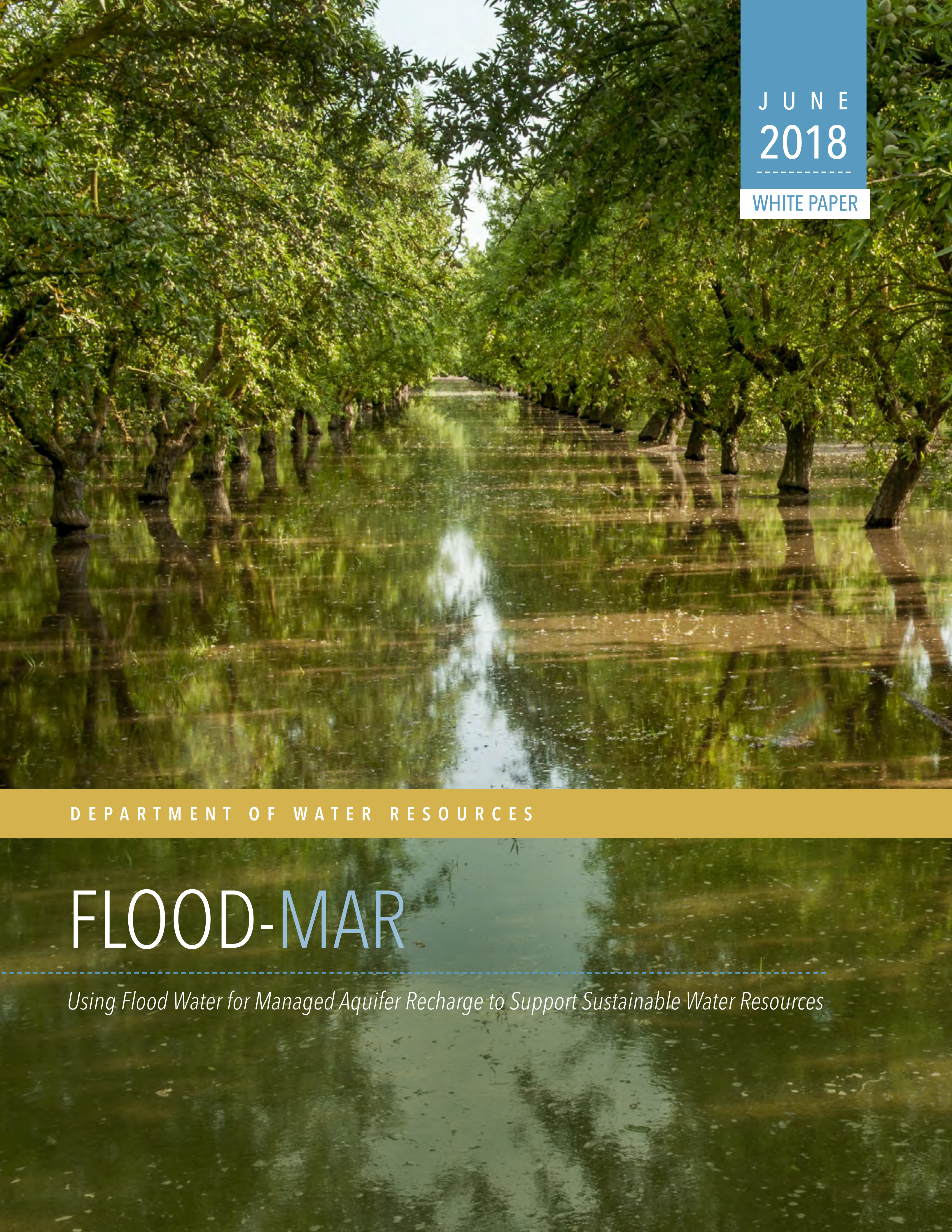

JUNE 2018

WHITE PAPER

DEPARTMENT OF WATER RESOURCES

# FLOOD-MAR

*Using Flood Water for Managed Aquifer Recharge to Support Sustainable Water Resources*

JUNE 2018 | WHITE PAPER

# FLOOD-MAR

*Using Flood Water for Managed Aquifer Recharge to Support Sustainable Water Resources*




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WATER FOUNDATION

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# SUMMARY

## Changes to Statewide Water Management are Imperative.

DWR recognizes the need to rehabilitate and modernize water and flood infrastructure in California is imperative. Recently, California experienced one of the driest winter seasons on record, which is on the heels of the 2nd wettest year on record. The driest four consecutive years of statewide precipitation in the historical record were 2012 through 2015.

These periods of extreme dry weather and extreme wet weather have stressed the state's water resources. Extreme dry periods have left some towns without safe and clean drinking water, aggravated groundwater overdraft, accelerated land subsidence, and exacerbated poor ecosystem conditions. Extreme wet weather caused local flooding and high water in major streams. More than 100 incidents, including boils, seepages, sloughing, bank erosion, overtopping, slippage, levee breaks, and local flooding, were reported to the State Flood Operations Center (FOC) by mid-March 2017. Several reservoirs encroached their flood reservation pool from the heavy precipitation and high reservoir inflows. The San Joaquin River flow remained near flood stage for months, as heavy rains were followed by snowmelt.

The state will continue to experience recurring extreme weather events, intensified by climate change, that will exacerbate flood risks and lead to longer and more severe droughts adding to challenges for water supply reliability. The effects of climate change are necessitating wholesale changes in how water is managed in California.

With less water storage from snowpack, California needs to leverage both the current water system and new opportunities to provide sustainable alternatives that can simultaneously accommodate longer and deeper droughts, and more severe, and frequent, episodic and seasonal flooding. This recent cycle of drought and flood, and the passage of the Sustainable Groundwater Management Act (SGMA), provide an enhanced opportunity to modernize State policies related to the nexus between flood management, land use, groundwater management, and ecosystem enhancement.

## Partnerships and Large-Scale Integration Improve System Resiliency and Sustainability.

Partnerships, among DWR; other State, federal, tribal, regional, and local entities; and university and private researchers, are actively exploring opportunities to determine how flood and groundwater management can be integrated for multiple benefits. Although integrating flood and groundwater management is not a new concept, the time is ripe to implement an expanded, large-scale integrated program. With the passage and early implementation of SGMA, in combination with climate-induced extreme events, the logic for communities to partner and integrate is evident and imperative. This partnership will help reduce the impacts of future swings between high- and low-flow periods while meeting their communities' objectives, with the added benefits of improving floodplain ecosystems, preserving working landscapes, and engaging California's agricultural community in needed solutions, among others.

This white paper explores "Flood-MAR", an integrated and voluntary resource management strategy that uses flood water resulting from, or in anticipation of, rainfall or snowmelt for groundwater recharge on agricultural lands and working landscapes, including but not limited to refuges, floodplains, and flood bypasses. Large-scale implementation of Flood-MAR will fundamentally change how flood and groundwater management are managed. 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's potential and value for California is achieved by integrating Flood-MAR with other regional recharge efforts, changing management of California's water system to better integrate surface water and groundwater, upgrading conveyance, storage, and operations, and considering Flood-MAR's opportunities as related to water transport and transfers are some of the system integration considerations.

This white paper demonstrates the need for Flood-MAR to become an important part of California's portfolio of water resource management strategies, now and in the future, to help significantly improve water resources sustainability and climate resiliency throughout the state.

## Using Flood Water for Managed Aquifer Recharge Can Provide Broad Benefits.

There is a clear State interest in encouraging, and participating in, Flood-MAR projects because they can provide broad and multiple public and private benefits for Californians and the ecosystems of the state. Potential public benefits include:

- Flood Risk Reduction.
- Drought Preparedness.
- Aquifer Replenishment.
- Ecosystem Enhancement.
- Subsidence Mitigation.
- Water Quality Improvement.
- Working Landscape Preservation and Stewardship.

- Climate Change Adaptation.
- Recreation and Aesthetics.

