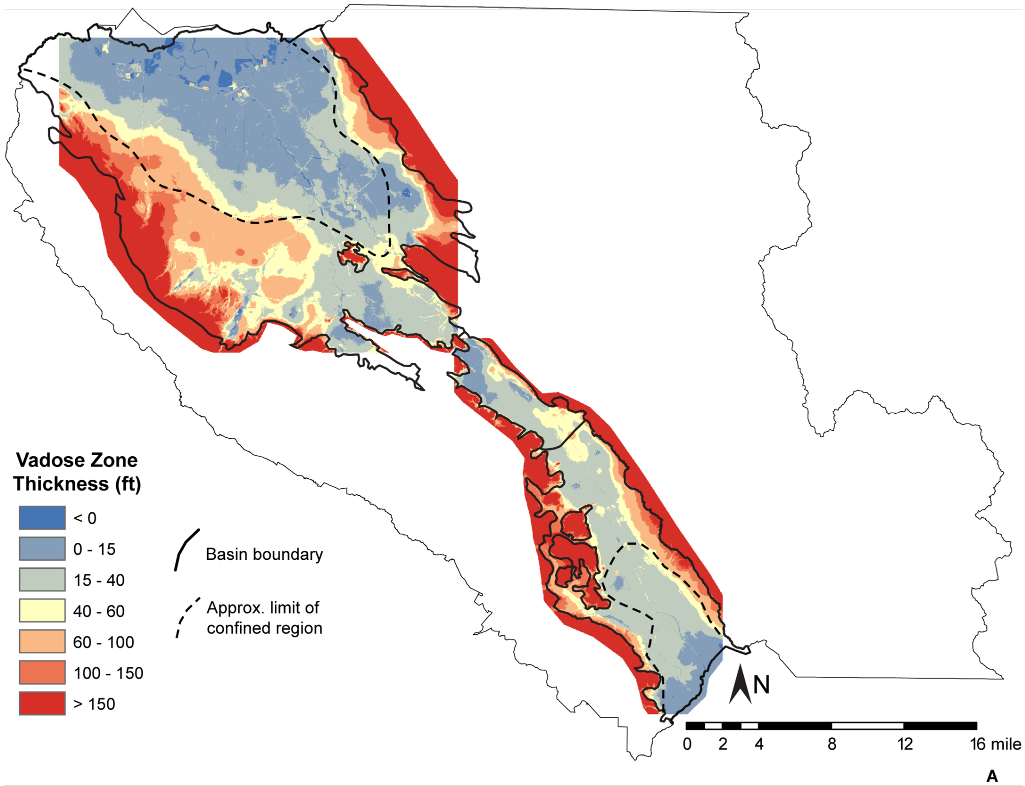
In addition, rural agricultural and residential activities may be supported by individual wells or small well networks in some areas, and the inclusion of older deposits from regional maps is helpful for assuring that there is analysis of surface datasets for the full project area, allowing identification of potential project sites that, while not accessing one of the main groundwater basins, could be useful for local pumpers, streams systems, and/or wetlands. As discussed in greater detail in the section on rating of geological units, many of the Quaternary units have similar descriptions that make interpretation difficult (for example: Qha = Holocene alluvial deposits, undifferentiated; Qhay = Latest Holocene alluvial deposits, undifferentiated). This is true particularly where designated units comprise a wide range of sediment/rock textures (e.g., gravel, sand, silt, clay), and where the dominant texture of deposits is expected to vary at a small spatial scale. Accurate representation of the influence of these deposits on potential Flood-MAR projects will require careful and site-specific field investigation, but the suitability analysis should nevertheless be useful in initial (desktop) screening of options.

vi. Hydrogeology – water levels

Several datasets were made available by Valley Water containing groundwater level data, expressed as depth below ground surface (aka, depth to water, *DTW*), and used for multiple calculations and data coverages: (a) median water levels in groundwater wells during 2010-19, (b) maximum depth to water during a recent drought, 2014-15, and (c) minimum depth to water during a long time period that includes multiple periods with relatively wet conditions, 1978-2019, with the majority of data being post-1994, and ~25% of minimum depth observations from 2005-06. These maps were provided as raster coverages created by Valley Water using measurements from monitoring and production wells. All of these subsurface datasets, and those for additional coverage discussed in this section of the report, extend close to the limits of groundwater basin extent, a subset of the total project area (Santa Clara County).

We examined additional maps of water levels around the groundwater management areas, including maps going back the early 1990s, but many of these were either PDF scans of hand-contoured maps or maps generated using *AutoCAD* software or *ArcGIS* "package files" with labeled contours rather than raster data. None of these maps could be used in the present application because Flood-MAR suitability index calculations require a gridded (raster) representation. In principle, contour lines could have been digitized and converted to point values, then these data could be gridded to generate a water level raster, but this would be twice removed from data values used to generate the original contours.

In application to the Flood-MAR suitability index, median water level was interpreted to be equivalent to vadose zone thickness, the depth from the ground surface to groundwater level in a producing aquifer (**Figure III-6A**). The coverages for maximum depth to water (under dry conditions, DTW_{dry}) and minimum depth to water (wet conditions, DTW_{wet}) were used to calculate a climate sensitivity factor, $C_s = DTW_{\mathrm{dry}} - DTW_{\mathrm{wet}}$, resulting in higher values at locations where there were the greatest differences in water levels between dry and wet conditions (**Figure III-6B**). We interpret larger values of C_s to be a positive indicator of Flood-MAR suitability, identifying locations where infiltrated surface water may have a good opportunity to reach a pumped aquifer where there is available storage space. We also note that higher groundwater levels under wet conditions and lower water levels under dry conditions could result from differences in pumping. Thus the phrase "climate sensitivity" represents a hybrid of hydrologic and human (behavioral) influences.



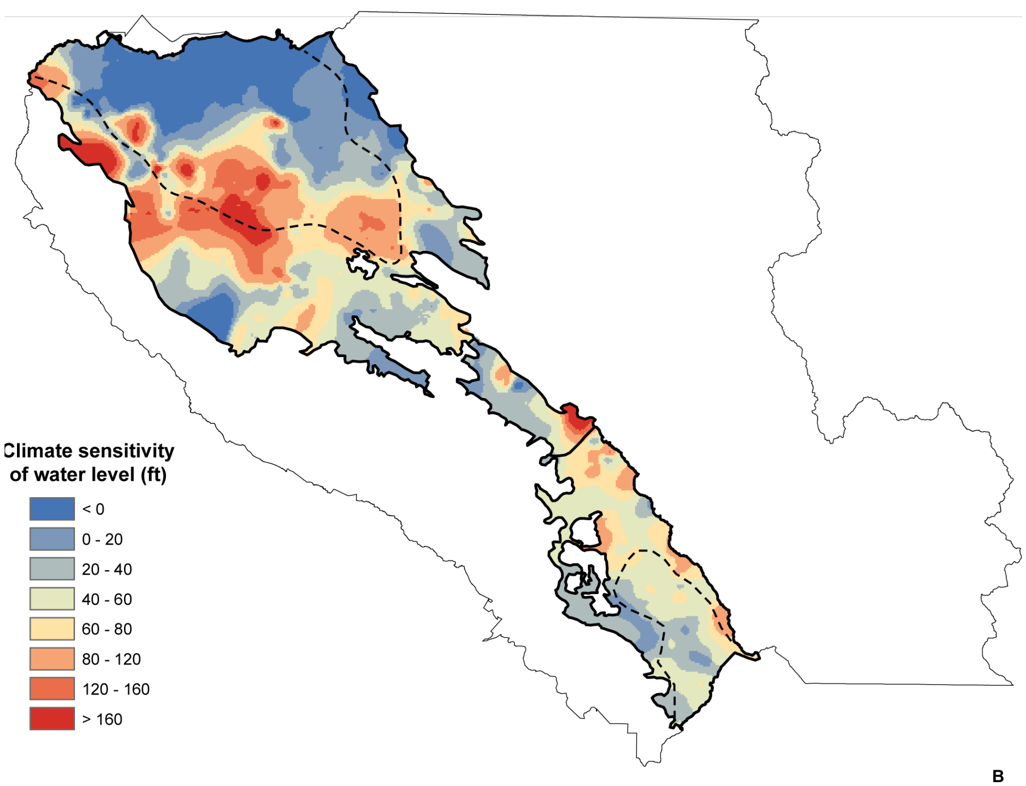


Figure III-6. **A.** Vadose zone thickness based on median depth to water (*DTW*) during 2010-19. **B.** Climate sensitivity of *DTW* defined as DTW_{dry} (2014-15) – DTW_{wet} (1978-2019, minimum). White spaces within the subbasins in panel A indicate areas where vadose zone thickness is not interpolated because of limited depth-to-water data.

The vadose zone tends to be thinnest near the basin centers, particular at the north end of the Santa Clara Plain and the southern end of the Llagas Subbasin, where confined conditions are dominant, and on the northern side of Coyote Valley. The vadose zone tends to be thickest where there are local topographic highs, including locations where bedrock formations are surrounded by valley fill deposits, and on the edges of the groundwater basins as they slope upward into surrounding mountain ranges (**Figure III-6A**). The climate sensitivity of water levels is highly variable around the project region, and is notably high in the central and western sides of the Santa Clara Plain (near large well fields and percolation basins), at the southeastern end of Coyote Valley, and along the margins of Llagas Basin (**Figure III-6B**).

vii. Hydrogeology – Transmissivity and Storage

Multiple data coverages were used to assemble maps of aquifer properties, as applied for groundwater models currently in use by Valley Water, including updated versions of simulations developed for the Santa Clara Plain, Coyote Valley, and the Llagas Subbasins (**Figure III-7**). Acquisition and development of these data coverages for use in the current project varied by management area and model, as summarized in this section. Transmissivity is defined as the product of horizontal hydraulic conductivity multiplied by aquifer thickness for a tabular, horizontal aquifer layer or layers. Thus for unconfined conditions, transmissivity varies with water level. The storage factor calculated for the present application is the product of specific yield (S_y) and aquifer layer thickness, indicating space available for storage of supplemental surface water. Data used for this analysis was provided by Valley Water personnel and subject to evaluation and discussion to determine how it might be applied.

For the model of groundwater flow in the Santa Clara Plain, data were evaluated for the top three model layers (1, 2, 3), for which lateral grid resolution was typically 1,000 to 6,000 ft. Layers 1 and 2 exist for this model only where the principal aquifer is confined, representing the upper unconfined and confining layers, respectively. Where Layer 1 exists, in the confined region, its thickness is ~80 to 100 ft. Where Layers 1 and 2 are absent (outside the confined region), Layer 3 is the uppermost active model layer and is ~100 to 500 ft thick. For transmissivity calculations for this model, we multiplied horizontal conductivity (K_h) by layer thickness for Layer 1 in confined areas, or by Layer 3 where the main aquifer is unconfined and model Layers 1 and 2 are inactive. This approach accounts for there being limited (but often non-zero) transmissivity above confined parts of the Santa Clara Plain, but generally results in greater transmissivity where there are unconfined conditions that correspond to thicker aquifer layers. Layer 1 values of horizontal conductivity were constant in the model, K_h = 70 ft/day, whereas Layer 3 values varied, K_h = 5 to 333 ft/day.

A similar approach was applied for storage from the Santa Clara Plain model, using Layer 1 where it was active above a confining layer, and Layer 3 where conditions were unconfined. In each case, we multiplied the value of S_y by layer thickness in the same cell location. Specific yield in the Layers 1 and 3 of this model varied with location, S_y = 0.02 to 0.21.

For input data used with groundwater models for Coyote Valley and the Llagas Subbasin, we worked only with the uppermost layer, Layer 1. For the Coyote Valley model, Layer 1 has spatial resolution of 250 by 250 ft. Although K_x and K_y are specified separately (with a range of 35 to 650 ft/day), they are assigned the same values ($K_x = K_y$) in individual cells. In addition, S_y = 0.08 in this model throughout the domain, so differences in storage calculations as applied in this study depend entirely on cell thickness. Cells in Layer 1 of the Coyote Valley model are assigned thicknesses of 13 to 376 ft.

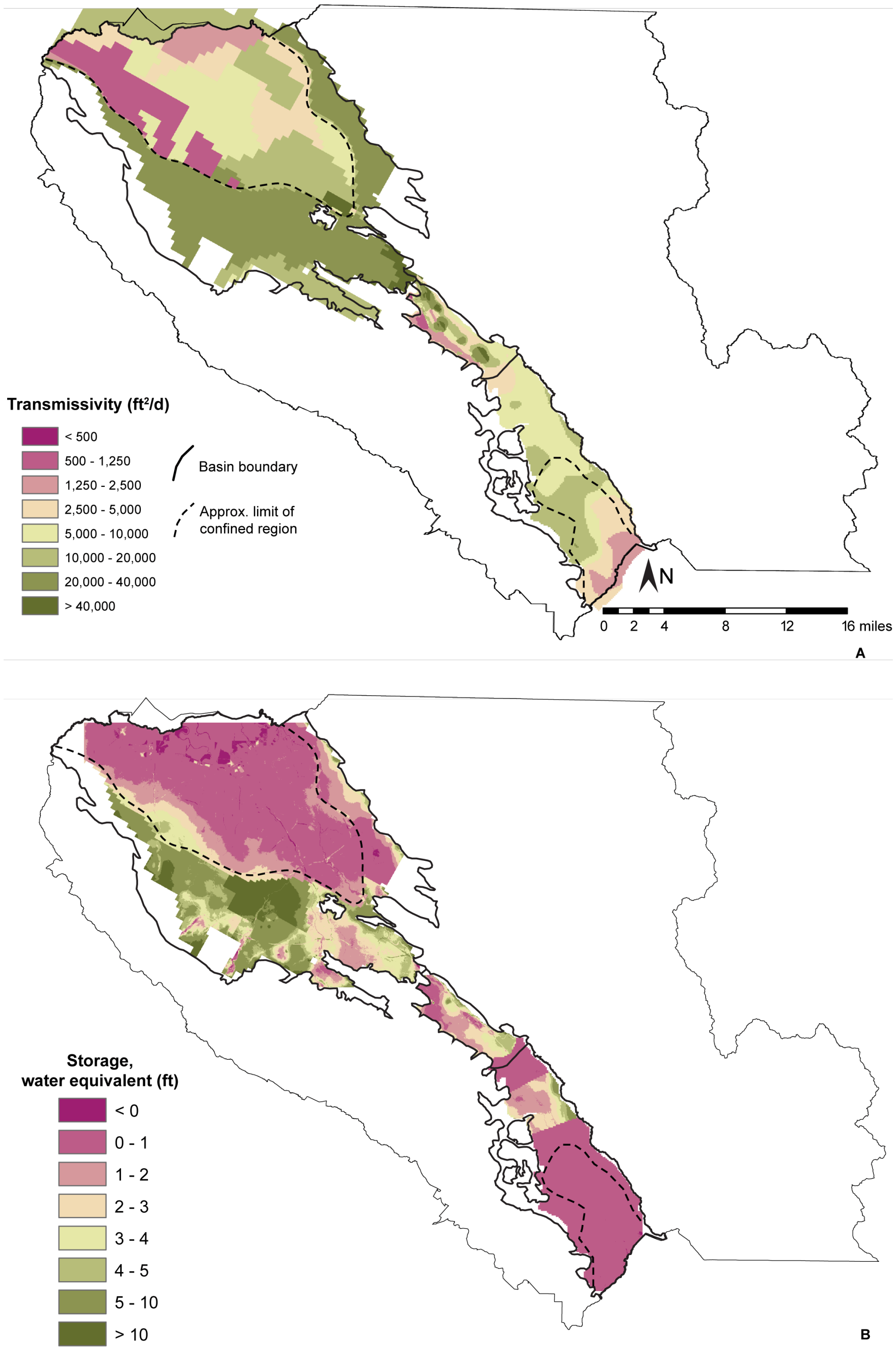


Figure III-7. Aquifer properties from MODFLOW property files. **A.** Transmissivity from upper layers. **B.** Storage from upper layers, defined as specific yield x thickness of vadose zone.