Private benefits include improved water supply reliability for urban and agricultural water uses through direct supply or improved system flexibility.

Flood-MAR projects can change local, regional, or statewide economic, environmental, or water resources system conditions. Changes can be beneficial, as indicated above, or may be adverse, such as terrestrial habitat impacts at the project site. Potential benefits and impacts will be project specific and will need to be carefully considered prior to project implementation. Robust tradeoff analyses are required to understand and evaluate project benefits and impacts.

## Flood-MAR Implementation Requires Many Considerations and There are Significant Challenges to Overcome.

The following questions must be considered to successfully implement Flood-MAR projects:

- How will project needs be coordinated?
- How will the project be funded and landowners compensated?
- Where will the surface water come from and how much is available?
- How will surface water get to the site?
- What are good candidate sites for recharge (including crop suitability)?
- How will water get into the ground?
- How will recharged water be accounted and recovered or otherwise used?
- Is the project feasible?

Complex technical, legal, and institutional barriers and challenges affect the planning and implementation of Flood-MAR, and strategies must be sought to overcome them. Overcoming these barriers and challenges will require open dialogue, strong leadership, robust partnerships, funding, and innovative research and pilot projects. In this white paper, barriers and challenges are organized by the following themes:

- Cooperation and Governance.
- Policy.
- Legal, including water rights and regulatory.
- Implementation, including land use, recharge, recovery, conveyance, reservoir operations, economics, environmental considerations, and data and capacity building.

## There is State Interest in the Public Benefits and Water Supply Reliability Improvements Associated with Flood-MAR.

There is a strong interest across the state in answering the questions above and understanding the benefits, limitations, concerns, costs, and funding opportunities for Flood-MAR projects. DWR plans to work with other State, federal, tribal, and local entities; academia; and landowners to build on the knowledge and lessons from past and on-going studies and programs to expand the integration of flood and groundwater management.

Pilot projects and feasibility studies are required to test and demonstrate the potential benefits and impacts of Flood-MAR projects. The economic, environmental, institutional, and operational aspects of Flood-MAR projects need to be well understood to ensure successful partnerships and leverage multiple funding sources.

DWR is developing a program communication strategy to identify venues to allow efficient and effective means to exchange Flood-MAR ideas and practices. Additionally, DWR encourages practitioners to develop Flood-MAR projects by providing planning, technical, and facilitation assistance, while supporting robust implementation of pilot projects in the near-term. DWR's continued support of Flood-MAR projects will require State authorization and funding.

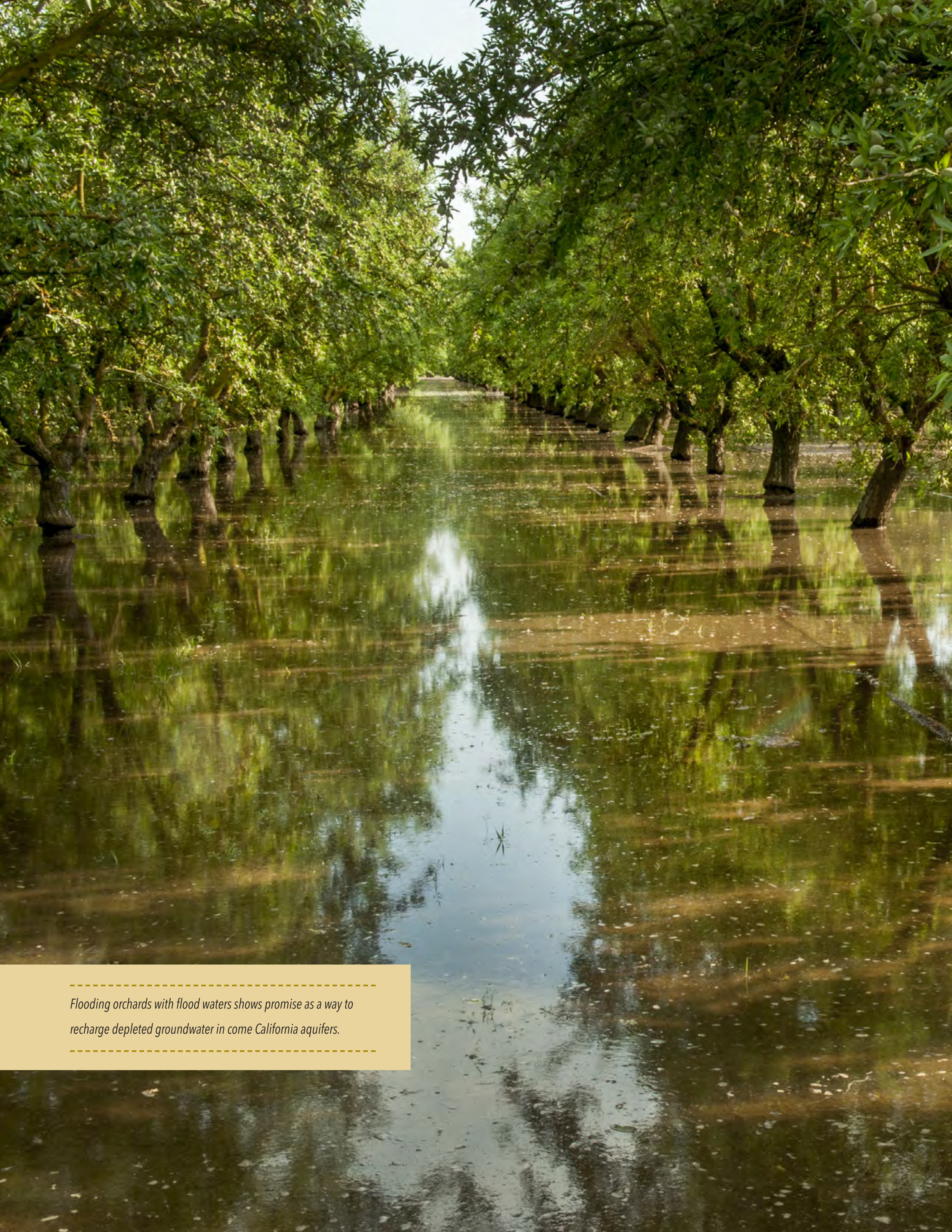
## Funding is Required to Pursue Flood-MAR Opportunities and Support Water Management Sustainability Throughout the State.

Contingent on available funding, DWR plans to initiate a Flood-MAR program and, in partnership, implement the Research and Data Development Framework (R&D Framework), which is available on the Flood-MAR website (https://www.water.ca.gov/Programs/All-Programs/Flood-MAR).

The purpose of the R&D Framework is to identify and categorize Flood-MAR relevant research themes, and coordinate ongoing and future research and pilot studies around a common research plan. The R&D Framework will identify gaps in data, information, and knowledge, and outline methods for developing, reviewing, and distributing information among stakeholders. It will also help inform the development of Flood-MAR reconnaissance studies. The intended outcomes of the R&D Framework are:

- Develop a body of knowledge and a living inventory of technical research needs for the Flood-MAR resource strategy.
- Inventory, develop, and coordinate technical expertise related to research needs.
- Matrix technical expertise among participating groups and stakeholders to develop and communicate within the Flood-MAR interest communities a clear, concise, and consistent message.
- Ensure availability of research and technical expertise for all stakeholders.
- Promote long-term and continued research and development.
- Provide guidance to stakeholders to support implementation of the Flood-MAR projects.

DWR's involvement in executing the R&D Framework and participation in, and development of, Flood-MAR studies and projects will require State authorization and funding.



*Flooding orchards with flood waters shows promise as a way to recharge depleted groundwater in come California aquifers.*

1

# INTRODUCTION

California's recurring cycles of droughts and floods, and fragmented and siloed water management, make planning for sustainability challenging.

The California Department of Water Resources (DWR) prepared this white paper to explore opportunities to use flood water[1] for managed aquifer recharge (Flood-MAR) because DWR recognizes the need to rehabilitate and modernize water and flood infrastructure in California. Large-scale implementation of Flood-MAR can fundamentally change how flood and groundwater management are integrated by using flood water resulting from, or in anticipation of, rainfall or snowmelt for groundwater recharge on agricultural lands and working landscapes, including but not limited to refuges, floodplains, and flood bypasses.[2]

DWR has observed a steady rise in local Flood-MAR studies, pilot projects, and research, and wants to facilitate scaling up of Flood-MAR.

Competing demands for water across water use sectors, a limited and variable water supply, and complex regulatory framework make planning for water resources sustainability challenging. Planning for water resources sustainability is more challenging now than ever because drought and flood events are increasing and intensifying with climate change. Climate change is having a profound impact on California's water resources, causing changes in snowpack, sea level, and river flows. The change in weather patterns are exacerbating flood risks, adding challenges for water supply reliability, and increasing stressors on ecosystems.

1 For this report, "flood water" is used to describe the high flows resulting from the largest annual precipitation events (e.g., atmospheric rivers) or snowmelt events typically during the winter and spring (with snowmelt extending to early summer in some parts of the state), or flows released from flood control reservoirs ahead of rain or snowmelt to evacuate additional flood control space. This report does not endeavor to strictly define "flood water" as a threshold or specific metric, as the availability of flows that could be used for managed aquifer recharge is location-specific and requires significant analysis of the potential benefits and impacts of using the water for managed aquifer recharge.

2 Flood-MAR is similar in concept to stormwater capture and reuse programs currently employed in many areas across the State. Flood-MAR focuses on agricultural and working landscapes.

## Terms Used in this White Paper

**Aquifer recharge** – The natural or managed infiltration or injection of water into an aquifer.

**Aquifer replenishment** – To recharge an aquifer by supplying what has been formerly withdrawn from storage to reduce overdrafted conditions. Replenishment occurs when a groundwater basin is managed so that groundwater levels are either maintained at or improved above a baseline condition (California Department of Water Resources 2017a). This white paper considers aquifer replenishment to be a public benefit if the recharged water is intended to remain in the aquifer, increase groundwater levels, and reduce overdrafted conditions. In other words, there is a State interest in healthy groundwater basins, and an indicator of health is groundwater level.

**Aquifer restoration** – The process of returning the aquifer to a former condition. For example, one may restore groundwater quality, groundwater levels, the surface/groundwater interaction, or all the above to conditions at a previous date.

**Groundwater banking** – Groundwater banks consist of water that is "banked" during wet or above-normal water years. The water to be banked is provided by the entity that will receive the water in times of need. Although transfers or exchanges may be needed to get the water to the bank and from the bank to the water user, groundwater banks are not transfers in the typical sense. The water user stores water for future use; this is not a sale or lease of water rights. It is typical for fees to apply to the use of groundwater banks. (California Department of Water Resources 2013a)

**Groundwater recovery** –The act of withdrawing recharged groundwater from an aquifer for use.

**Managed aquifer recharge** – A resource management strategy that can help replenish depleted aquifers or store water for later use or other benefits through intentional recharge of water to suitable aquifers.

This white paper presents the need for Flood-MAR to become an important part of California's portfolio of water resource management strategies, now and in the future, to help significantly improve water resources sustainability and climate resiliency throughout the state. MAR has been practiced for decades in several parts of the state, such as Santa Clara Valley, Los Angeles, and Orange County. It will be imperative to learn from past efforts, fill knowledge and technology gaps, and introduce successful strategies more broadly to support statewide sustainability and resiliency. Expanded implementation of the Flood-MAR resource management strategy will directly support Action 6 (expand water storage capacity and improve groundwater management) of the Governor's Water Action Plan, specifically the sub-action to increase statewide groundwater recharge:

> *The administration will work with the Legislature to discourage actions that cause groundwater basin overdraft and provide incentives that increase recharge. State agencies will work with tribes and federal, regional and local agencies on other actions related to promoting groundwater recharge and increasing storage, including improving interagency coordination, aligning land use planning with groundwater recharge, and identifying additional data and studies needed to evaluate opportunities, such as capturing and recharging stormwater flows and other water not used by other users or the environment.*

Expanded implementation of the Flood-MAR resource management strategy will also directly support a recommended action in the soon to be released Update 2018 of the California Water Plan to pursue integrated flood management and managed aquifer recharge (California Department of Water Resources 2018).

Specifically, this white paper:

- Explores past efforts and future opportunities to expand Flood-MAR to reduce flood risk and replenish aquifers.
- Describes the foundational concepts associated with Flood-MAR; potential benefits beyond flood risk reduction and aquifer replenishment; potential barriers, challenges, and opportunities associated with larger scale implementation; and information gaps.
- Presents recommendations for next steps, research and data needed to fill information gaps and support a more comprehensive and expansive program, and the partnerships needed to successfully implement this strategy.
- Encourages ongoing dialogue to pursue partnerships and establish State government support to leverage opportunities and overcome challenges and barriers to further local- and system-level study and implementation.

*Flooding of Twin Cities Rd in Elk Grove, CA, on January 13, 2017. Storms in late November 2016 through February 2017 resulted in the 2nd wettest year on record.*

2

# CALIFORNIA WATER – A TALE OF TWO EXTREMES

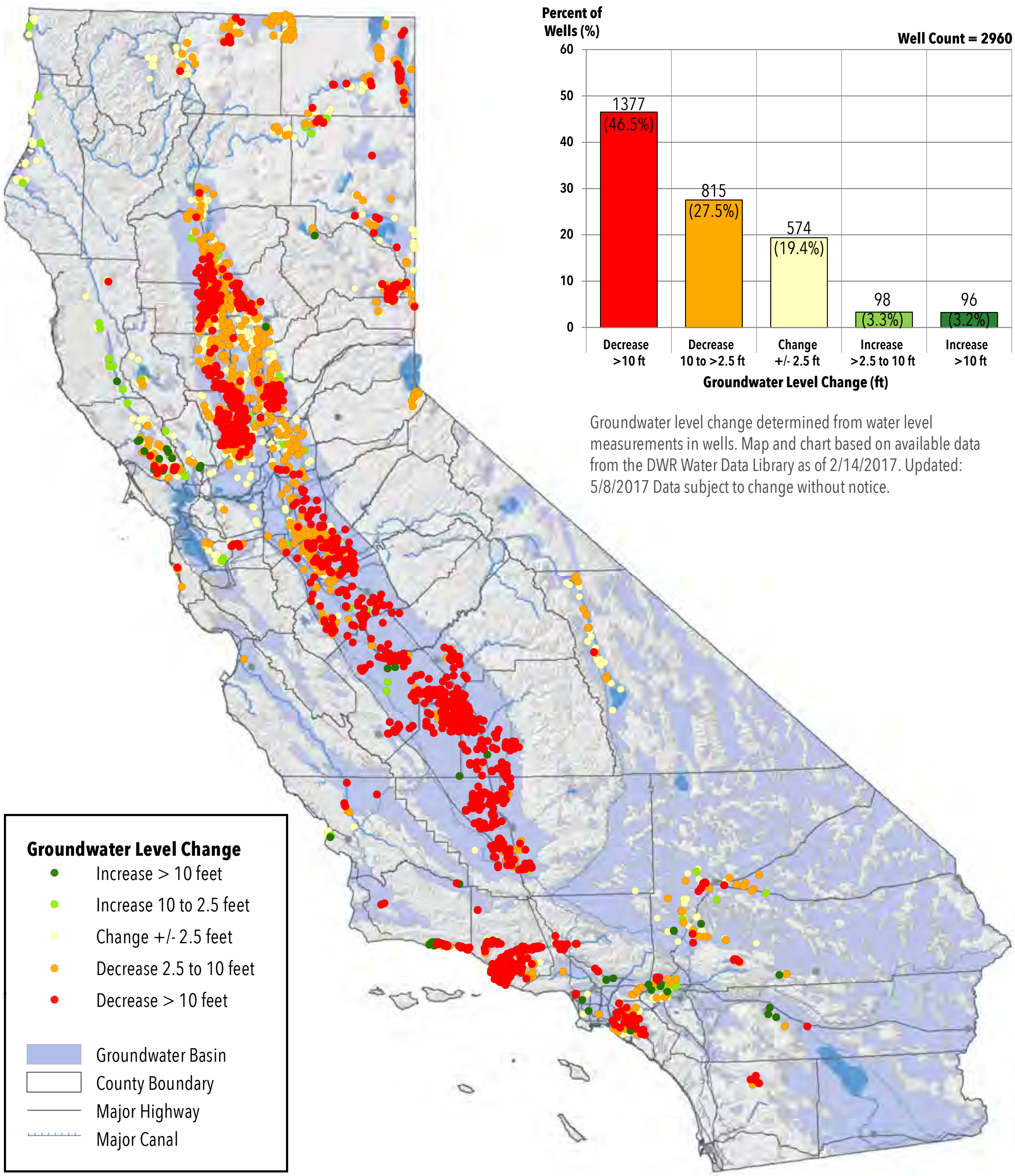
California's water history is a tale of droughts and floods.