For the Llagas Subbasin model, calculations were made for Layer 1, which has a spatial resolution of 500 x 500 ft. As with the Coyote Valley model, K_x and K_y are specified separately (with a range of 14 to 134 ft/day), but are assigned same values ($K_x = K_y$) within individual cells. Specific yield is much lower in the Llagas Subbasin model than in the other two models, with values of $S_y = 0.005$ to 0.06, and cell thicknesses are 150 to 295 ft.

Resulting values of transmissivity vary from <500 ft^2/day to >40,000 ft^2/day, with the highest values calculated from model input data in the unconfined part of the Santa Clara Plain (**Figure III-7A**). There are some elevated values apparent along the center of Coyote Valley, and transmissivity is lower along valley edges, especially on the southwest side. Transmissivity values tend to be lower overall in Llagas Subbasin, with the lowest values in the confined area along the southeastern side of the basin. The overall coarse granularity of model cells is apparent in the calculated transmissivity values, as the model resolution is several orders of magnitude coarser than the ~10 x 10 ft pixel size applied in this study, but there is "structure" in the variability that seems to be broadly consistent with the nature of basin fill deposits.

The distribution of storage factor values suffers in comparison, with large areas in which there is little variability. In the Santa Clara Plain, there appears to be considerable storage associated with the unconfined area along the southwestern side of the basin. There are much smaller parts of Coyote Valley and Llagas Subbasin with elevated storage potential, and large sections of Llagas Subbasin, in particular, with little available storage based on values used in the groundwater models (**Figure III-7B**). As discussed later in the report, after an initial analysis using transmissivity and storage ratings and discussion with Valley Water personnel, we elected to not use transmissivity and storage values in the suitability analysis.

c. Filters and constraints for application of Flood-MAR

Remaining factors applied in this pre-feasibility assessment of Flood-MAR suitability for the Valley Water service area were not applied directly as part of suitability index calculations, but were used instead as either (a) *filters* to limit the extent of the analysis to a subset of the total project region, or (b) *constraints* that help to focus investigation of specific subregions. Each of these approaches is explained in this section. These should be considered as examples of a filter and/or constraint approach, for which numerous additional datasets could be applied, as discussed later.

We apply DEM slope as a filter to suitability index calculations, removing areas having a ground surface slope ≥10%, reasoning that these areas are less desirable based on challenges in collection of hillslope runoff under steep conditions (**Figure III-8**). Some areas with slopes >10% might still be viable for projects, but the most feasible sites are likely to be in or close to the main groundwater basins that occupy valleys. That said, we don't include slope as a numerical factor as part of suitability index calculations because we don't consider there to be a continuous, monotonic relation between slope and project feasibility. Instead, we suggest that this factor is suitable for binary categorization, separating areas that are too steep from other areas that could be viable. Setting a limit at 10% slope is admittedly arbitrary, but we include the map of slope values as part of the working GIS project, and an alternative slope filter could be created and applied if desired.

Other potential filters that were discussed as this project was developed included (a) proximity to a known channel (perhaps gaining channels or channels with groundwater dependent ecosystems, GDEs) and (b) the mapped extent of confined areas. We did not include the first of these factors as a filter because how it would be applied depends on several additional considerations, and could vary depending on potential project goals and methods used for MAR. For example, if a project were conceived entirely as a means to enhance groundwater storage for subsequent recovery by pumping, then closer proximity to a stream (especially a gaining stream) might be considered to be a negative factor. Alternatively, if the stream channel were known to contain a GDE or other important species, proximity of a Flood-MAR project could be considered to be a positive factor. If any of these considerations were to apply, one would also need to decide how to design the filter, what distance limit might be appropriate (1000 ft, 5000 ft, etc.). Similar considerations could apply depending on whether the primary approach to be taken is infiltration in a dedicated basin, with an area of perhaps 1-10 acres, or if flood-plain inundation across a larger area were possible. We don't argue against adding these or other constraints, but for this pre-feasibility analysis, we elected to filter locations based only on slope.

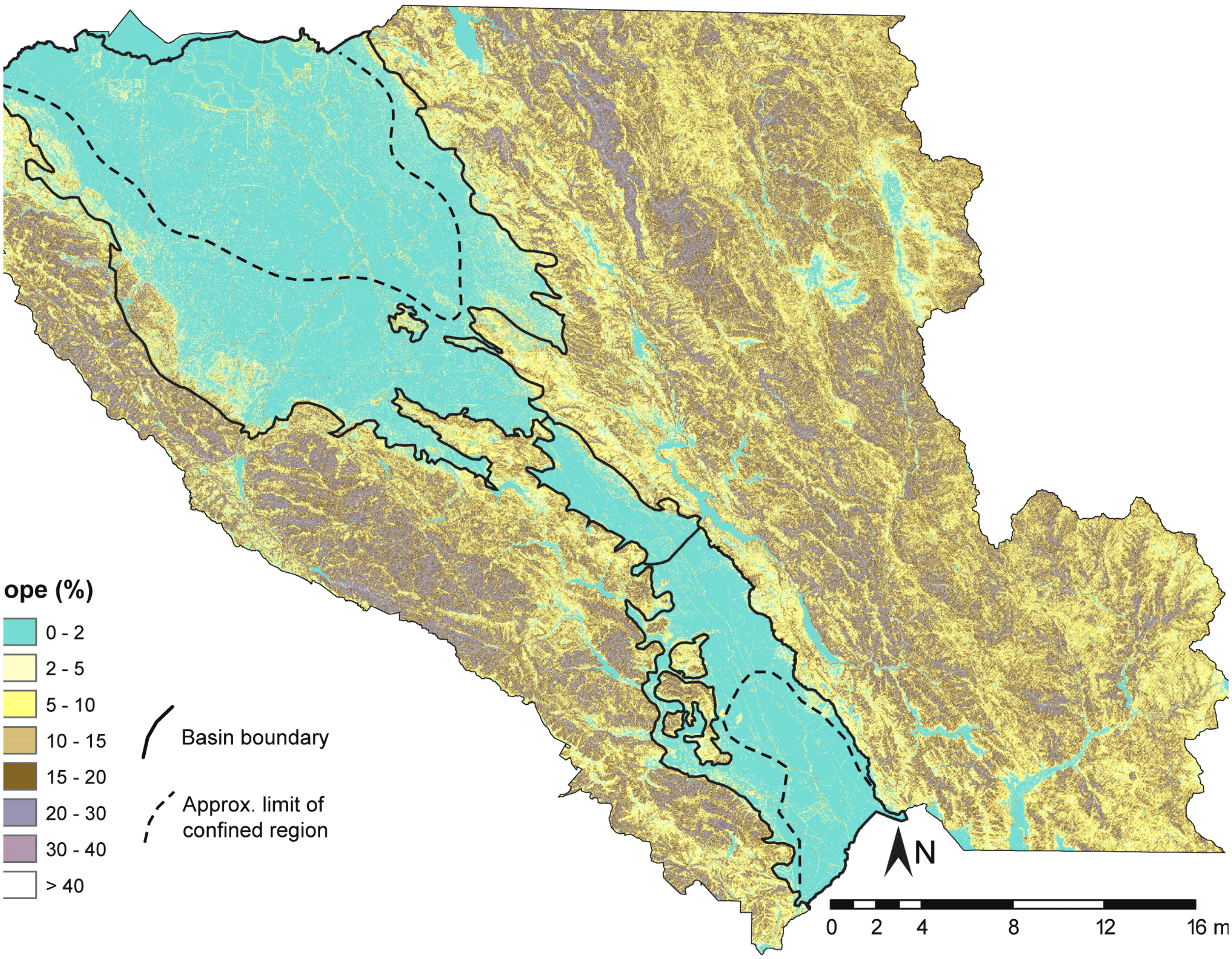


Figure III-8. Values of slope from the digital elevation model, used as a filter for Flood-MAR suitability maps (areas with slopes ≥10% removed from consideration).

Considerations for placement of a Flood-MAR project could include identification of parcels designated as open space, for which restoration goals might be consistent with enhanced infiltration for Flood-MAR (**Figure III-9**). Open space parcels could be additionally categorized based on ownership; flood zone designation; or presence of endangered, threatened, or endemic species. Additional considerations could include the boundaries of Valley Water benefit zones (**Figure I-1**), or the presence of disadvantaged communities. We also added data to the project showing the distribution of water quality indicators (**Figure III-10**). Whether these or other factors were considered to be positive or negative with respect to placement of a Flood-MAR project depends on numerous additional considerations, and it will often be useful to simply render maps of a Flood-MAR suitability index with an overlay of polygons representing additional information. Addition of these coverages also helps to illustrate the benefit of working directly with the GIS project, rather than as single-display maps, so that additional features can be added and symbology to clarify spatial variations.

d. Suitability ratings

Ratings for each factor used in the calculation of a suitability index were applied on a scale from 0 to 7, where lower ratings indicate less suitability for Flood-MAR and higher ratings indicate more suitability. The establishment of a rating scale for each factor is discussed in the next section. Once surface and subsurface factors were assigned spatially, three Flood-MAR suitability indices were calculated for the project region: surface suitability, subsurface suitability, and composite suitability. Each suitability index calculation was based on rated and weighted factors, using the following formulas:

$$SI_{\mathbf{surface}} = (0.33 \text{ x } IC_{\mathrm{r}}) + (0.33 \text{ x } LULC_{\mathrm{r}}) + (0.33 \text{ x } Geol_{\mathrm{r}}) \quad (2a)$$

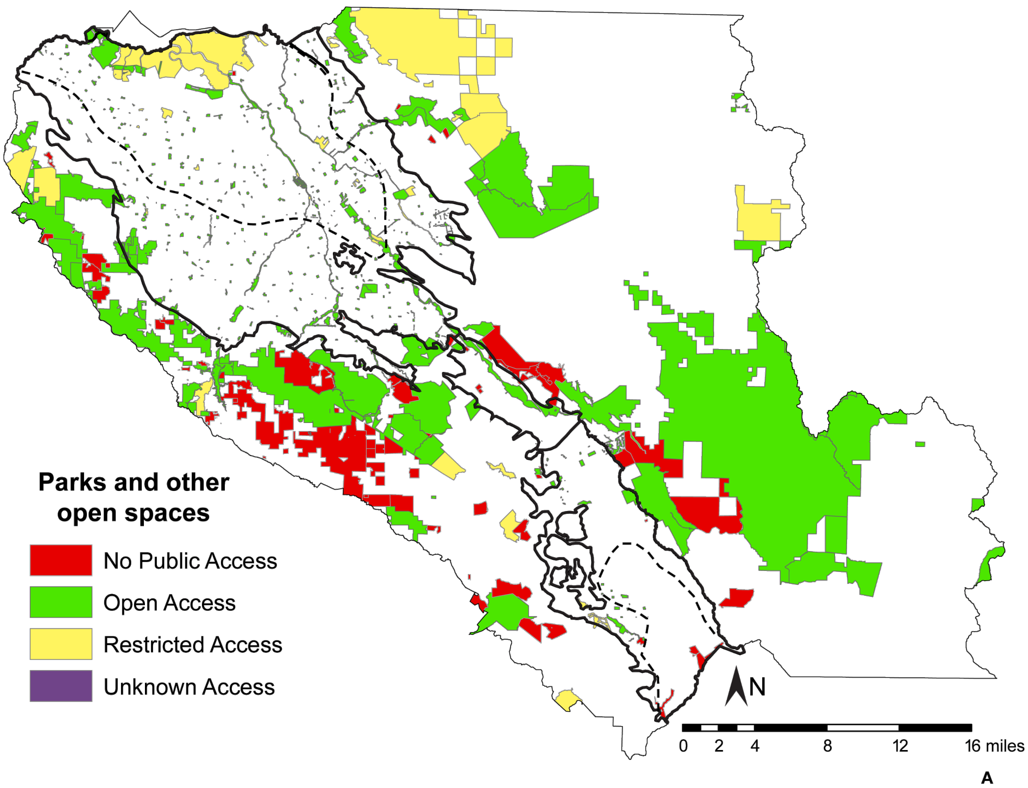
$$SI_{\mathbf{subsurface}} = (0.50 \text{ x } VZ_{\mathrm{r}}) + (0.50 \text{ x } CS_{\mathrm{r}}) \quad (2b)$$

$$SI_{\mathbf{composite}} = (0.6 \text{ x } SI_{\mathbf{surface}}) + (0.4 \text{ x } SI_{\mathbf{subsurface}}) \quad (2c)$$

with the last equation being equivalent to:

$$SI_{\mathbf{composite}} = (0.2 \text{ x } IC_{\mathrm{r}}) + (0.2 \text{ x } LULC_{\mathrm{r}}) + (0.2 \text{ x } Geol_{\mathrm{r}}) + (0.2 \text{ x } VZ_{\mathrm{r}}) + (0.2 \text{ x } CS_{\mathrm{r}})$$

The use of equal weights for the five main factors considered is broadly consistent with other analyses of MAR suitability (e.g., Sallwey et al., 2018). These formulae could be modified in the future on the basis of new information or to assess the sensitivity of associated calculations.



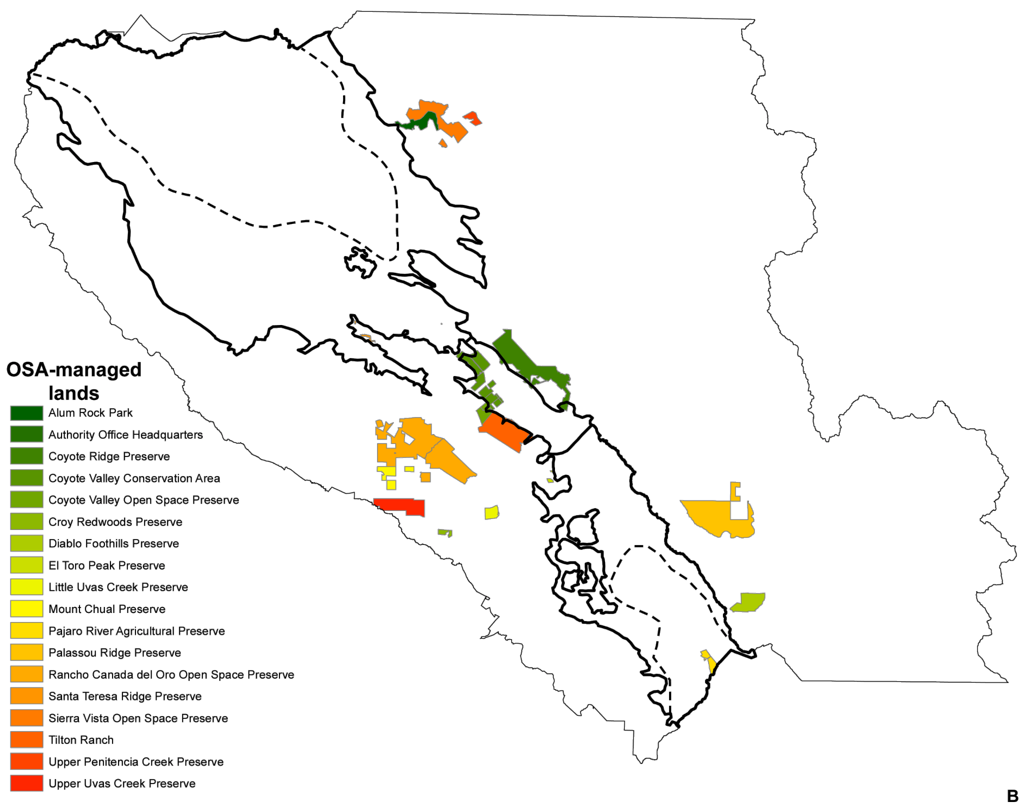


Figure III-9. Selected categories of open space, which could be used to focus application of suitability maps. **A.** Regional parks and related spaces. **B.** Properties managed by the Open Space Authority of Santa Clara County.