A four-year drought began in 2012 and stressed the state's water resources—leaving some towns without safe and clean drinking water, aggravating groundwater overdraft, accelerating land subsidence, and exacerbating poor ecosystem conditions. The driest four consecutive years of statewide precipitation in the historical record were 2012 through 2015. In March 2015, the state had record-low statewide mountain snowpack of only 5 percent of average. The drought resulted in a lack of adequate surface water supply, which forced numerous water users to modify their water use, including an increase of groundwater pumping in many areas. By 2016, counties reported more than 3,500 dry wells to the Office of Emergency Services (California Department of Water Resources 2015a). Figure 1 illustrates the change in groundwater levels between the springs of 2011 and 2016.

During this drought, the Sustainable Groundwater Management Act (SGMA) went into effect, establishing a new State framework and local tools for managing California's groundwater—fundamentally changing how groundwater is managed in the state.

*The severe drought in 2014 resulted in a lack of adequate surface water supply, which forced many water users to increase groundwater pumping. Above, Lake Oroville and the Enterprise Bridge looking from the South Fork on September 5, 2014.*

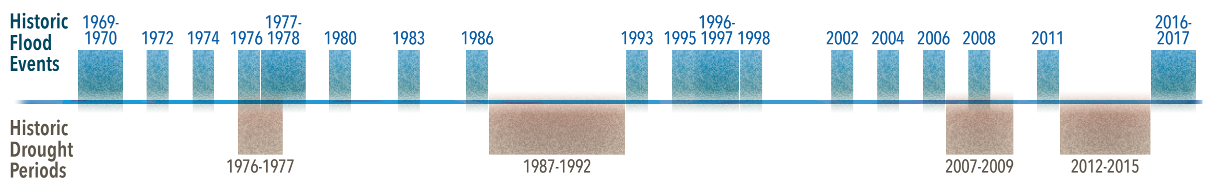
**FIGURE 1.** *Groundwater Level Change – Spring 2011 to Spring 2016*



As is typical of California water—a tale of the two extremes of drought and flood (Figure 2) —the five years of drought were followed by the second wettest water year on record. Storms started in late November 2016 and intensified through February 2017. These storms caused local flooding and high water in major streams. More than 100 incidents, including boils, seepages, sloughing, bank erosion, overtopping, slippage, levee breaks, and local flooding, were reported to the State-Federal Flood Operations Center (FOC) by mid-March 2017. Several reservoirs encroached their flood reservation pool from the heavy precipitation and high reservoir inflows. The San Joaquin River flow remained near flood stage for months, as heavy rains were followed by snowmelt.

After enduring four years of drought followed by the second wettest year on record, impacts were especially devastating in the San Joaquin Valley. With many groundwater basins heavily overdrafted, vast areas of the San Joaquin Valley experienced subsidence and some areas experienced drinking water shortages. In 2017, high water persisted in the valley for months. We can only speculate on the lost opportunity to take flood waters from the 2017 precipitation events and strategically inundate agricultural lands and working landscapes to recharge overdrafted basins.

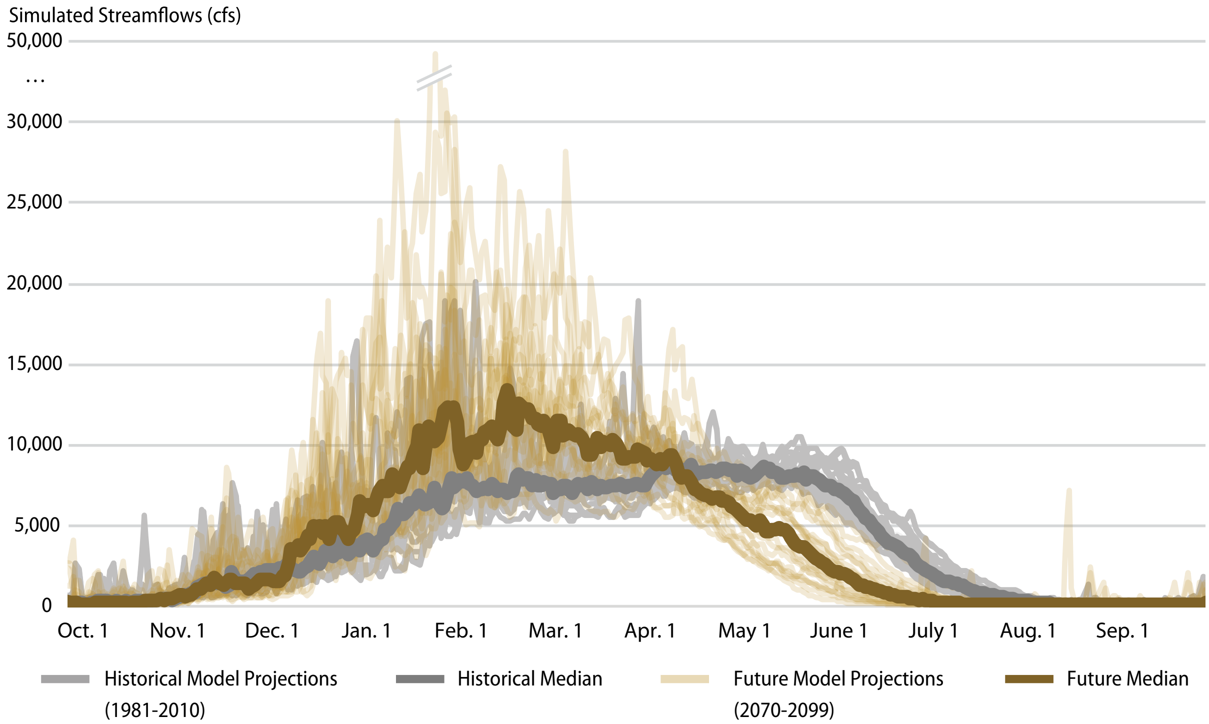
**FIGURE 2.** *California Flood and Drought Timeline*




The effects of climate change are necessitating wholesale changes in how water is managed in California. The state will continue to experience recurring extreme weather events, which are being intensified by climate change. Climate change is expected to continue to change snowpack, sea level, and river flows. More precipitation will likely fall as rain instead of snow. The example hydrograph in Figure 3 illustrates a change in the timing and volume of peak flows. Future projections (brown lines) illustrate higher peak flows earlier in the season as more precipitation falls as rain instead of snow, whereas historical runoff flows (gray lines) persisted later into the spring as snow melted. Climate change impacts related to flooding and increased flood risk are expected to be particularly severe in the San Joaquin River Basin because it is a high-elevation, snow-melt-driven watershed. Climate change is also expected to result in more variable weather patterns throughout California. This potential change in weather patterns will exacerbate flood risks and lead to longer and more severe droughts adding to challenges for water supply reliability.

With less water storage from snowpack, California needs to leverage both the current water system and new opportunities to provide sustainable alternatives that can simultaneously accommodate longer and deeper droughts, and more severe, and frequent, episodic and seasonal flooding.

**FIGURE 3.** *Example of Recorded and Projected Streamflow Models Simulating American River Flows near Folsom, CA*




*Source: California Department of Water Resources 2017a*

This recent cycle of drought and flood, and the passage of SGMA, has provided an enhanced opportunity to discuss and inform long-term State policies related to the nexus between flood management, land use, groundwater management, and ecosystem enhancement.

Partnerships, among DWR; other State, federal, tribal, regional, and local entities; and university and private researchers, are actively exploring opportunities to determine how flood and groundwater management can be integrated to their mutual benefit. Although integrating flood and groundwater management is not a new concept, the time is ripe for implementation of an expanded, large-scale integrated program.

The current need is great for better integration of flood and groundwater management systems. Doing Flood-MAR on a large scale can reduce flood risks to downstream areas, recharge groundwater in some shallow aquifers, and improve ecosystem conditions. Compensating landowners for easements to flood their lands could support a larger scale, public-private implementation effort that helps reduce systemwide flood risks and recharges depleted shallow aquifers.

## Planning for Sustainability

The *California Water Action Plan*, released by Governor Jerry Brown's administration in January 2014 and updated in January 2016, called attention to the need to respond to changing conditions. It established the three goals of "more reliable water supplies, the restoration of important species and habitat, and *a more resilient, sustainably managed water resources system* (water supply, water quality, flood protection, and environment) that can better withstand inevitable and unforeseen pressures in the coming decades" (California Natural Resources Agency et al. 2016).

At the start of 2015, SGMA set in motion a foundational transformation to the governance, planning, and management of groundwater basins in California. This new State policy takes a long-term, outcome-driven approach for groundwater management. Inherent in this approach is the understanding that it will take years, if not decades, to stabilize and restore groundwater basins, and that proactive management will need to continue in perpetuity to deliver the intended outcomes. All changes mandated in SGMA are designed to prevent six undesirable results[3] and support the sustainable use of water. Further, Flood-MAR strategies can go beyond the requirements of SGMA and help address many of the state's sustainability issues.

Water Year 2017 was a stark reminder of the potential impacts of flooding and intense atmospheric river events. The Lake Oroville spillway is currently under repair and many communities are still recovering from the effects of flooding. Across the state, people and communities are at risk for catastrophic flooding. One in five Californians live in a floodplain, and more than $580 billion in assets (i.e., crops, property, and public infrastructure) are at risk (California Department of Water Resources 2013b). At the same time, ecosystems across the state continue to decline, and several species are on the brink of extinction. Californians recognize that water resources management systems are vulnerable. Water management systems in California must be planned, designed, and operated for resiliency and sustainability in the face of current and future vulnerabilities.

Sustainability is the ultimate goal of water resources management in California. As described in the pending California Water Plan Update 2018 (California Department of Water Resources 2018), sustainability is not an end point but an ongoing combination of four societal values — public health and safety, a healthy economy, ecosystem vitality, and opportunities for enriching experiences.

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3 Per the Sustainable Groundwater Management ACT, "Undesirable result" means one or more of the following effects caused by groundwater conditions occurring throughout the basin:

(1) Chronic lowering of groundwater levels indicating a significant and unreasonable depletion of supply if continued over the planning and implementation horizon. Overdraft during a period of drought is not sufficient to establish a chronic lowering of groundwater levels if extractions and groundwater recharge are managed as necessary to ensure that reductions in groundwater levels or storage during a period of drought are offset by increases in groundwater levels or storage during other periods.
(2) Significant and unreasonable reduction of groundwater storage.
(3) Significant and unreasonable seawater intrusion.
(4) Significant and unreasonable degraded water quality, including the migration of contaminant plumes that impair water supplies.
(5) Significant and unreasonable land subsidence that substantially interferes with surface land uses.
(6) Depletions of interconnected surface water that have significant and unreasonable adverse impacts on beneficial uses of the surface water.

2

To prepare for longer droughts and more severe flooding, California must engage in the strategic and integrated water management planning required to implement Flood-MAR. Water users, planners, managers, and policy-makers must collectively plan, manage, and adapt California's water systems in a proactive way, to ensure the systems are resilient to changing conditions and able to adapt nimbly and dynamically to stressors. Only proactive strategic planning and adaptation, at State, federal, regional, and local levels, can ensure a sustainable future for California. Flood-MAR can significantly improve water resources sustainability throughout the state.

3

# DESCRIPTION OF FLOOD-MAR

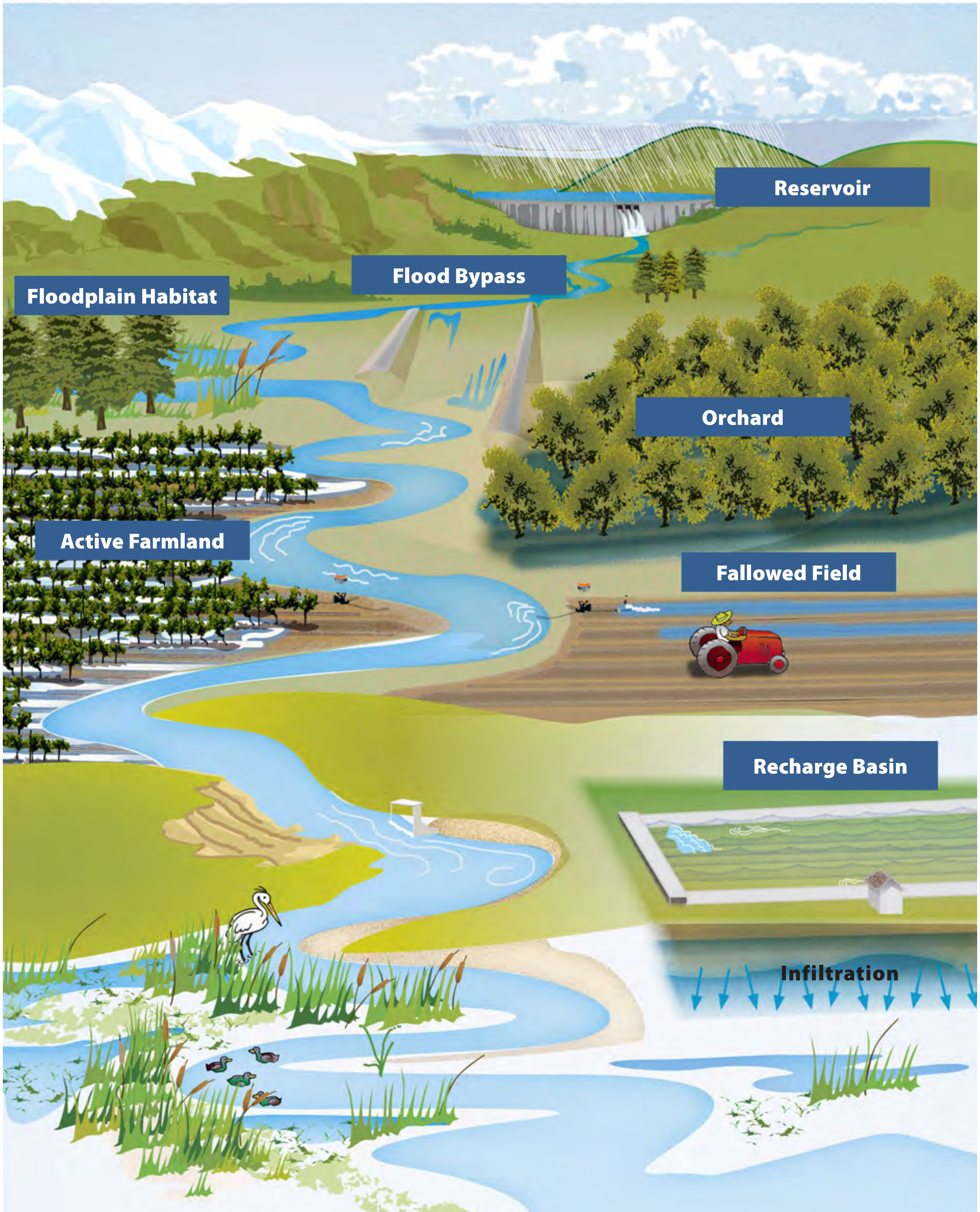
Flood-MAR is an integrated and voluntary resource management strategy that uses flood water resulting from, or in anticipation of, rainfall or snowmelt for groundwater recharge on agricultural lands and working landscapes, including but not limited to refuges, floodplains, and flood bypasses. Figure 4 illustrates the basic elements of Flood-MAR.