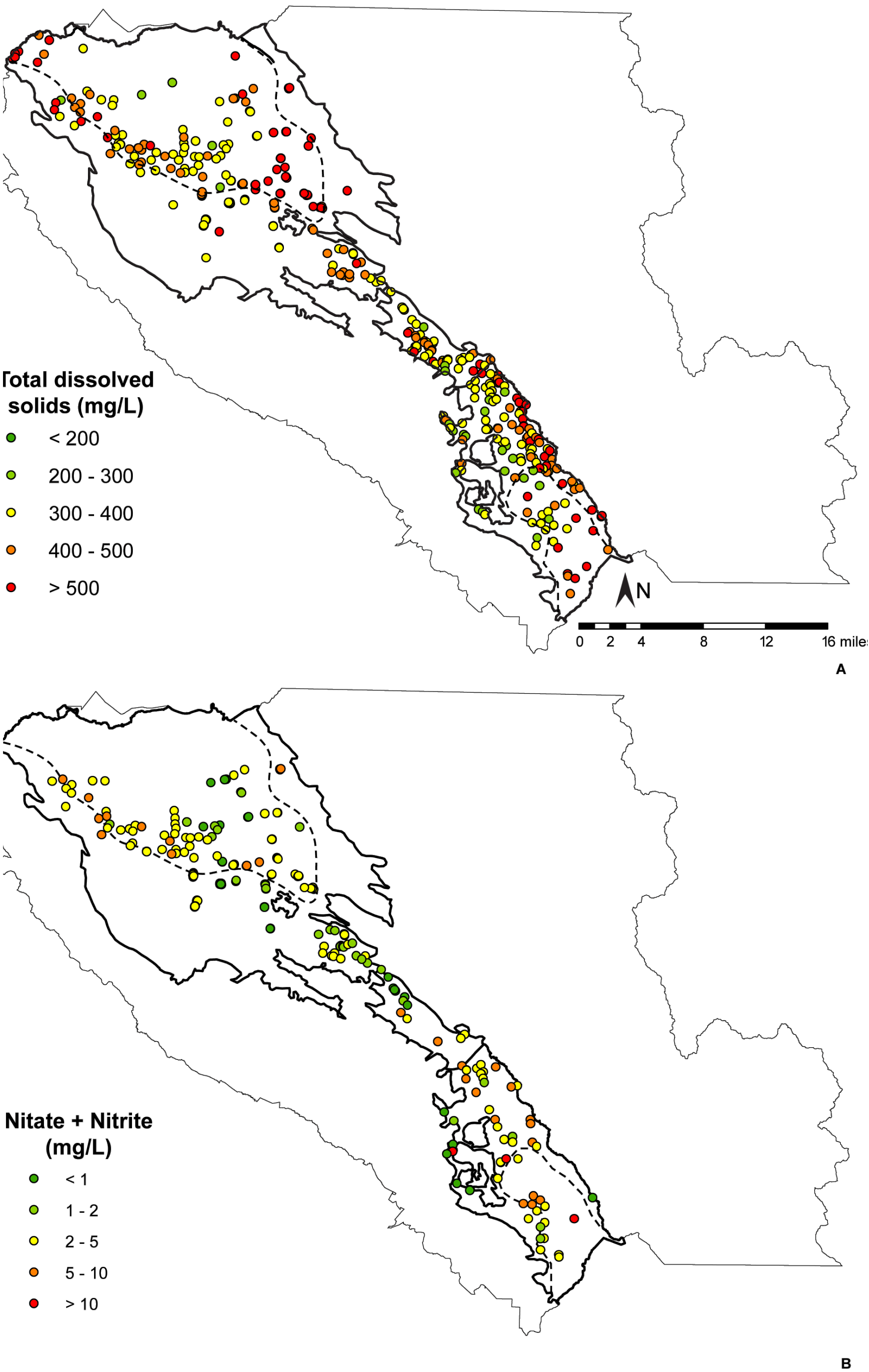


Figure III-10. Water quality indicator examples, which could be used to focus application of Flood-MAR projects. **A.** Total dissolved solids. **B.** Concentrations of nitrate+nitrite.

B. MAR Suitability Analyses

1. Surface factor ratings and suitability index

a. Infiltration capacity

The rating scale was set so that *IC* values that are moderately favorable for a Flood-MAR project would be rated IC_r = 3 to 4 on a scale of 0 to 7, representing values of *IC* = 1 to 2 ft/day (**Table III-2**). Areas with the highest infiltration capacity rating are located mainly in association with current streams, previous channels, and sandstone units in the Santa Cruz Mountains (**Figure III-11**). Active stream channels (either perennial or ephemeral) are not likely to be used for creation of new Flood-MAR projects, but near-stream areas could prove useful for this purpose if there is a suitable water supply available.

Overall, soils in Santa Clara County tend to be unfavorable for infiltration for recharge, with *IC* ≤ 1 ft/day ($IC_r \leq 2$) mainly because many of the valley fill and wetland units are a complex mixture of textures and depositional facies, including common fine units. About 10% of the study region has moderately to highly favorable soils based on *IC*, comprising ~90,000 acres (**Table III-2**). Within the groundwater management areas, favorable soils tend to occur in clusters, particularly at the southern end of Coyote Valley, the northern and southwestern side of Llagas Basin, and around the edges of the limit of confined aquifer conditions in the Santa Clara Plain (**Figure III-11**). In many cases, these are active, ephemeral, or paleo-stream channels or associated deposits, as identified in earlier studies.[61]

Table III-2. Summary of ratings for infiltration capacity.

Suitability Rating	Infiltration Capacity (ft/day)	Area (acres) [a]	% Land Area [a]
0	< 0.25	328,200	39.3
1	0.25 - 0.5	173,900	20.8
2	0.5 - 1.0	210,800	25.2
3	1.0 - 1.5	33,700	4.0
4	1.5 - 2.0	42,600	5.1
5	2.0 - 2.5	13,800	1.6
6	2.5 - 3.0	1,800	0.2
7	> 3.0	30,400	3.6

[a] Area rounded to nearest 100 acres. Percent land area calculated based on the total area represented in Santa Clara County.

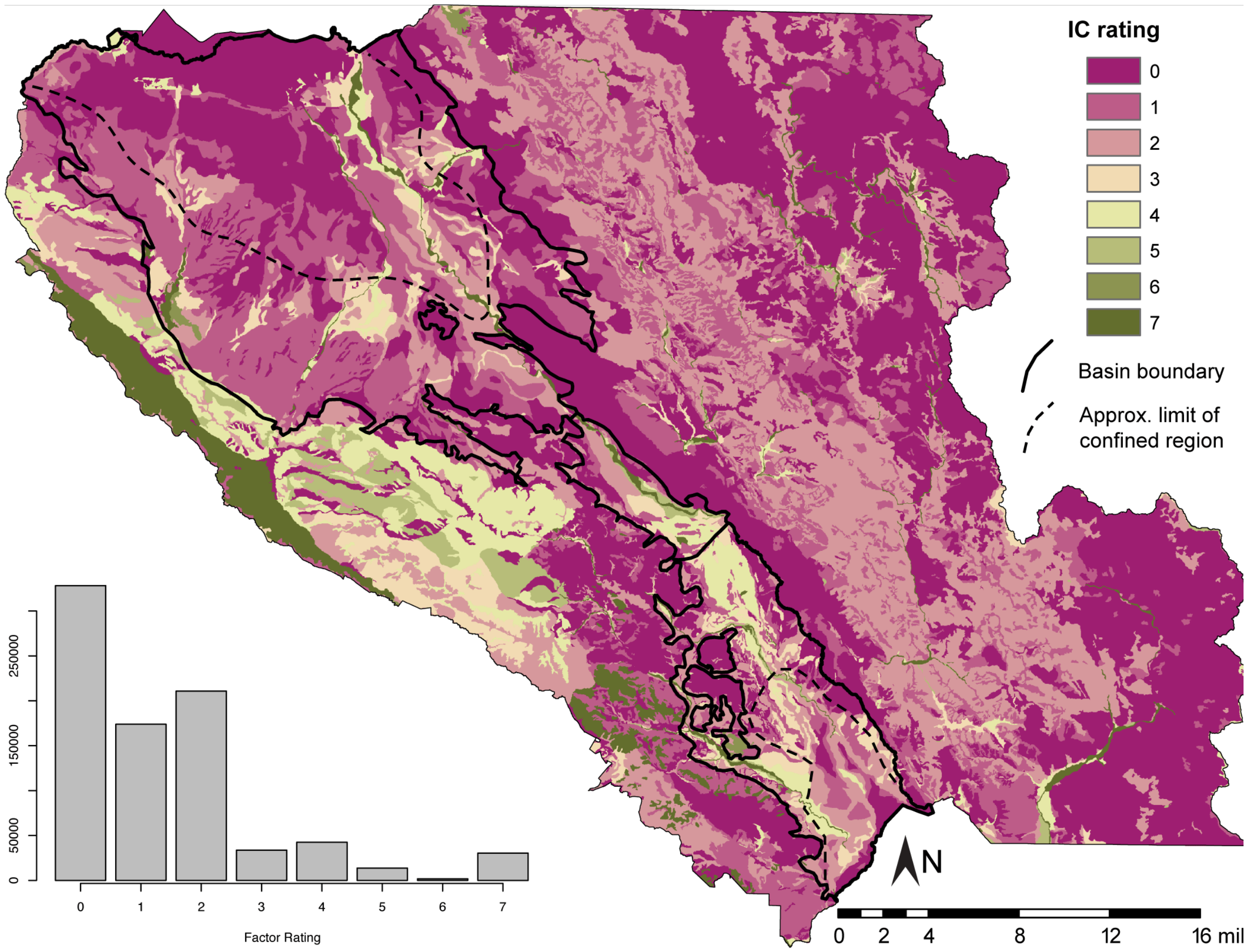


Figure III-11. Infiltration capacity ratings. Rating values defined in **Table III-2** and discussed in text.

b. Land use/land cover

Much of the project area appears to be favorable for Flood-MAR on the basis of land use/land cover (LULC) (**Figure III-12**). However, the regions with the most continuous favorable LULC ratings are outside the groundwater management areas, particularly outside the Santa Clara Plain. The rating system used for LULC extends across the full range of 0 to 7, but we elected to use a somewhat less granular categorization scheme, with six rating values (0, 1, 3, 5, 6, 7). $LULC_r = 0$ was assigned mainly for open water and wetlands (which often have hydrophobic soils), whereas $LULC_r = 1$ was assigned only for high-intensity development (urban areas) (**Table III-3**). Medium- and low-intensity development was rated 3 and 5, respectively, reasoning that the latter could prove suitable for Flood-MAR if there were sufficient open spaces capable of hosting a project. This could be compatible with developed land use if a parcel were zoned as a park or for environmental benefit.

Areas with *LULC* categories indicating extensive vegetation, other than wetland, were rated $LULC_r = 5$, 6, or 7 (**Table III-3**). Scrub/shrub and herbaceous landscapes were rated $LULC_r = 5$ and 6, respectively, and all forests, cultivated crops, and hay/pasture were rated $LULC_r = 7$. The latter rating deserves particular justification. Unlike other studies that favored particular crop types,[62] we are more neutral with regard to using this factor to indicate suitability, for several reasons. As noted previously, the presence of specific crops is likely to be a weak indicator of

Flood-MAR suitability on its own because (a) cropping changes over time, (b) within individual crops there can be large differences in landscape management, (c) and it is possible that a grower may wish to set aside some land for Flood-MAR, even if that land is productive. Alternatively, there could be incentives for land fallowing, or limitations in access to water for that makes land less valuable for agriculture.

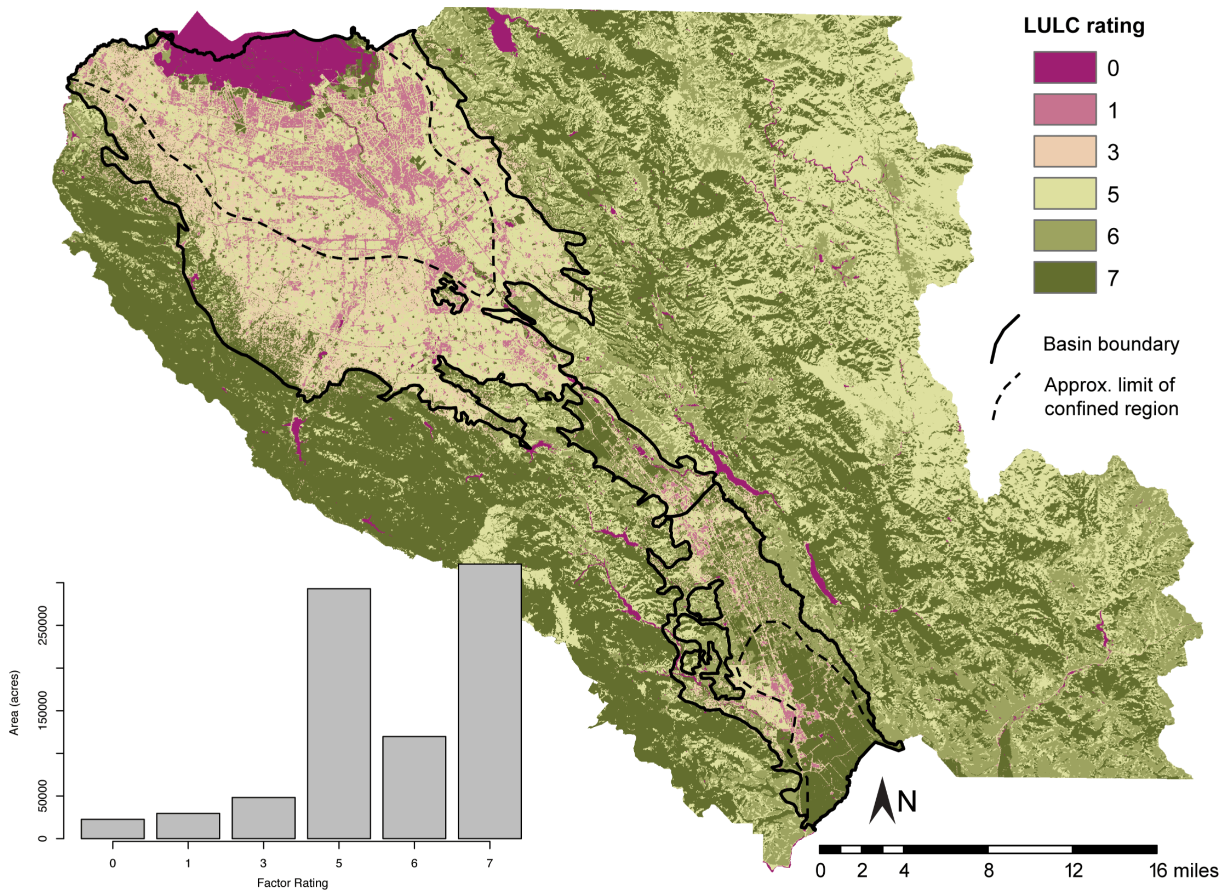


Figure III-12. Land use/land cover ratings. Rating values defined in **Table III-3** and discussed in text.

Table III-3. Summary of ratings for land use/land cover.