The flood protection and groundwater management communities have traditionally worked independent of each other. In some respects, this has been done by design, such as flood protection agencies working to keep flood waters off property, while leaving groundwater management to local water agencies and landowners. With the passage and implementation of SGMA, in combination with climate-induced extreme events, the logic for these communities to partner and integrate is becoming clear and imperative. This partnership will help reduce the impacts of future swings between high- and low-flow periods while meeting their communities' objectives, with the bonus of improving floodplain ecosystems, preserving working landscapes, and engaging California's agricultural community in needed solutions, among other benefits.

Flood-MAR epitomizes integrated water management. The concept is designed to be multi-benefit—providing flood risk reduction, drought preparedness, aquifer replenishment, ecosystem enhancement, and other potential benefits. It is also a promising climate change adaptation strategy that takes an integrated approach to help address two of the most challenging elements of future climate changes: more flashy/intense flood flows, and longer/deeper droughts. In addition, agricultural lands and working landscapes are assets as they become effective and essential pathways to storage. In practice, projects will need to be carefully planned, operated, and designed to achieve these important benefits.

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. Achieving Flood-MAR's potential and value for California will need integration into the broader water system. Integrating Flood-MAR with other regional recharge efforts, changing management of California's water system to better integrate surface water and groundwater, upgrading conveyance, storage and operations, and considering Flood-MAR's opportunities as related to water transport and transfers are some of the system integration considerations.

**FIGURE 4.** *Elements of Flood-MAR*



4

# BENEFITS OF USING FLOOD WATER FOR MANAGED AQUIFER RECHARGE

Integrating flood and groundwater management by actively managing flood water to recharge aquifers has multiple benefits, public and private.

## Public Benefits

This white paper focuses on public benefits to demonstrate a clear State interest in participating in, and encouraging, Flood-MAR projects. Potential public benefits include:

- Flood Risk Reduction.
- Drought Preparedness.
- Aquifer Replenishment.
- Ecosystem Enhancement.
- Subsidence Mitigation.
- Water Quality Improvement.
- Working Landscape Preservation and Stewardship.
- Climate Change Adaptation.
- Recreation and Aesthetics.

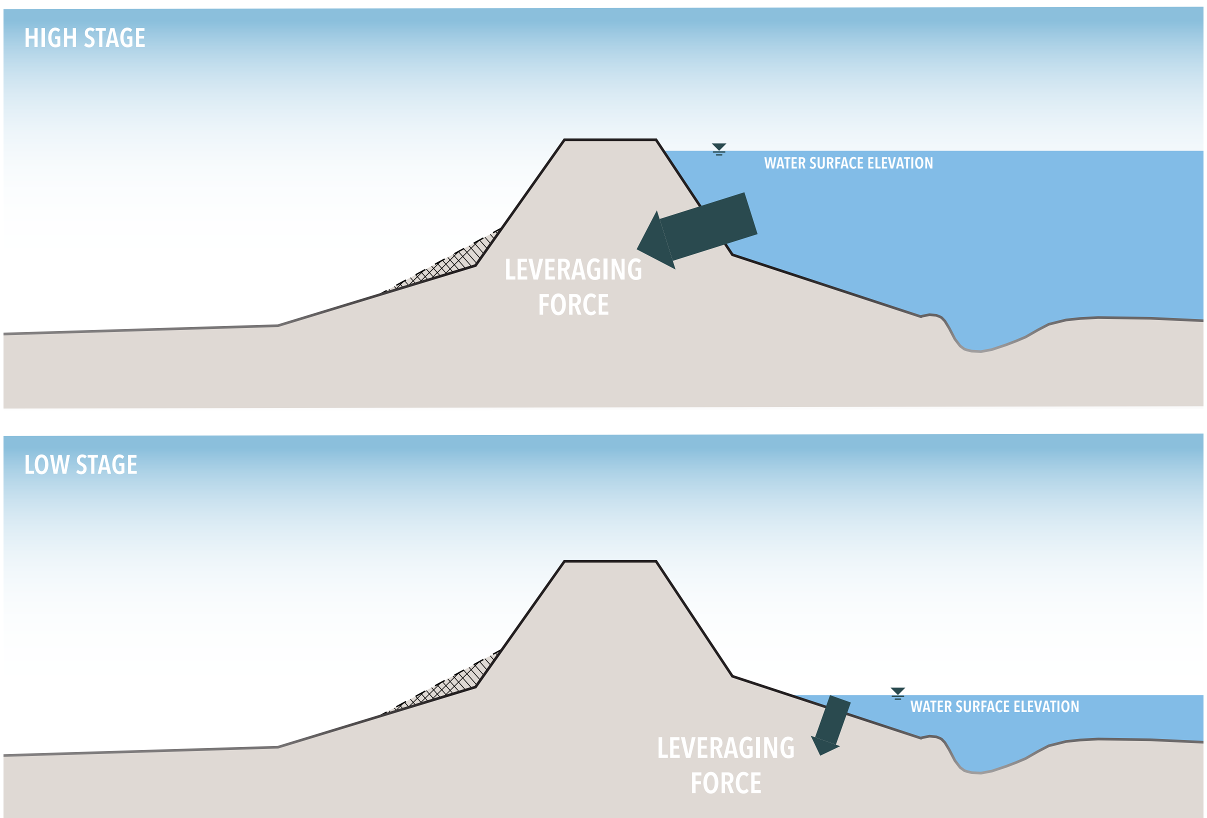
As with any project, potential benefits and impacts will be site specific and need to be carefully considered prior to project implementation.

## FLOOD RISK REDUCTION

Aging infrastructure, deferred maintenance, and climate change have intensified the flood risk to people and property (California Department of Water Resources 2017b). Flood-MAR can reduce peak river flow and stage, and reduce downstream flood risk by diverting flows from river channels onto working landscapes (including floodplains and flood bypasses). For instance, benefit/cost ratios have been calculated near 1.8 for implementing such an approach on farmland adjacent to the Kings River, primarily from reducing damages associated with 10- to 100-year flood events (Bachand et al. 2013).

As illustrated in Figure 5, reductions in water stage can reduce the risk of levee failure by reducing seepage potential and leveraging forces on levees.

**FIGURE 5.** *Reducing River Stage Decreases Levee Failure Modes*




The reduction of flow and stage also provides reservoir operators with additional flexibility to manage flood releases to increase flood space in reservoirs—providing greater potential for flood-risk reduction benefits. Alternatively, Flood-MAR strategies coupled with reservoir reoperation and improved forecasting can further reduce flood risk by allowing reservoirs to release water ahead of precipitation or snowmelt to increase flood storage space in reservoirs.

By implementing Flood-MAR, flood benefits (i.e., flood-risk reduction) are attained in multiple ways:

1. Taking water off the channel during high-flow events (i.e., skimming peak flows) and purposefully delivering water to lands (through flooding or irrigation) to promote groundwater infiltration. This methodology requires flexibility and access to significant land area to achieve flood-risk reduction benefits downstream of diversion points.