Suitability Rating	Land Use	Area (acres)	% Land Area [a]
0	Open Water, Woody Wetlands, Emergent Herbaceous Wetlands	22,600	2.7
1	Developed-High Intensity	29,600	3.5
3	Developed-Medium Intensity	48,300	5.8
5	Developed-Low Intensity, Shrub/Scrub	293,000	35.1
6	Herbaceous	119,700	14.3
7	Developed-Open Space, Barren Land, Deciduous Forest, Evergreen Forest, Mixed Forest, Hay/Pasture, Cultivated Crops	321,900	38.5

[a] Area rounded to nearest 100 acres, percent is relative to all of Santa Clara County.

There are exceptions to this approach that may be worth considering, for example areas planted in perennial crops that do not tolerate frequent or long-term inundation (e.g., stone fruit trees); but even in those areas, an infiltration basin with an area of 1 to 5 ac might be accommodated, particularly if that part of a parcel were not especially productive and had favorable characteristics for MAR. There also could be specific agricultural land uses that are contraindicators for Flood-MAR, e.g., dairy operations that tend to generate animal waste, and thus elevated TDS and nitrate values in runoff. The current framework allows for more specificity that could include lower $LULC_r$ for particular land uses, but we have not attempted this in the initial set of calculations.

c. Geology

Geology and landscape type categories were rated for 72 specific substrate types (**Figure III-13**). Quaternary units that include former stream channels have the highest geology ratings $Geol_r = 6$ or 7 (**Table III-4**), and tend to be found close to current/active channels. Other Quaternary valley fill and fluvial units generally have high ratings as well $Geol_r = 4$ or 5, but some units were largely undifferentiated (gravel to sand to silt to clay) or were identified as generally being older and more lithified, resulting in classification of $Geol_r = 3$. $Geol_r \leq 3$ were generally assigned to units that were Plio-Pleistocene or older, including crystalline rocks in the Santa Cruz Mountains.

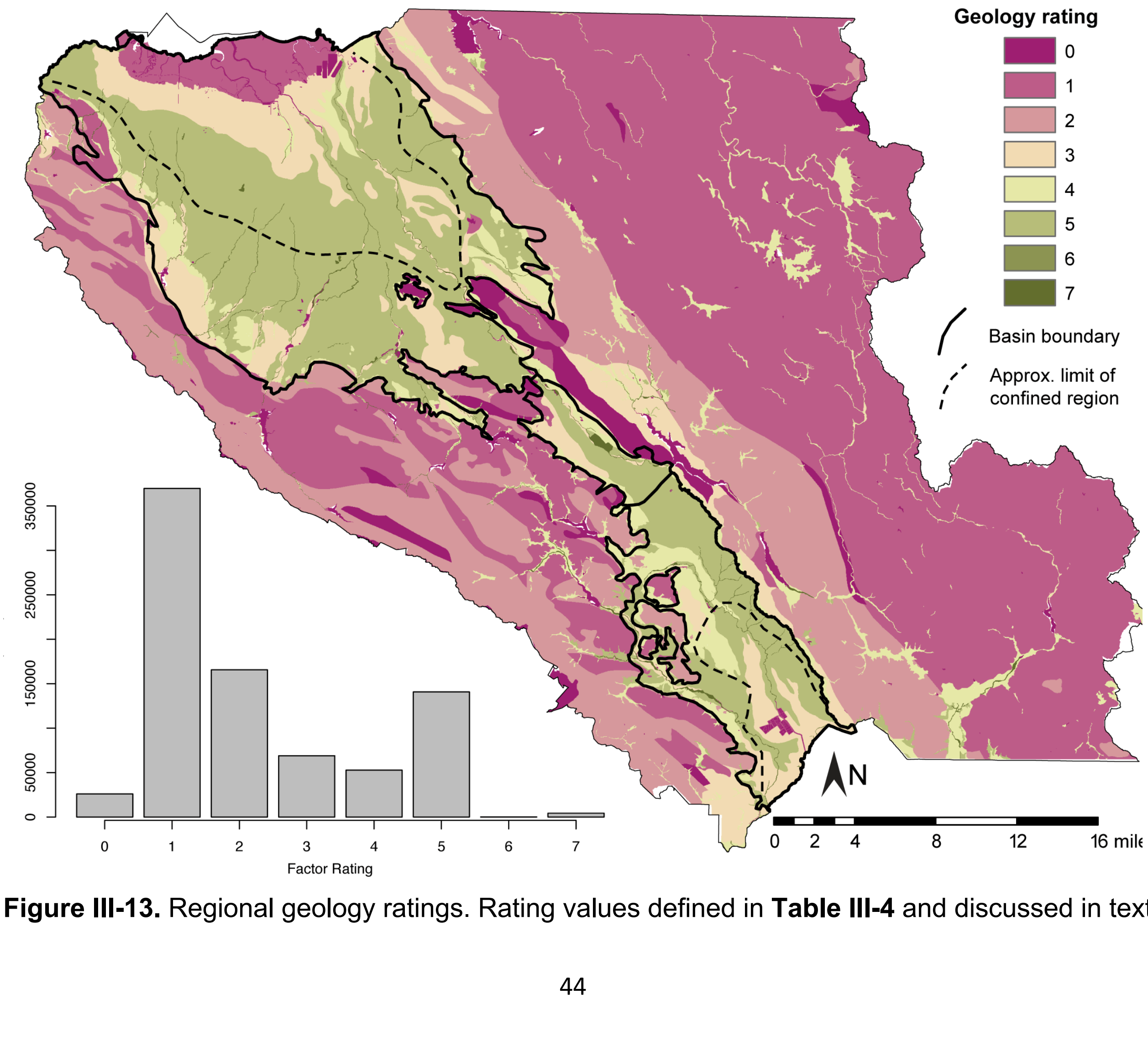


Figure III-13. Regional geology ratings. Rating values defined in **Table III-4** and discussed in text.

In general, the groundwater basins have more favorable geology for Flood-MAR, and there is considerable variability and structure (**Figure III-13**). More than 7% of the land area in Santa Clara County has geology characterized as $Geol_r \geq 5$, comprising nearly 60,000 acres, most of which is located in the groundwater management areas.

Table III-4. Summary of ratings for geology.

Suitability Rating	Lithology[a]	Area (acres)	% Land Area [b]
0	Ultramafic rocks, chiefly Mesozoic, unit 3 (Coast Ranges and Western Klamath Mountains), H2O, nm	26,000	3.1
1	Franciscan mélange/Franciscan Complex, unit 1 (Coast Ranges)/Tertiary intrusive rocks (hypabyssal), unit 2 (Quien Sabe Volcanic Field)/Qhbm/adf/Qhb/Qhf	370,000	44.6
2	Mesozoic volcanic rocks, unit 1 (Coast Ranges)/Cretaceous marine rocks (in part nonmarine), unit 1 (Coast Ranges)/Eocene marine rocks/Miocene marine rocks	166,000	20.0
3	Plio-Pleistocene and Pliocene loosely consolidated deposits/Pliocene marine rocks/Qhff/Qt/Qhfe/Qht/Qhty/Qhc-br/Qot/Qpt/Qht1/Qht2/Qt1/Qt2	69,000	8.3
4	Older Quaternary alluvium and marine deposits/Quaternary alluvium and marine deposits/Qha/Qa/Qpa/Qf/Qhfy/Qoa/Qhly-Qhty/Qhf-Qhff	52,700	6.4
5	Qhl1/Qpf/Qhly/Qhf1/Qhl/Qhf2/Qhf/Qof/Qhf-Qpf/Qhf-Qhl/Qhl-Qpf/Qof2/Qof1	141,000	17.0
6	Qhc-Qhly	65	0.01
7	Qhc/gq	4,300	0.5

[a] Lithologic units as identified on USGS geological maps. Full definitions available for all units in metadata on suitability rating factors, https://docs.google.com/spreadsheets/d/1qTl0mknAR5wT8NDZxh9YfkHwd_g0RzeQ6uQ0Umtm9KA/edit?usp=sharing

[b] Percent land area was calculated based on the total area of Santa Clara County.

d. Surface suitability index

The three surface factors were weighted equally to derive a Flood-MAR Suitability Index (**Figure III-14**). Because the three surface factors applied are mostly independent (perhaps with limited correlation between IC_r and $Geol_r$), the resulting map is highly granular and shows considerable variability and complexity across the project region. We also filtered out all pixels having slopes ≥10%, which removed mountainous areas to the west and east of the groundwater basins. More than 7% of the land area has Flood-MAR Suitability based on surface data characterized as $SI_{surface}$ = 4 to 7, comprising ~60,000 acres, most of which is located in the groundwater management areas, and particularly Coyote Valley and the Llagas Subbasin. If we consider areas with $SI_{surface}$ = 3-4, the center of the range calculated, this comprises another ~19% of land area, an additional ~150,000 acres that is (once again) mostly in the groundwater management areas.

On the one hand, this is a promising result, suggesting that there may be many opportunities around the Valley Water service area to accomplish Flood-MAR goals. On the other hand, one application for this GIS project is to set priorities for specific regions, so having too much of an area rated highly could make screening difficult. The addition of subsurface data helps to narrow the spatial focus of potential Flood-MAR project sites.

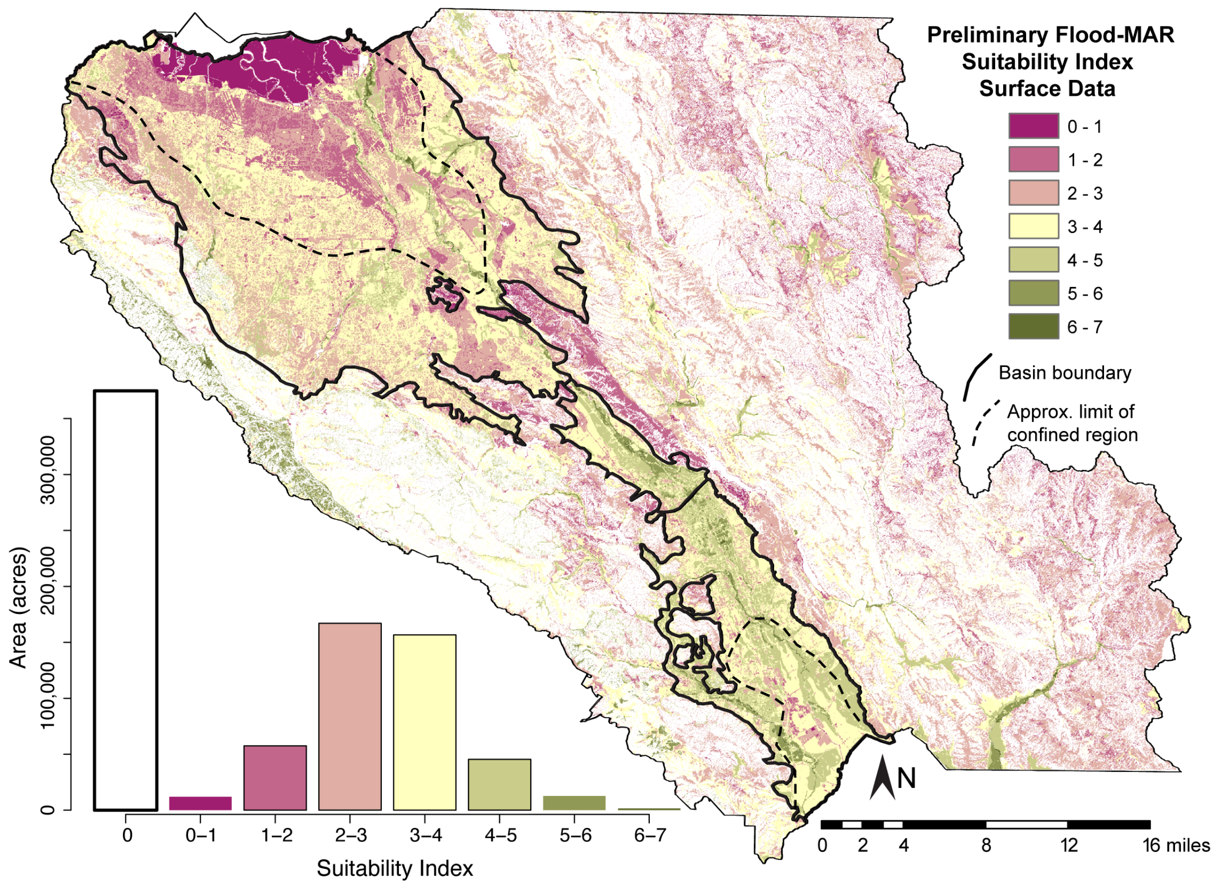


Figure III-14. Preliminary Flood-MAR suitability index for full project area based on surface datasets, filtered to remove areas with slopes ≥10% (resulting in suitability index = 0). Factors used for this analysis include: infiltration capacity, geology, and land use/land cover, filtered using the digital elevation model. Areas with each index are listed in **Table III-5**.

Table III-5. Summary of Flood-MAR suitability based on surface datasets.

Suitability Rating	Area (acres) [a]	% Land Area [a]
0 [b]	374,800	45.3
0 - 1	11,900	1.4
1 - 2	57,500	6.9
2 - 3	167,000	20.2
3 - 4	156,600	18.9
4 - 5	45,500	5.5
5 - 6	12,700	1.5
6 - 7	1,600	0.2

[a] [a] Area rounded to nearest 100 acres, percent is relative to all of Santa Clara County.

[b] Includes land filtered by slope >10%.

2. Subsurface suitability ratings and index

a. Vadose zone thickness

Ratings for vadose zone thickness have the most complex (and arguably, the most subjective) categorization system. At the limits, a high water table with $DTW < 10$ ft is considered too shallow for Flood-MAR; mounding and saturation of shallow soils are likely to occur ($VZ_r = 0$ in this analysis). A somewhat thicker vadose zone, 10-20 ft, was assigned $VZ_r = 1$. At the other extreme, a vadose zone >200 ft thick indicates that groundwater is so deep that surface infiltration seems likely to be perched rather than reach a depth from which groundwater pumping is common ($VZ_r = 2$). VZ values between 20 and 200 ft were assigned intermediate VZ_r values, with the peak in thickness assigned for $VZ_r = 7$ when $DTW = 20\text{-}60$ ft (**Table III-6**).

Table III-6. Summary of ratings for vadose zone thickness.

Suitability Rating	Vadose Zone Thickness (ft)	Area (acres) [a]	% Land Area [a]
0	< 10	44,000	15.7
1	10 - 20	34,300	12.2
7	20 - 60	91,400	32.6
5	60 - 100	31,300	11.2
3	100 - 200	27,400	9.8
2	> 200	51,500	18.4

[a] Area rounded to nearest 100 acres, percent is relative to extent of the vadose zone thickness coverage.

Much of the project area (groundwater basins for this and other subsurface datasets) has relatively high vadose zone ratings ($VZ_r = 5$ to 7, 44% of the basin areas), particularly unconfined areas in the Santa Clara Plain and Llagas Basins, and the southern and eastern sides of Coyote Valley (**Figure III-15**). We used a limited rating scale, omitting values of 4 and 6, mainly because there was not enough confidence in finer granularity in classification (e.g., it was not clear if *DTW* = 120 ft is really much better than *DTW* = 175 ft).

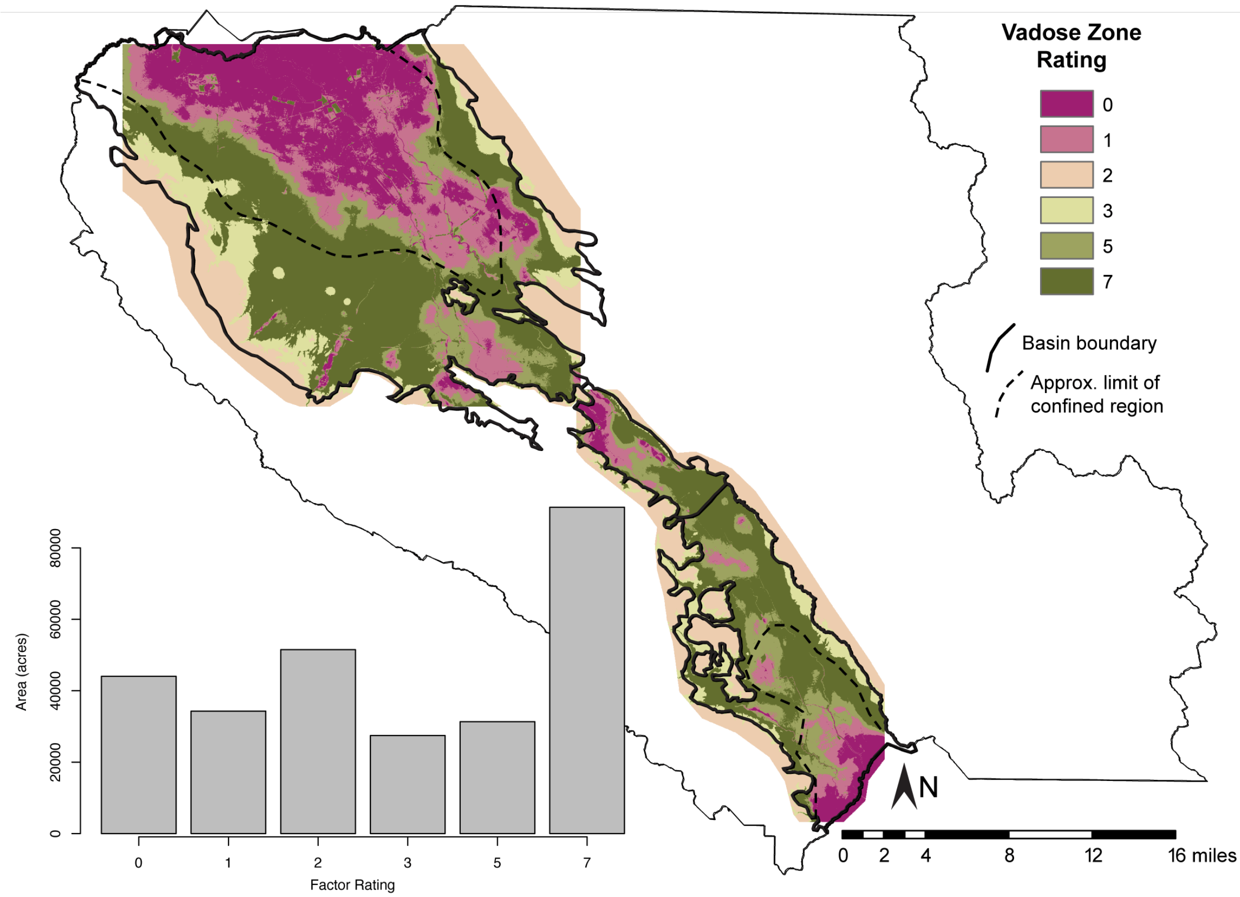


Figure III-15. Vadose zone thickness ratings. Rating values defined in **Table III-6** and discussed in text.

b. Climate sensitivity of groundwater levels

Climate sensitivity of groundwater levels is more variable across the project region, with scattered patches having elevating ratings (**Figure III-16**). This factor is based on the difference in water levels during dry and wet periods; it is intended to indicate which areas appear to be capable of receiving recharge or being highly susceptible to differences in pumping rates or patterns. Large areas of elevated CS_r (5 to 7) are found in the Santa Clara Plain, but there are also patches in Coyote Valley and the Llagas Subbasin, particularly along the eastern basin edges. These areas comprise >20% of the groundwater management areas, covering >50,000 acres (**Table III-7**).

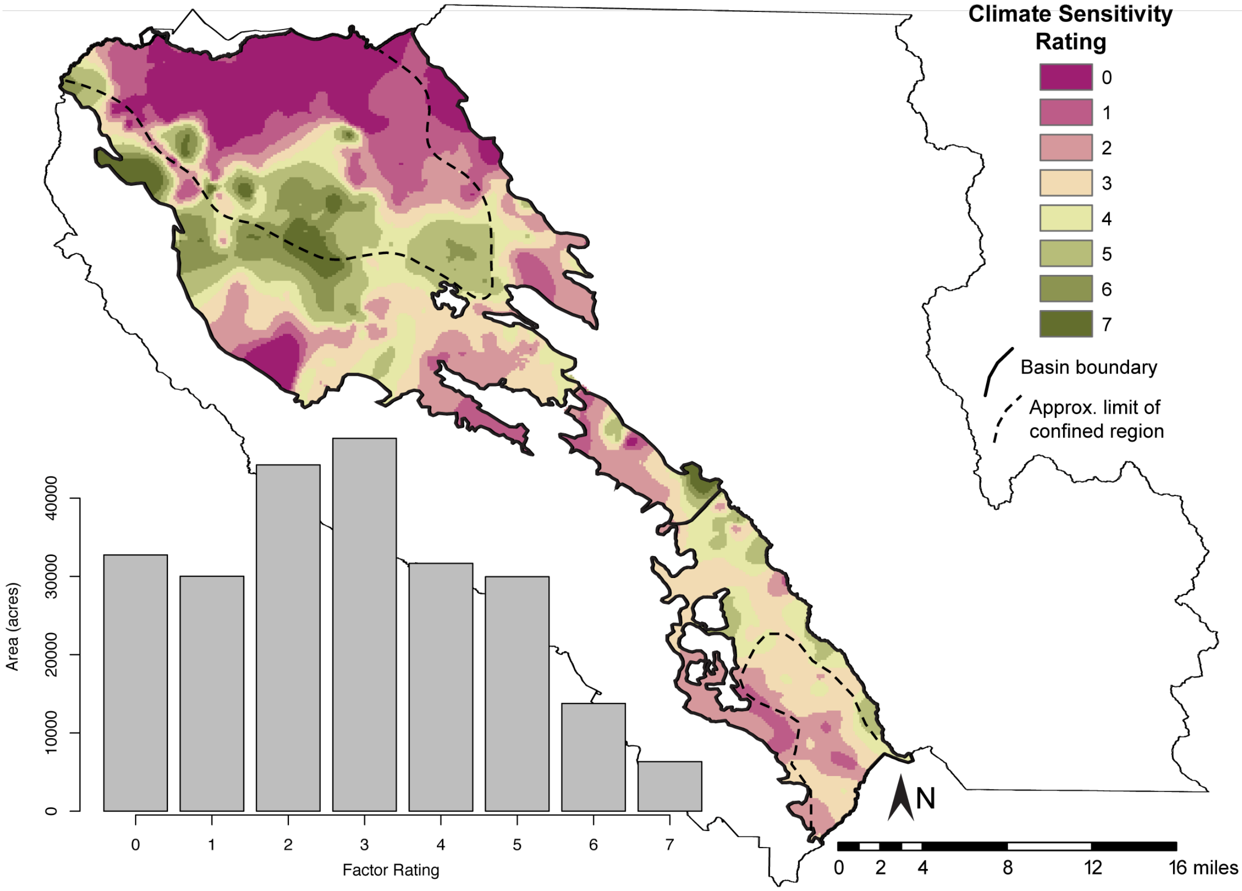


Figure III-16. Ratings of climate sensitivity of groundwater levels. Rating values defined in **Table III-7** and discussed in text.

Table III-7. Summary of ratings for climate sensitivity of groundwater water levels.

Suitability Rating	Difference in depth to water, DTW_{dry} - DTW_{wet} (ft)	Area (acres) [a]	% Land Area [a]
0	< 0	32,700	13.9
1	0 - 20	30,000	12.7
2	20 - 40	44,300	18.7
3	40 - 60	47,600	20.2
4	60 - 80	31,700	13.4
5	80 - 120	30,000	12.7
6	120 - 160	13,800	5.8
7	> 160	6,300	2.7

[a] Area rounded to nearest 100 acres, percent is relative to extent of the climate sensitivity coverage.

c. Transmissivity

Transmissivity ratings (T_r = 6 to 7) are highest in unconfined areas where there are thick and conductive surface layers, with the highest values in southern Santa Clara Plain and central Coyote Valley. Moderate ratings (T_r = 4 to 5) are common in clusters throughout the project region, including much of Llagas Subbasin (**Figure III-17**). Because the Santa Clara Plain groundwater model incorporates no variation in horizontal conductivity in the confined area, variations in T_r result entirely from variations in cell thickness. Somewhat greater granularity is apparent in Coyote Valley and the Llagas Subbasin (**Figure III-17**). The majority of the management areas have shallow transmissivity on the upper 50% of the rating scale (**Table III-8**). As noted previously, ratings for transmissivity are not included in the final suitability analysis.

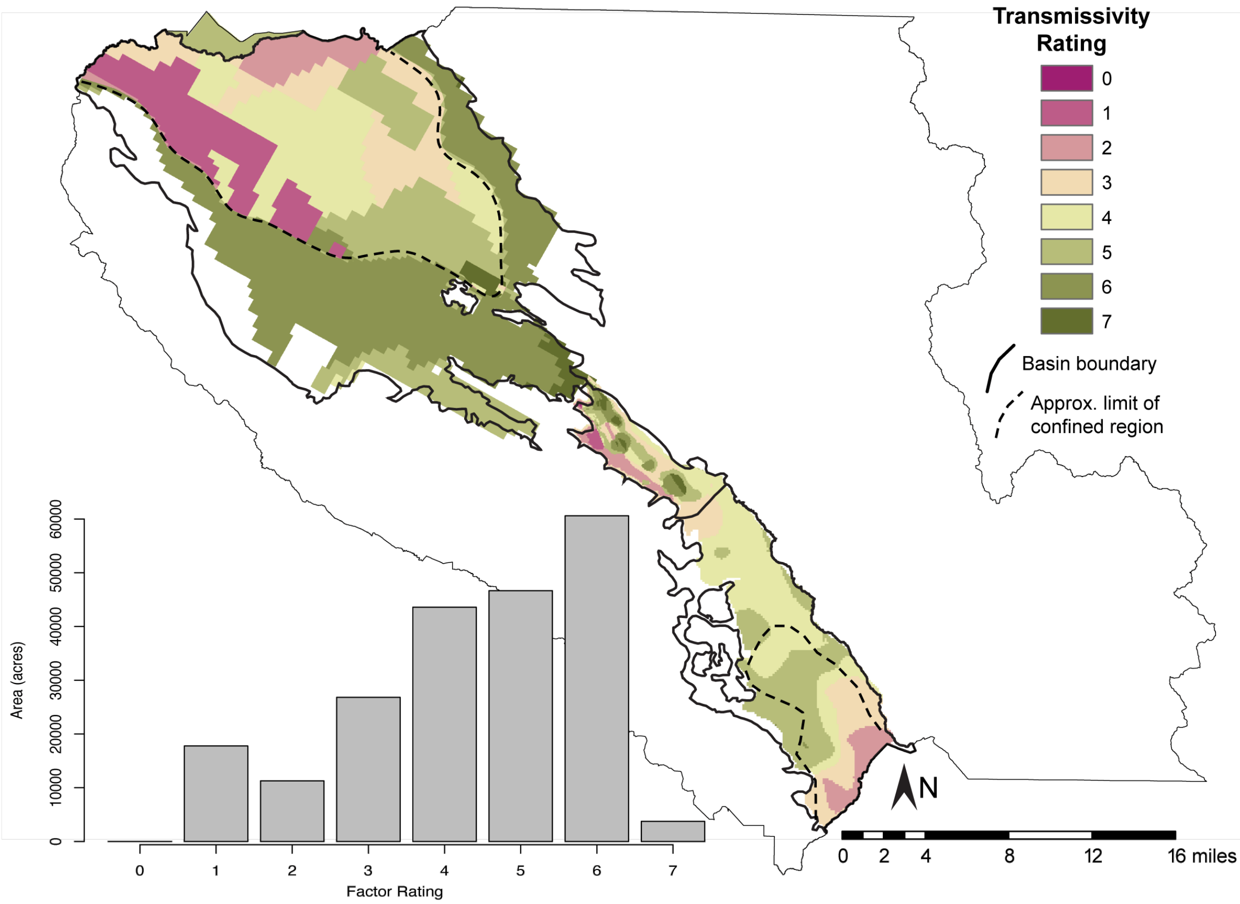


Figure III-17. Ratings of transmissivity from groundwater model datasets. Rating values defined in **Table III-8** and discussed in text.

Table III-8. Summary of ratings for transmissivity.

Suitability Rating	Transmissivity (ft^2/day)	Area (acres) [a]	% Land Area [a]
0	0 - 500	0	0
1	500 – 1,250	17,800	8.4
2	1,250 – 2,500	11,300	5.4
3	2,500 – 5,000	26,800	12.7
4	5,000 – 10,000	43,600	20.7
5	10000 – 20,000	46,700	22.2
6	20,000 – 40,000	60,600	28.8
7	> 40,000	3,700	1.8

[a] Area rounded to nearest 100 acres, percent is relative to the total extent of the transmissivity coverage.

d. Available storage

The distribution of rated storage factors (S_r) is similar in some ways to that for shallow transmissivity, with the lowest values in confined areas (**Figure III-18**). The overall range is low, with 85% of the study areas apparently having <5 ft of available storage ($S_r \leq 5$, product of vadose zone thickness and specific yield). There is reason to suspect that values of aquifer thickness and/or specific yield might be underrepresented in computer models. Particularly in the Llagas Subbasin, the majority of the study region is rated as having essentially no available storage, mainly on the basis of low S_y values. Given the distribution of values derived from the regional computer models, there would be little benefit to expanding the storage rating scale to boost intermediate values (S_r = 3 to 5), but this analysis suggests that it may be worth considering a more holistic assessment of basin stratigraphy that incorporates detailed information available from groundwater well logs and other data.[63] Still, >25% of the study region has moderate to high S_r values (**Table III-9**). As noted previously, ratings for available storage are not included in the final suitability analysis.

e. Subsurface suitability index

Subsurface datasets were combined to generate a Flood-MAR suitability index based on these data coverages alone (**Figure III-19, Table III-10**). Given limitations in transmissivity and storage data as represented in regional groundwater models, and following discussion with Valley Water personnel, we eliminated use of these factors and focused instead on vadose zone thickness and climate sensitivity of water levels (**Figure III-1**). The areas with the highest suitability index for Flood-MAR based on subsurface data are in unconfined regions of the three groundwater management areas where water levels are moderately deep, allowing for reasonable transit times for infiltration to reach the water table and demonstrating considerable variability between wet and dry climate periods. There is a relatively uniform distribution of $SI_{\text{subsurface}}$ ratings, and ~50% of the study region has moderate to high suitability based on subsurface data, $SI_{\text{subsurface}}$ = 4 to 7 (**Table III-10**). During an earlier analysis, when transmissivity and storage data originating from groundwater models was applied to subsurface suitability assessment, the mapped pattern was much the same, although average values were lower overall and there was less area with higher ratings, mainly because storage ratings tend to be low (compare **Figure III-19** to **Figure III-18**).