2. Lowering reservoir storage levels prior to, during, or after the flood season or discrete events, to vacate reservoir storage before anticipated precipitation/snowmelt, which can reduce flood risks below the reservoir. The vacated water is conveyed to specific areas for managed aquifer recharge.

3. Slowing runoff from properties to encourage groundwater infiltration on public and private lands and reduce runoff from entering already swollen channels.

Flood-MAR projects can also be utilized on floodplains and expanded flood bypasses to further reduce flood risk and increase groundwater recharge potential, as well as provide ecosystem benefits and potentially reconnect floodplains.

Beyond affecting flood management, changes in reservoir operations will potentially affect other aspects of California water and its management as related to water supply, water quality, environmental flow requirements, and contracted water delivery requirements. These effects will need consideration and require coordination agreements with numerous parties. The analysis of benefits and impacts of reoperation must also consider how benefits and impacts change over time (e.g., resiliency of project benefits to climate change).

### DROUGHT PREPAREDNESS

Flood-MAR results in more water being stored in aquifers. The stored water could be used for multiple purposes, including keeping water in storage for future dry years, droughts, or water shortages. Like "carryover" storage in surface-water reservoirs, groundwater may be dedicated and managed for use in the next season or potential future dry water years.

### AQUIFER REPLENISHMENT

Because of several factors, and exacerbated by the recent drought, aquifers in many areas are in a condition of overdraft, and groundwater levels continue to decline. Flood water represents another source of water that can be used to replenish aquifers and reverse declining groundwater levels. Recharged groundwater may be extracted for beneficial uses, but a water agency may choose to leave water in the basin for the purpose of aquifer replenishment, or to increase or maintain groundwater levels.

This white paper proposes that State government has an interest in healthy aquifers and aquifers should be recognized as green infrastructure and an environmental asset. As such, aquifer replenishment should be considered a public benefit and eligible for State cost share in future financial assistance programs. The Water Quality, Supply, and Infrastructure Improvement Act of 2014 found that "Sustainable water management in California depends upon reducing and reversing overdraft and water quality impairment of groundwater basins. Investments to expand groundwater storage and reduce and reverse overdraft and water quality impairment of groundwater basins provide extraordinary public benefit and are in the public interest." Chapter 8 of the Act recognizes ecosystem improvements, water quality improvements, flood control benefits, emergency response, and recreational purposes as public benefits eligible for State cost share, but not aquifer replenishment. Consideration of aquifer replenishment as a public benefit eligible for State cost share would enhance the successful implementation of SGMA and support sustainable management of the state's water resources.

### ECOSYSTEM ENHANCEMENTS

Flood-MAR can provide ecosystem benefits by reconnecting and inundating floodplains; creating floodplain habitat (e.g., riparian), marsh, and wetlands; supplementing baseflows; and supporting groundwater dependent ecosystems through increased baseflow resulting from higher groundwater levels. Factors that will determine the potential ecosystem and habitat enhancement opportunities are land use, proximity and connectivity to the river, timing of recharge flows, and length of flooding. Seasonal flooding of land will boost food productivity (e.g., insects, zooplankton) to support aquatic and terrestrial species. For example, flood bypasses and large areas of flooded rice straw decomposition in the Sacramento Valley provide ecosystem benefits that can accrue when water is spread out and slowed down, such as important benefits to birds along the Pacific Flyway, food web production, and salmon-rearing habitat.

Recharging groundwater supplies also has the potential to provide ecosystem benefits by boosting instream baseflow or reducing surface water temperature through surface and groundwater interactions. This resource management strategy may also help reduce undesirable conditions caused by overdraft by restoring the physical conditions of an aquifer.

Groundwater may also be used to support environmental water accounts that use water stored in the ground during wetter periods to help increase instream flows during drier years (via groundwater extraction or in-lieu use).

### SUBSIDENCE MITIGATION

Flood-MAR has the potential to reduce groundwater overdraft conditions and stop or slow land subsidence. Land subsidence has been an issue for decades. Areas of the San Joaquin Valley have been particularly affected, especially in the recent drought. Between May 2015 and May 2016, some areas of the San Joaquin Valley saw ground elevations sink as much as 2 feet. Land subsidence can significantly damage infrastructure, including water supply conveyance facilities, levees, and flood channels, by reducing their water storage and carrying capacities. Subsidence also affects conveyance capacity by reducing hydrologic gradients (Faunt et al, 2016). Land subsidence can permanently reduce the water storage capacity of an aquifer, and may damage ecosystems if drainage is altered, leading to anoxic (i.e., oxygen deficient) conditions.

### WATER QUALITY IMPROVEMENT

Flood-MAR can improve groundwater quality by increasing the amount of water in storage and potentially diluting impaired or contaminated aquifers, especially with respect to salts and nutrients. Salts and nutrients may occur across large aquifer areas, at concentrations that are near or above regulatory levels. But even in heavily affected regions, regulatory limits are not exceeded by one or several orders of magnitude. As a result, dilution may provide significant benefits (this would not apply to many industrial and urban point-source pollution cases). Increasing water levels through Flood-MAR can also help prevent or slow seawater intrusion into coastal aquifers.

On the other hand, flooding recharge areas could mobilize surface/soil pollutants from current or past land uses and contaminate aquifers. Increasing recharge could also further spread contaminated groundwater contaminant plumes by altering rates and direction of groundwater flow. It is anticipated that any potential adverse water quality changes will be short term and local, followed by long term and regional benefits as a result of dilution.

### WORKING LANDSCAPE PRESERVATION AND STEWARDSHIP

Flood-MAR strategies could compensate landowners for keeping their lands in their current use (e.g., agricultural production) while allowing periodic flooding. This strategy allows farmland to stay in production, rather than retiring lands to create recharge basins (Bachand et al 2014, 2016; Dahlke et al 2018). This strategy relies on thriving landscapes that can adapt to changing hydrologic conditions. These recharge areas should be protected in a manner that ensures they remain available for recharge, rather than be converted to other uses, such as urban infrastructure. Recharge areas should also be protected to prevent pollutants from entering groundwater. As there is local authority over land use planning, activities need to be coordinated and consistent with local general planning and other local land using planning efforts. Water and flood managers will need to work with local land use planners to protect watersheds and recharge areas.

### CLIMATE CHANGE ADAPTATION

The effects of climate change, such as water supply reductions caused by a loss of snowpack, are anticipated to have wide-reaching impacts on the way water is managed in California. Both groundwater use and flood risks are projected to increase as the climate changes. Changes in hydrology will require modifications to the way reservoirs and flood management infrastructure are operated. Flood-MAR improves the flexibility of the water resources management system to adapt to the extreme events that are expected to become more common in a changing climate. Flood-MAR adds flexibility to system operations that is needed to compensate for earlier snow melt runoff and potential changes in water demand. Flood-MAR can help address extreme events in an integrated way. It can also help address contributions of groundwater extraction to greenhouse gas emissions, and recharge may provide a sink for greenhouse gases (Wood and Hyndman 2017).

### RECREATION AND AESTHETICS

Flood-MAR has the potential to provide recreation and/or aesthetic benefits based on the land use of the recharge area. Recreation and aesthetics benefits would be significantly tied to the ecosystem enhancements of the project. For example, increased flooding on refuges can improve bird watching, hunting opportunities, or creation of wetlands. Reconnection of rivers and streams to floodplain habitat can improve the natural beauty of a landscape over non-vegetated, dedicated recharge basins.

## Private/Local Benefits

Some benefits of Flood-MAR are strictly private.

### WATER SUPPLY RELIABILITY

Groundwater is a critical and integral component of California's overall water supply, serving residents, businesses, farms, and industries. Approximately 30 million Californians (about 75 percent) depend on groundwater for a portion of their water supply. On average, groundwater provides approximately 40 percent of total annual agricultural and urban water uses. Some areas are 100 percent dependent on groundwater for their supply (California Department of Water Resources 2015a). In certain parts of the state, long-term groundwater use has had serious impacts on water supply reliability, including declines in groundwater levels, and storage and degradation in water quality. Flood-MAR can significantly increase water supply reliability for agricultural and urban users.