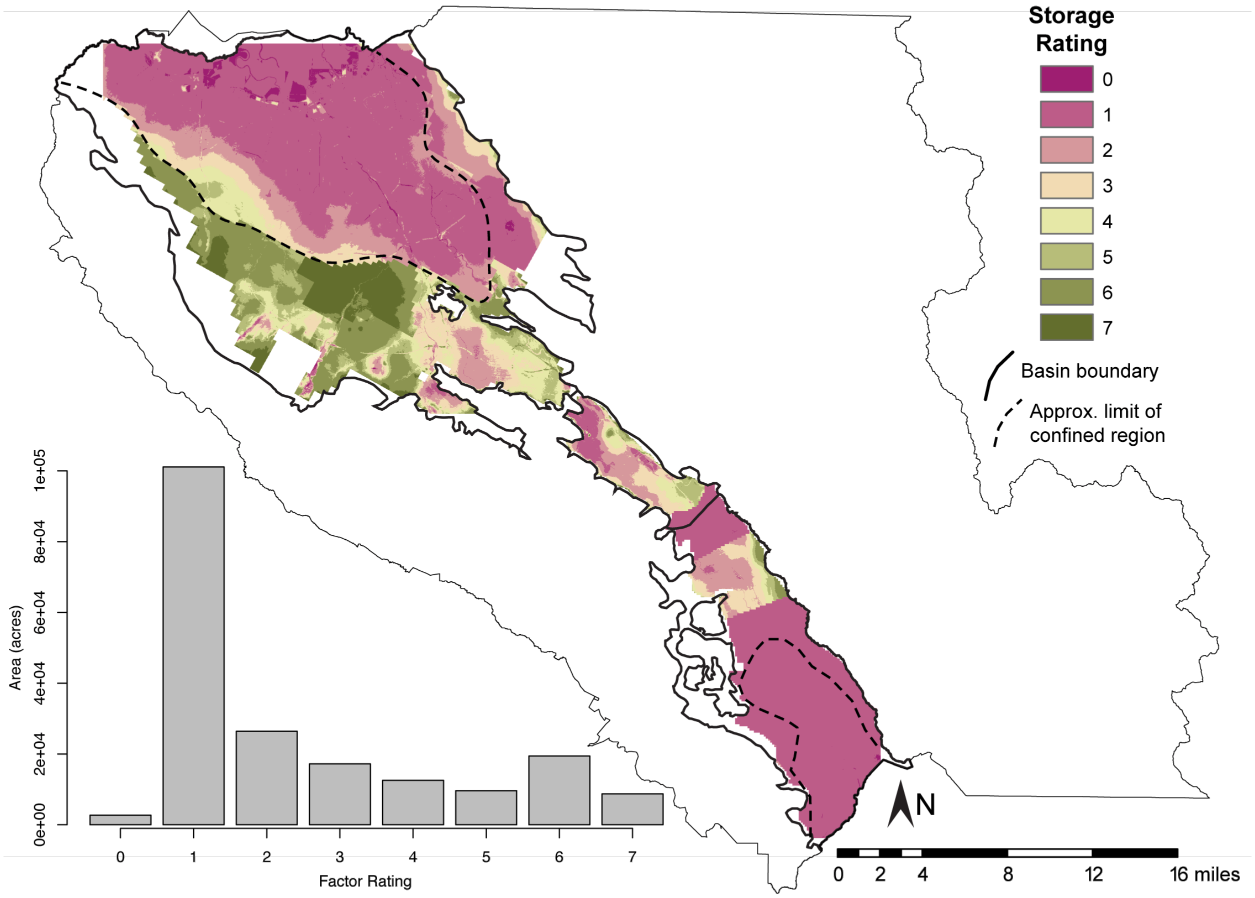


Figure III-18. Ratings of available storage. Rating values defined in **Table III-8** and discussed in text.

Table III-9. Summary of ratings for available storage.

Suitability Rating	Storage (ft)	Area (acres) [a]	% Land Area [a]
0	0	2,700	1.4
1	0 - 1	101,100	51.1
2	1 - 2	26,400	13.4
3	2 - 3	17,200	8.7
4	3 - 4	12,600	6.4
5	4 - 5	9,600	4.9
6	5 - 10	19,400	9.8
7	> 10	8,700	4.4

[a] Area rounded to nearest 100 acres, percent is relative to extent of the storage coverage.

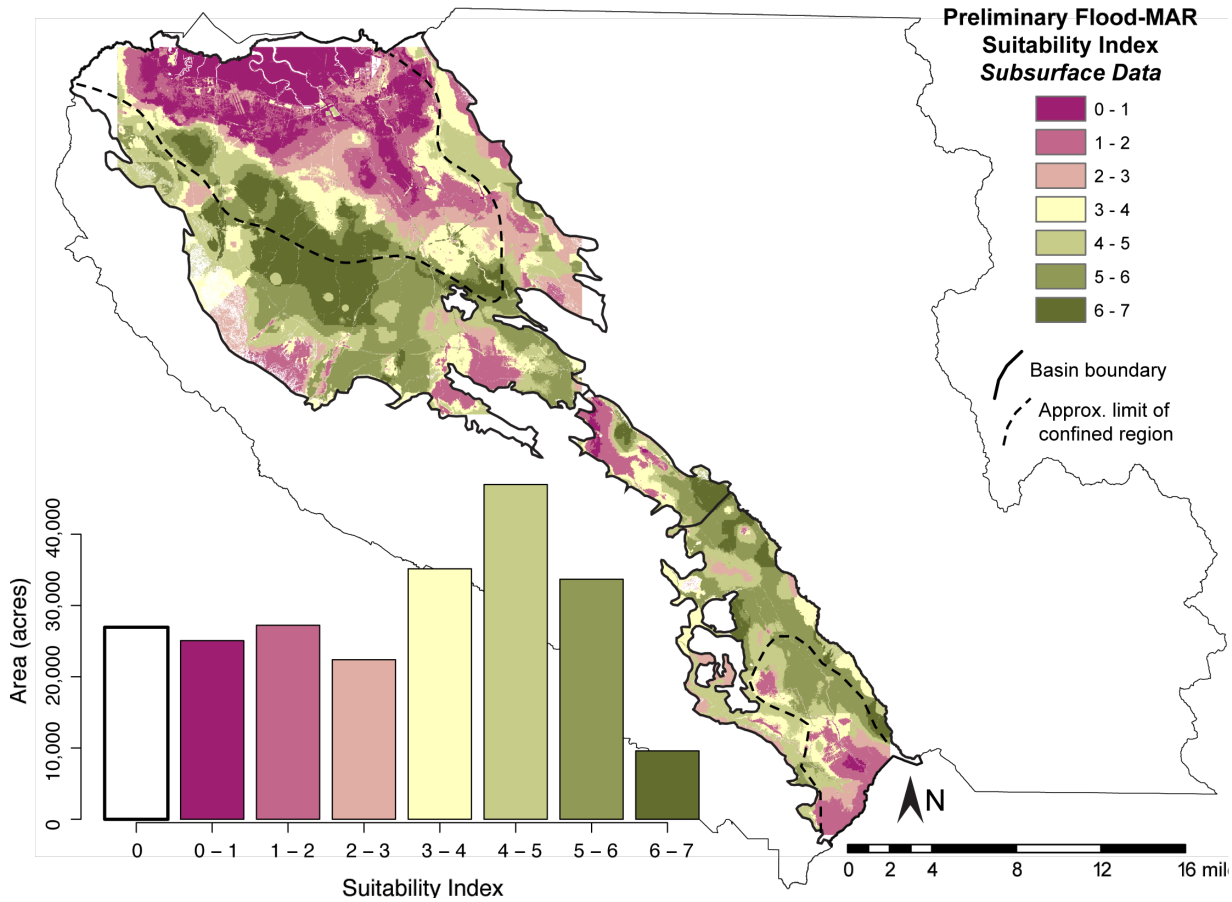


Figure III-19. Preliminary Flood-MAR suitability index for groundwater basins based on subsurface datasets. Factors used for this analysis were vadose zone thickness and climate sensitivity of groundwater levels. Shallow aquifer properties as represented in groundwater models were applied initially, but not used in the (final) analysis shown above because of coarse resolution and concerns about reliability based on model calibration. Areas with each index are listed in **Table III-10**. White spaces within the subbasins in panel A indicate areas where vadose zone thickness is not interpolated because of limited depth-to-water data.

Table III-10. Preliminary Flood-MAR suitability based on subsurface datasets.

Suitability Rating	Area (acres) [a]	% Land Area [a]
0	26,900	11.9
0 - 1	25,100	11.0
1 - 2	27,200	12.0
2 - 3	22,400	9.9
3 - 4	35,100	15.5
4 - 5	47,000	20.7
5 - 6	33,700	14.8
6 - 7	9,600	4.2

s

[a] Area rounded to nearest 100 acres, percent is relative to extent of the subsurface rating coverage.

3. Composite suitability index

A composite Flood-MAR suitability index map, based on all surface and subsurface factors that were rated and weighted, shows considerable spatial variability (**Figure III-20**). This is largely a consequence of the granularity and resolution of surface datasets. More than 35% of the study region for which all datasets exist (i.e., within the groundwater subbasins) has $SI_{composite}$ values of 4 to 7, comprising ~79,000 acres (**Table III-11**). Importantly, patches with elevated $SI_{composite}$ values are found throughout the basins.

Three additional displays illustrate ways in which preliminary Flood-MAR *SI* maps can be helpful in planning and screening project activities. **Figure III-21** shows $SI_{composite}$ with Valley Water's existing managed recharge operations, including in-stream recharge and groundwater recharge ponds, which are located outside the confined areas within the groundwater subbasins. The location of the mapped boundary between the confined and unconfined aquifer conditions is based on long-standing geologic interpretations, going back decades. While this boundary is considered approximate due to geologic uncertainty and aquifer heterogeneity, it continues to be supported by substantial geologic and hydrogeologic data. Flood-MAR projects would likely be prioritized outside the confined areas in the recharge zones and in locations that complement the spatial coverage of existing managed recharge operations.

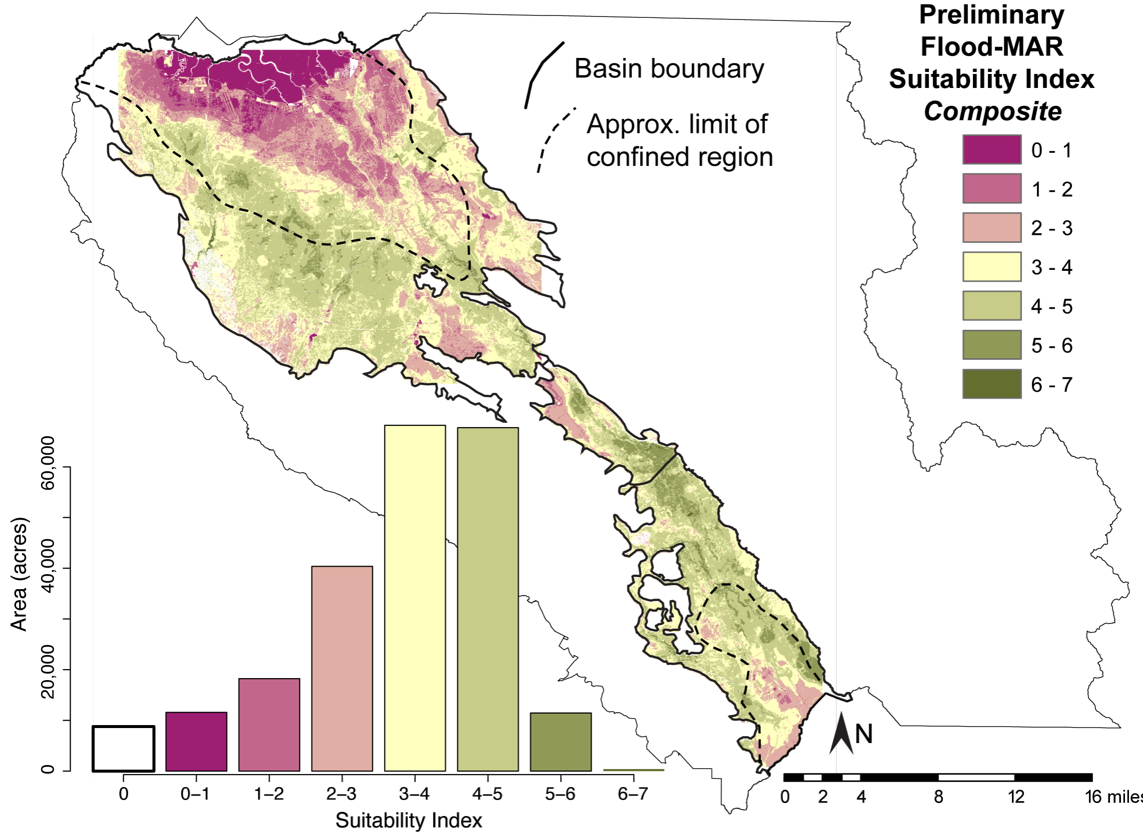


Figure III-20. Preliminary Flood-MAR suitability index for groundwater basins based on composite of surface and subsurface datasets, filtered to remove areas with slopes ≥10%. Combined surface and subsurface factors were weighted evenly (**Figure III-1A**). Areas with each index are listed in **Table III-11**. White spaces within the subbasins in panel A indicate areas where vadose zone thickness is not interpolated because of limited depth-to-water data.

Table III-11. Preliminary Flood-MAR suitability based on composite analysis.

Suitability Rating	Area (acres) [a]	% Land Area [a]
0	8,800	3.9
0 - 1	11,600	5.1
1 - 2	18,200	8.0
2 - 3	40,400	17.8
3 - 4	68,200	30.1
4 - 5	67,700	29.9
5 - 6	11,500	5.1
6 - 7	400	0.2

[a] Area rounded to nearest 100 acres, percent is relative to extent of the composite rating coverage.

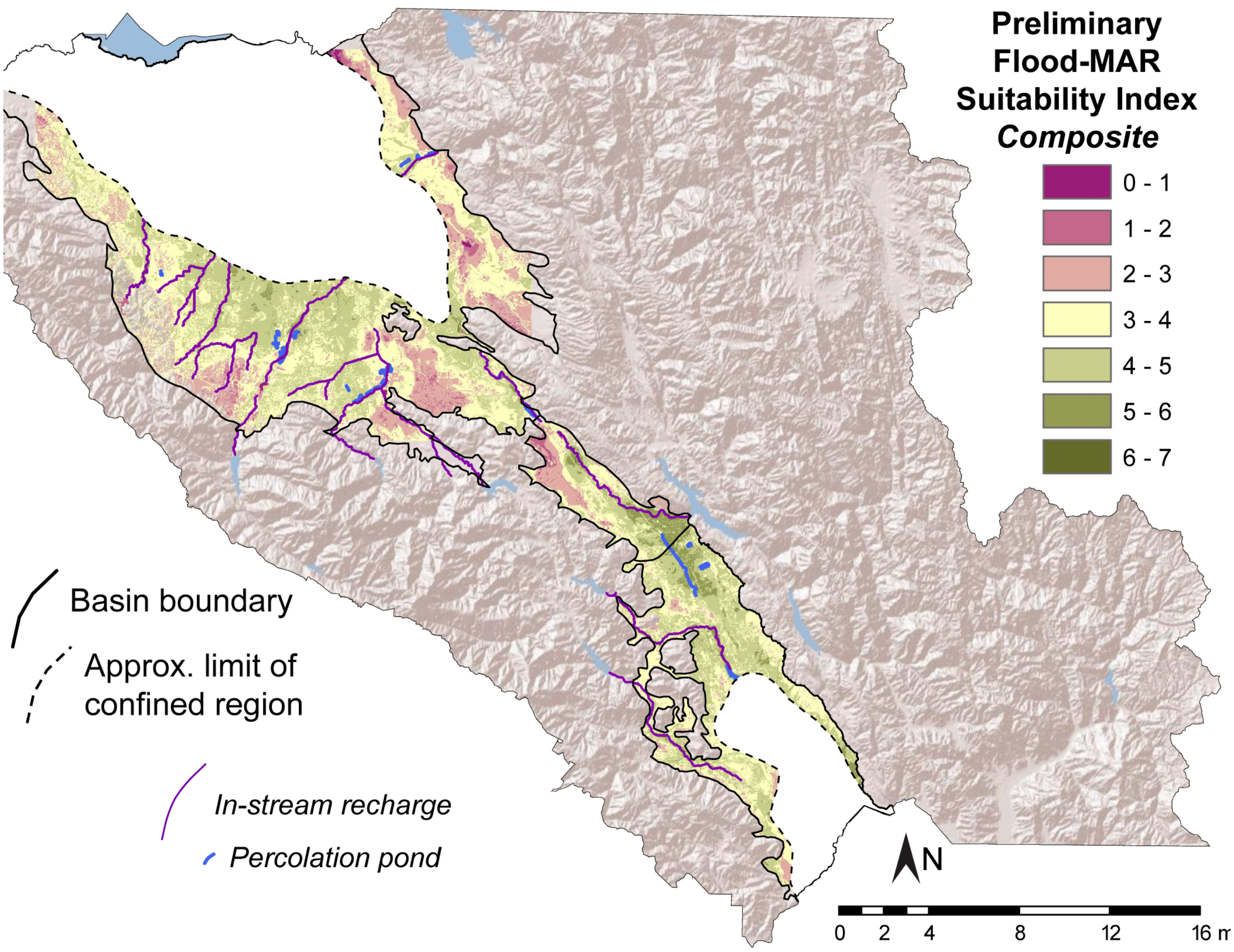


Figure III-21. Valley Water's existing managed recharge operations and losing streams overlayed on the preliminary Flood-MAR suitability index map. Comparison of these data allows identification of potential Flood-MAR project sites that complement existing activities and conditions. Areas having confined conditions are denoted with white polygons having dashed boundaries.

A plot of water quality (represented by TDS concentration) on top of $SI_{\text{composite}}$ helps to show where areas with elevated suitability have more or less salt in ambient groundwater (**Figure III-22A**). Depending on project goals, Flood-MAR projects could be prioritized where was quality is better or worse, implying consequent application of recovered water having higher quality or likely dilution where groundwater is impaired, respectively. A map showing parks and related open spaces over $SI_{\text{composite}}$ (**Figure III-22B**) could help with identification of potential project sites that could help to generate multiple ancillary benefits, including improved habitat, where there are fewer concerns about food safety compared to areas that are developed for agriculture. These maps are shown as examples; one benefit of generating a working GIS project is that this allows for new factors to be considered, analyses to be revised, and new maps generated as program and project ideas develop. The working GIS also allows for higher-resolution assessment of potential site locations than is apparent on printed pages or image files with a fixed raster format.

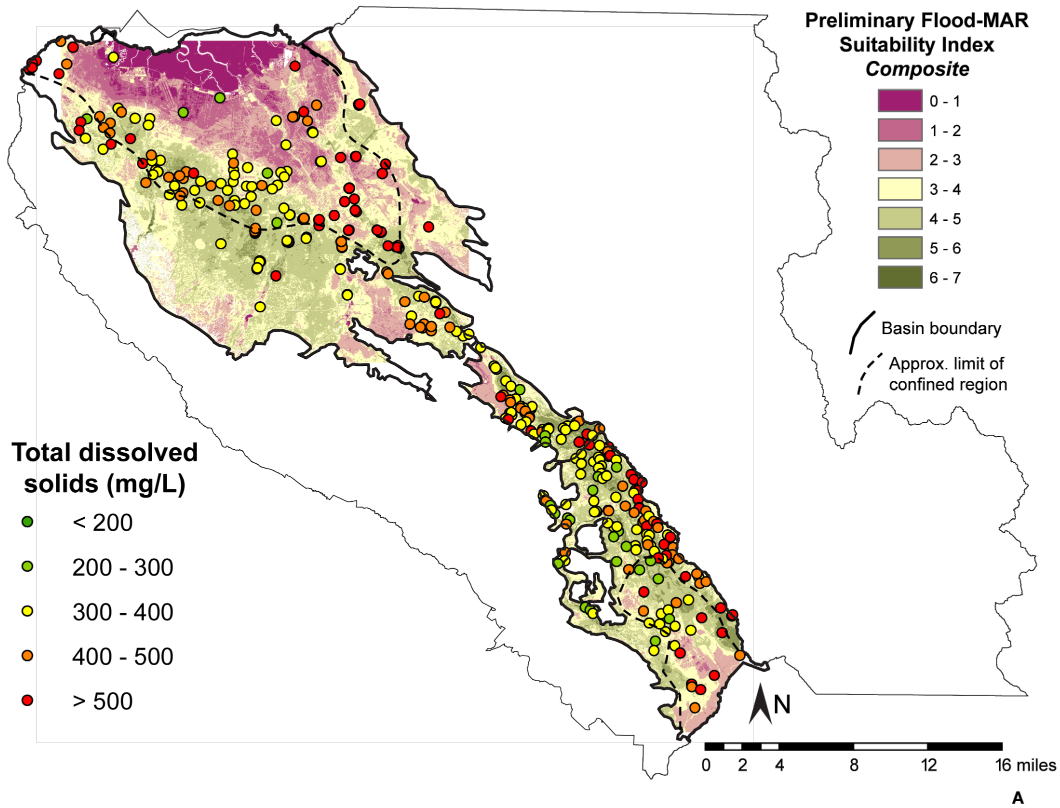
C. Discussion of Results, Limitations, and Next Steps

1. Use and limitations of work to date

This GIS project should prove useful to Valley Water and their stakeholders, contractors, and collaborators in exploring options for developing a Flood-MAR program in the Valley Water service area. Resulting *SI* maps (**Figures III-14, III-19, and III-20**) suggest that there could be opportunities, but also indicate important limitations to this approach. First, mapping of Flood-MAR suitability should be considered as useful mainly as a screening tool, particularly in the early stages of program and site assessment. It can also be useful for explaining why a site that "seems good" to a stakeholder or based on initial inspection may not be suitable because subsurface conditions are often not well correlated to those seen at the surface.

Even within this context and use case, the *SI* maps are fundamentally limited by the accuracy and resolution of available data. For surface coverages like *LULC*, these can change over short time periods, and factor coverages derived over multiple years (or even decades) could result in inconsistent merging of data periods. For subsurface coverages like transmissivity or available storage, there are limitations based on model resolution and the direct measurements that provided the basis for calibrating groundwater models. Groundwater models have been calibrated multiple times over a period of years, beginning when there was much less available data and the development of a three-dimensional stratigraphic model was more difficult than it would be today, and the resolution of these models is relatively coarse.

We encourage considering the datasets used in this study to be a useful snapshot of the state of available knowledge, a foundation upon which Valley Water can build greater understanding and aid in systematic decision making about if, how, and where to create a Flood-MAR program and develop initial projects. Because the main product of this work is a dynamic GIS project, not a small series of static maps, the potential for expansion and application of this work can grow over time. The dynamic nature of the GIS also allows for a sensitivity study to assess how robust the *SI* maps may be to different choices in the MCDA process.



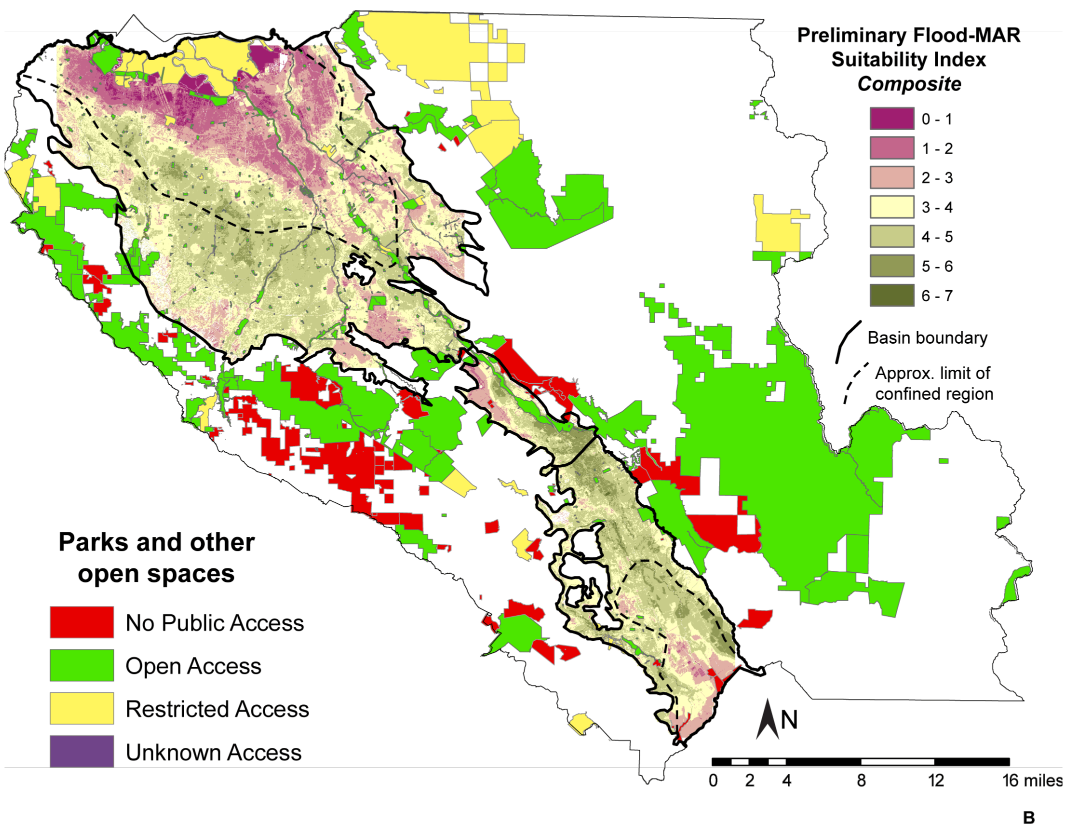


Figure III-22. Examples of data overlays that could be used to focus on specific areas for potential Flood-MAR projects, with composite suitability index used as base map. **A.** Water quality indicator (total dissolved solids). **B.** Open space.

2. Additional filters and constraints that could be applied

Numerous additional considerations were not included in this pre-feasibility assessment. Perhaps the most important of these is an evaluation of available water supplies. In the Pajaro Valley, a similar GIS-based assessment of Flood-MAR suitability was augmented by hydrologic runoff analyses, using a catalog of climate responses under different land-use scenarios, to quantify how much stormwater runoff could be generated at potential project sites.[64] Deterministic simulations of this kind are certainly useful, but they require compilation and manipulation of dozens of high-resolution datasets, then running numerical models and performing a complex calibration process. It may be that some form of statistical assessment could provide useful indications of opportunities for stormwater collection in non-urban areas within the Valley Water service area. Other potential water sources in support of Flood-MAR could, in principle, include storm flows in creeks and streams, advanced purified water, or imported water. However, Valley Water presently has sufficient managed recharge facilities to recharge its available local and imported water. In addition, there are infrastructure limitations that would pose challenges for delivering advanced purified water to a decentralized system of Flood-MAR basins. Some assessment of water supply options is provided in Part II.

Given options for water supplies, as well as methods for accomplishing Flood-MAR objectives, water cost and value considerations could be incorporated into the MCDA process for assessing site suitability. Valley Water could also take into account the presence of disadvantaged communities or other social factors, and potential benefits of Flood-MAR efforts for baseflow and aquatic systems. As previously noted, this project is being delivered as a working GIS that can be updated, revised, or modified to incorporate priorities and values as desired and as conditions and interests shift over time.

3. Implications and Next Steps

Maps of Flood-MAR suitability can be used to focus (a) incorporation of additional datasets that currently exist, (b) generation of new datasets that could be useful for improving the *SI* analyses, and (c) screening or targeting specific locations for potential Flood-MAR projects. These next steps could be managed in series or parallel.

SI maps indicate that there could be many good opportunities to accomplish Flood-MAR objectives in the Valley Water service area. In general, the Flood-MAR opportunities appear to be most common (as a percentage of groundwater management areas) in the Coyote Valley and Llagas Subbasin. Areas with the highest suitability include old stream channels and other features that have relatively coarse surface and near-surface lithologies, as well as room in the subsurface to receive and transmit excess surface water.

Part III of this report and the associated GIS project should be considered in the context of the findings in **Part II**, which focuses on institutional, incentive, legal, and policy issues. In particular, cost and access considerations could be important filters that help to focus attention on specific physical locations. If institutional and suitability indicators are positive, initial field visits and exploration of water supply options may be justified. It may also be worth considering larger-scale efforts in data collection and generation of datasets that could be added to the existing GIS. Most MAR suitability studies have focused on surface data coverages, but the complexity of the hydrogeologic framework in Valley Water's groundwater basins could help to justify updating the three-dimensional stratigraphic understanding of one or more of these systems, perhaps in concert with efforts to add resolution to representation of groundwater flow processes simulated with numerical models. The latter could aid in testing of Flood-MAR scenarios. The effort needed to revise the subsurface stratigraphic framework would be significant. For comparison, analysis of ~1,000 groundwater well logs in the Pajaro Valley to define the complex layering and variability of subsurface deposits was a multi-year effort, with a large USGS and agency team, as part of development of a new, regional groundwater model.[65]

D. Summary of Findings and Recommendations

Multicriteria decision analysis of spatial data from the Valley Water service area, using a GIS, suggests that there are numerous locations where surface and subsurface conditions are favorable for Flood-MAR. Within the three primary groundwater management areas, preliminary Flood-MAR suitability based on a composite MCDA using surface and subsurface data is relatively high across ~79,000 acres, equivalent to >35% of the land area. Sites with the highest suitability for Flood-MAR tend to be located where many of these criteria are satisfied: on old stream channels, on and near active (although often ephemeral) stream channels, and on other coarse Quaternary fluvial and alluvial deposits; where land is undeveloped, has low-intensity development, or is used for agricultural activities; where there is a vadose zone 20-100 ft thick; where there have been large differences in groundwater levels during dry climate periods compared to wet periods; and where shallow aquifer properties include high transmissivity and/or high potential for storage of supplemental recharge.

Conditions in the Santa Clara Plain appear to be most favorable for Flood-MAR along the western and southern margins, around and outside of the region dominated by confined conditions. Areas that are unfavorable for Flood-MAR include those underlain by fine-grained bay, wetland, and estuarine deposits. Groundwater levels are relatively high and space for augmenting storage is limited within the urbanized core of this management area, where Valley Water efforts in MAR have operated successfully for decades, but other areas could be considered if suitable water sources were found.

Conditions in the Coyote Valley appear to be most favorable for Flood-MAR along the southern and eastern half of the basin, particularly along active and old stream channels and other fluvial deposits. The northwestern part of Coyote Valley is part of the Laguna Seca wetland complex that has a shallow water table and hydrophobic soils, making it unfavorable for Flood-MAR activities.

Conditions in the Llagas Subbasin appear to be most favorable for Flood-MAR in the northern half and along western margin of the basin, particularly where fluvial deposits cut across areas having finer soils. The southern part of this basin is mapped as being mostly confined, and the regional groundwater flow direction is to the south-southeast and out of the basin, so focusing on northern areas may be most beneficial in terms of improving resource conditions.

There are multiple steps that Valley Water may find useful in advancing Flood-MAR efforts in its service area; these are not mutually exclusive, and it will likely accelerate the pace of progress to undertake more than one at a time.

- The MCDA was completed using a stand-alone GIS with a limited suite of available data coverages. More datasets could be added if it were decided that standard rating scales could be applied. For example, a dataset showing proximity to losing stream reaches could be added if this were considered to be desirable as a means to enhance aquatic ecosystems, or water quality data could be gridded and added based on whether it would be preferred to adding recharge to areas with higher or lower water quality indicators.

- The existing MCDA can be used to start identifying potential field sites, allowing for a quantitative feasibility assessment of specific project options like site access, permitting, and available water supplies. For the latter variable, an assessment of drainage areas and runoff potential could help to identify sites that meet some threshold criteria (e.g., 200 AFY of available runoff at a single project during a median water year, based on historical or project hydrologic conditions).
- Existing MCDA datasets can be updated to generate new data coverages that will provide additional benefit to Valley Water operations. As one possible example, knowledge of subsurface aquifer properties is currently limited by the resolution and accuracy of existing groundwater models. It is likely that hundreds of well logs that were not available when these models were initially developed could be used to generate a higher-resolution representation of subsurface geological conditions, and this information could be used to assess likely transmission and storage properties. This would be a major effort and is probably not justified on the basis only of improving the MCDA for Flood-MAR; but if an improved stratigraphic representation were helpful for updating groundwater models, it could provide co-benefits for Flood-MAR assessment.
- Potential Flood-MAR sites identified by Valley Water personnel or service area constituents that pass a desktop assessment (including consideration of water supplies, access, and other factors) could be prioritized for nested and increasingly detailed field investigations, to help screen out areas that are not likely to result in a successful project. A typical field assessment might include one or more of these steps:
    - Systematic geophysical surveys using electrical, radar, and/or seismic methods, to determine the site-specific layering and nature of subsurface materials in the upper 75-150 ft-below ground surface.
    - Exploratory drilling using a relatively efficient approach like direct push to collect geotechnical data and/or continuous cores, to assess soil texture, available carbon, shallow groundwater levels, and other characteristics.
    - Monitoring of rainfall on site and in areas contributing to drainage, and potentially measuring (and sampling) runoff if channelized flow occurs, to better understand local patterns and magnitudes relative to those available from long-term meteorological stations.
    - Sampling of local production wells, or monitoring wells if available, with repeat visits on a monthly or quarterly schedule. Standard water quality panels can be run to improve understanding of local groundwater quality and variability.
    - Sites that look favorable following one or more of the criteria noted above could be tested directly for infiltration conditions, at a scale of tens of ft^2 to acres, if there were access to a suitable water supply for multi-day testing.

Designing, creating, and operating Flood-MAR projects remains at the forefront of technical and institutional innovation. Each region and every potential site is different, and while there are many practices that have proven successful in other areas, a staged and thoughtful approach is important, as is the recognition that one goal of testing and evaluation is to eliminate sites that are not likely to work for Flood-MAR. Evaluating five or ten sites may be required in order to find one or two that have a high probability of success. Screening of projects and sites that would not work for Flood-MAR is an essential part of building a successful Flood-MAR program.

Additional considerations for developing a Flood-MAR program are listed and discussed in Part II of this report. In aggregate, these analyses should help Valley Water to develop a plan for advancing Flood-MAR, helping to distribute a variety of benefits across their service area, and strengthening the resilience and sustainability of essential water resources.

Endnotes

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[1] *See* Mahesh L. Maskey Mustafa S. Dogan, Angel Santiago Fernandez-Bou, Liying Li, Alexander Guzman, Wyatt Arnold, Erfan Goharian, Jay R. Lund, and Josue Medellin-Azuara, *Managing Aquifer Recharge to Overcome Overdraft in the Lower American River, California, USA*, 14 WATER 966 (2022), *available at* https://doi.org/10.3390/w14060966*; see also Climate Change Basics*, CALIFORNIA DEPARTMENT OF WATER RESOURCES, https://water.ca.gov/Water-Basics/Climate-Change-Basics (last visited July 27, 2022); California Department of Water Resources, News Release: State Agencies Fast-track Groundwater Recharge Pilot Project to Capture Flood Waters for Underground Storage (Jan. 13, 2021), *available at* https://water.ca.gov/News/News-Releases/2023/Jan-23/State-Agencies-Fast-track-Groundwater-Recharge-Pilot-Project.

[2] Herman Bouwer, *Artificial recharge of groundwater: hydrogeology and engineering*, 10 HYDROGEOLOGY JOURNAL 121–142 (2002), *available at* https://doi.org/10.1007/s10040-001-0182-4.

[3] P. Dillon, S. Toze, D. Page, J. Vanderzalm, E. Bekele, J. Sidhu, and S. Rinck-Pfeiffer, *Managed aquifer recharge: rediscovering nature as a leading edge technology*, 62 WATER SCIENCE & TECHNOLOGY 2338–2345 (2010).

[4] *See, e.g.,* Janny Choy and Geoff McGhee, *Groundwater: Ignore It, and It Might Go Away*, WATER IN THE WEST (July 31, 2014), https://waterinthewest.stanford.edu/groundwater/overview/.

[5] Elad Levintal, Maribeth L. Kniffin, Yonatan Ganot, Nisha Marwaha, Nicholas P. Murphy, and Helen E. Dahlke, *Agricultural managed aquifer recharge (Ag-MAR)—a method for sustainable groundwater management: A review*, 53 CRITICAL REVIEWS IN ENVIRONMENTAL SCIENCE &TECHNOLOGY 291–314 (2022), *available at* https://doi.org/10.1080/10643389.2022.2050160.

[6] *Flood-Managed Aquifer Recharge*, CALIFORNIA DEPARTMENT OF WATER RESOURCES, https://water.ca.gov/Programs/All-Programs/Flood-MAR (last visited Feb. 21, 2023).

[7] California Department of Water Resources, White Paper: Flood-MAR: Using Flood Water for Managed Aquifer Recharge to Support Sustainable Water Resources (June 2018) ("2018 Flood-MAR White Paper"), *available at* https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Flood-Management/Flood-MAR/DWR_FloodMAR-White-Paper_a_y20.pdf.

[8] *See* 2018 Flood-MAR White Paper, *supra* note 7, at 23–28.

[9] Santa Clara Valley Water District, Groundwater Management Plan for the Santa Clara and Llagas Subbasins at 1-7 (2021) ("2021 Groundwater Management Plan"), *available at* https://www.valleywater.org/your-water/where-your-water-comes/groundwater/sustainable; *see also id.* Appendix I, with modifications based on personal communication with Valley Water staff (J. Gurdak, B. Kassab, 5/31/23).

[10] 2021 Groundwater Management Plan, *supra* note 9, at 4-4, 4-6, fig. 4-4.

[11] 2021 Groundwater Management Plan, *supra* note 9, at 4-4, 4-14 to 4-19.

[12] *See Current Water Charges*, VALLEY WATER, https://www.valleywater.org/your-water/current-water-charges (last visited Feb. 21, 2023); *see also 2022–23 Groundwater Production Charge-Setting Process*, VALLEY WATER, https://www.valleywater.org/your-water/current-water-charges/groundwater-production-charge-setting-process-2022-23 (last visited Feb. 21, 2023).

[13] *Current Water Charges*, *supra* note 12.

[14] Santa Clara Valley Water District, Water Supply Master Plan 2040 at 13–16 (2019) ("Master Plan"), *available at* https://www.valleywater.org/sites/default/files/Water%20Supply%20Master%20Plan%202040_11.01.2019_v2.pdf.

[15] Master Plan, *supra* note 14, at Appendix G (Board Agenda Memorandum for January 14, 2019).

[16] Master Plan, *supra* note 14, at Appendix H (Project List as of February 2019).

[17] 2021 Groundwater Management Plan, *supra* note 9, figures 4-2, 4-3.

[18] Hannah Waterhouse, Taylor Broadhead, Aysha Massell, Helen Dahlke, Thomas Harter, and Daniel Mountjoy., *Management considerations for protecting groundwater quality under agricultural managed aquifer recharge*, at 3 (2021), *available at* https://suscon.org/wp-content/uploads/2021/06/Management-Considerations-for-Protecting-Groundwater-Quality-Under-AgMAR.pdf.

[19] Levintal et al. (2022), *supra* note 5.

[20] Levintal et al. (2022), *supra* note 5.

[21] *See* Sarah Fakhreddine et al., *Mobilization of Arsenic and Other Naturally Occurring Contaminants during Managed Aquifer Recharge: A Critical Review*, 55 ENVIRONMENTAL SCIENCE & TECHNOLOGY 2208–2223 (2021), *available at* https://dx.doi.org/10.1021/acs.est.0c07492.

[22] Waterhouse et al. (2021), *supra* note 18, at 3; Levintal et al. (2022), *supra* note 5.

[23] Waterhouse et al. (2021), *supra* note 18, at 10, 17; Levintal et al. (2022), *supra* note 5.

[24] Levintal et al. (2022), *supra* note 5.

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[33] *See* State Water Resources Control Board, Fact Sheet: Purposes of Use for Underground Storage Projects, https://www.waterboards.ca.gov/waterrights/water_issues/programs/applications/docs/purposes_of_use_fact_sheet_final.pdf (last updated June 2020).

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[35] *See Temporary Permits for Groundwater Recharge*, STATE WATER RESOURCES CONTROL BOARD, https://www.waterboards.ca.gov/waterrights/water_issues/programs/applications/groundwater_recharge/temporary_permits.html (last visited Feb. 21, 2023); *see also* CAL. WATER CODE §§ 1425–1431 (governing 180-day temporary permits); CAL. WATER CODE §§ 1433–1433.6 (governing 5-year temporary permits); State Water Resources Control Board, Water Rights Fiscal Year 2022–2023 Fee Schedule Summary, *available at* https://www.waterboards.ca.gov/resources/fees/water_rights/docs/FY-22-23-Fee-Schedule-Summary-Final.pdf. It is important to note that temporary permits are simply conditional, temporary approvals to divert and use available water. A temporary permit is not a water right, and applying for one does not get the applicant a spot in line in California's first-in-time, first-in-right system of appropriative water rights. See **Figure II-4**.

[36] See *Streamlined Processing for Standard Groundwater Recharge Water Rights*, STATE WATER RESOURCES CONTROL BOARD, https://www.waterboards.ca.gov/waterrights/water_issues/programs/applications/groundwater_recharge/streamlined_permits.html (last visited Feb. 21, 2023).

[37] *See also* Kate Fritz and Nell Green Nylen, *Water right permitting options for groundwater recharge: Avoiding unintended consequences*, LEGAL PLANET (July 27, 2020), https://legal-planet.org/2020/07/27/water-right-permitting-options-for-groundwater-recharge-avoiding-unintended-consequences/.

[38] *See Permits for Groundwater Recharge*, STATE WATER RESOURCES CONTROL BOARD, https://www.waterboards.ca.gov/waterrights/water_issues/programs/applications/groundwater_recharge/ (last visited Feb. 21, 2023); *see also* web pages linked from this page.

[39] *See Pending Temporary Permits for Underground Storage consistent with Governor Executive Orders*, STATE WATER RESOURCES CONTROL BOARD, (hereinafter "Pending Temporary Permits"), https://www.waterboards.ca.gov/waterrights/water_issues/programs/applications/groundwater_recharge/pending_applications.html (last visited Feb. 21, 2023) (listing temporary permit applications and explaining how to look up application documents in the State Water Board's eWRIMS database).

[40] *See* State Water Resources Control Board, Fact Sheet: Flood Control, Groundwater Recharge, and Water Rights, *available at* https://www.waterboards.ca.gov/publications_forms/publications/factsheets/docs/flood_control_factsheet.pdf (last updated July 2020); *see also* Kate Fritz and Nell Green Nylen, *When does a groundwater recharge project NOT need a water right?*, LEGAL PLANET (August 3, 2020), https://legal-planet.org/2020/08/03/when-does-a-groundwater-recharge-project-not-need-a-water-right/.

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[42] *See* Pending Temporary Permits, *supra* note 39.

[43] Application T033322 by Omochumne-Hartnell Water District and the approved Temproary Permit to Divert and Use Water are both *available at* https://ciwqs.waterboards.ca.gov/ciwqs/ewrims/DocumentRetriever.jsp?appNum=T033322&wrType=Temporary%20Permit&docType=DOCS.

[44] Application T033287 by Central California Irrigation District is available at https://ciwqs.waterboards.ca.gov/ciwqs/ewrims/DocumentRetriever.jsp?appNum=T033287&wrType=Temporary%20Permit.

[45] Table is from Fritz & Green Nylen (July 27, 2020), *supra* note 37.

[46] *See* State Water Resources Control Board, Order WR 98-08 Revising Declaration of Fully Appropriated Stream Systems (Nov. 19, 1988), *available at* https://www.waterboards.ca.gov/waterrights/board_decisions/adopted_orders/orders/1998/wro98-08.pdf.

[47] *See Groundwater Recharge Permitting - Frequently Asked Questions*, State Water Resources Control Board, https://www.waterboards.ca.gov/waterrights/water_issues/programs/applications/groundwater_recharge/faqs.html (last visited Feb. 21. 2023); State Water Resources Control Board, Water Rights Fiscal Year 2022–2023 Fee Schedule Summary, *available at* https://www.waterboards.ca.gov/resources/fees/water_rights/docs/FY-22-23-Fee-Schedule-Summary-Final.pdf.

[48] See *Fully Appropriated Stream Systems*, State Water Resources Control Board, https://www.waterboards.ca.gov/waterrights/water_issues/programs/fully_appropriated_streams/ (last visited Feb. 21, 2023) (displaying FASS on an interactive map); see also State Water Resources Control Board, Map: Declaration of Fully Appropriated Stream Systems, Santa Clara County (August 22, 1991), *available at* https://www.waterboards.ca.gov/waterrights/water_issues/programs/fully_appropriated_streams/docs/fas_maps/santa_clara.pdf.

[49] Miller et al. (2018), *supra* note 41.

[50] Miller, Fisher, and Kiparsky (2021), *supra* note 32.

[51] *See* Christina Babbitt, Kate Gibson, Scott Sellers, Nicholas Brozović, Anthony Saracino, Ann Hayden, Maurice Hall, and Sandra Zellmer, The Future of Groundwater in California: Lessons in Sustainable Management from Across the West (2018), *available at* https://www.edf.org/sites/default/files/groundwater-case-study.pdf.

[52] *See Rates*, PV Water, https://www.pvwater.org/rates (last visited Feb. 21, 2023). PV Water collects "groundwater augmentation charges" from those who pump groundwater in its service area and does not distinguish between agricultural and non-agricultural users. For the period from December 2022 through November 2023, the augmentation charge for metered users pumping groundwater outside the delivered water zone is $282 per AF. *Id; see also* Pajaro Valley Water Management Agency, Ordinance No. 2021–02, April 21, 2021, *available at* https://www.pvwater.org/images/board-and-committees/board_of_directors_assets/ordinances/Ord.2021-02_Augmentation.Charge.Increase.in.Rates_web.pdf (adjusting groundwater augmentation charges).

[53] *Current Water Charges*, *supra* note 12. For 2022–2023, agricultural groundwater production charges are $36.85 per AF in all benefit zones, while non-agricultural groundwater production charges range from $368.50 to $1,724.00 per AF. *Id.* Valley Water's District Act caps groundwater charges for "agricultural water" at "one-fourth of the rate for all water other than agricultural water." Santa Clara Valley Water District Act, § 26.7(a)(3)(D), codified at Cal. Water Code § 60-26.7(a)(3)(D). Valley Water's Board of Directors has further restricted charges for agricultural water users through its pricing policies. It adopted Resolution 99-21 in 1999, establishing an "open space credit" that limits groundwater production charges for agricultural water to "one-tenth of the rate for all water other than agricultural water." LAFCO of Santa Clara County, 2011 Countywide Water Service Review: Chapter 3. Santa Clara Valley Water District at 77 (2011), *available at* https://santaclaralafco.org/sites/default/files/service_reviews/Santa%20Clara%20Valley%20Water%20District.pdf.

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