### REDUCED GROUNDWATER PUMPING COSTS

Increasing groundwater levels from aquifer recharge will help groundwater users reduce their groundwater pumping costs, and could prevent the need for wells to be deepened (another cost saving to groundwater users). There are many factors that dictate the cost of pumping groundwater. This benefit is likely only possible if all other factors remain the same (e.g., volume of water pumped) and only groundwater elevation changes.

### WATER MARKETS AND TRANSFERS

With the implementation of SGMA, groundwater sustainability agencies may look at water transfers to augment supplies. Water markets are becoming more common in California. Currently, water transfers are complex to implement and not always reliable, being affected by conveyance timing, bottlenecks in the conveyance system (such as through the Sacramento-San Joaquin Delta), and by cost. Pairing on-farm flood capture and recharge, and other Flood-MAR approaches, with water transfers potentially provides flexibility to the receiving agency or its members with additional water storage capabilities.

## Avoiding Negative Impacts of Flood-MAR Projects

All projects have the potential to change local, regional, or statewide economic, environmental, or water resources system conditions. These changes can be beneficial, as described above, or may be adverse, such as terrestrial habitat impacts at the project site. In general, changes should be quantified and benefits should outweigh the impacts of a project. Quantifying changes requires estimating how physical conditions would change with the project relative to the conditions without the project, and assigning a monetary value to the changes where possible.

Potential benefits and impacts will be project specific and need to be carefully considered prior to project implementation. Robust tradeoff analyses are required to fully understand and evaluate project benefits and impacts. For example, Flood-MAR projects have the potential to affect reservoir operations. Changes in reservoir operations can affect flood management, water supply, water quality, environmental flows, and meeting contracted water deliveries. All impacted operators and stakeholders need to be partners in the project and consulted for developing operations strategies that limit or mitigate impacts that are determined to be unacceptable.

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# IMPLEMENTATION FACTORS

There are several important considerations when implementing Flood-MAR projects.

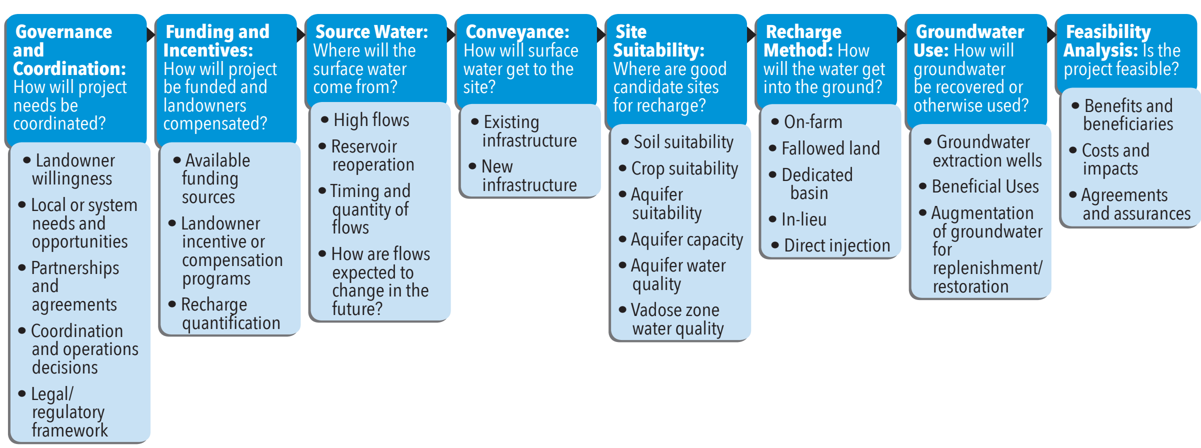
Figure 6 describes the fundamental factors for implementing this resources management strategy. The following pages provide a brief description of these factors.

## Governance and Coordination

Governance and coordination may be the most critical factor in developing successful Flood-MAR projects. Governance and coordination is essential to understanding local and system needs and opportunities; developing the necessary partnerships and agreements; navigating the permitting process; and coordinating facility operations and making planned and real-time adjustments.

Water systems in California are very complex, not just in hydrology, but in the way water management is conducted and coordinated. Water infrastructure is owned, operated, and maintained by numerous local, regional, State, federal, tribal, and private entities. Water management decisions need to be coordinated across jurisdictional boundaries, water sectors, interests, uses, and, in some cases, across hydrologic boundaries. Adding to this complexity is the different

**FIGURE 6.** *Factors for Implementing Flood-MAR*



way surface water and groundwater is managed across the state. Only during the last few years have surface water and groundwater interactions, and the need to manage both resources in an integrated manner, been understood and embraced on a broader scale (with the help of SGMA).

Cooperation of many entities is required for Flood-MAR to be successful. First and foremost, Flood-MAR requires the voluntary participation of landowners, who are compensated for the public benefits from the use of their land. Cooperation among the owners, operators, and maintainers of pertinent water management facilities; potential beneficiaries; and the land owners bearing potential impacts, is required for this resource management strategy to be successful. Successful implementation of Flood-MAR strategies may require new governance structures, decision-making processes, and operations agreements to support cooperation. No one-size-fits-all strategy for governance and cooperation will work throughout the state. Strategies must be appropriate and specific to the location and parties involved.

## Funding and Incentives

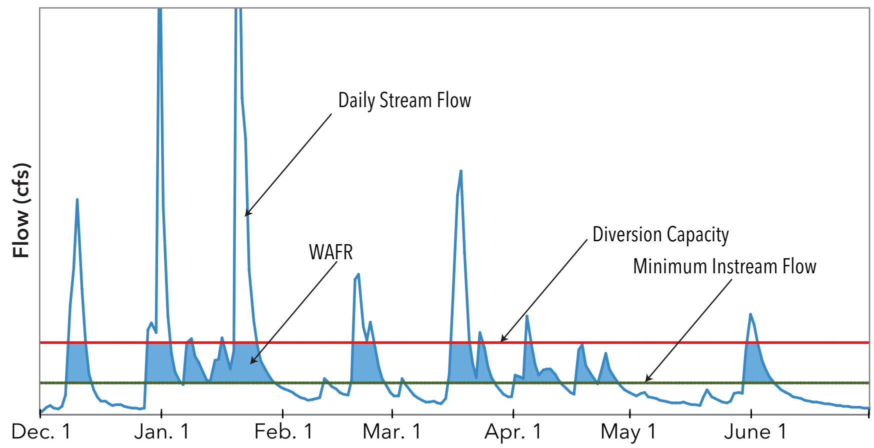
Having sufficient and stable funding to conduct studies, implement pilot and permanent projects, and operate and maintain projects is essential to achieve the intended benefits of Flood-MAR. Currently, most Flood-MAR projects are funded by local entities with some limited support from the State through grant and loan programs. Mechanisms for funding projects in both rural and urban areas will need to be evaluated. Although urban areas have large customer bases to share costs, they still rely on State grant funding to support project implementation. Financing for rural areas is an even greater challenge. Funding partnerships will be critical to wide-scale implementation. Being able to accurately account for recharged water and leveraging multiple benefits to share costs are also critical to funding Flood-MAR projects.

In addition, wide-scale implantation of Flood-MAR projects on private lands will require landowner incentives and/or compensation programs to encourage their participation.

## Determining Flood Water Available for Recharge

DWR released the final Water Available for Replenishment (WAFR) report, as required by SGMA, in April 2018. The WAFR report summarizes estimates of surface water available for replenishment that were determined using a synthesis of information—monthly simulated Water Evaluation and Planning (WEAP) model outflows, historical daily gauge data, regulatory environmental flow requirements, water rights, and existing storage and conveyance facilities. Figure 7 provides a simplified hydrograph to illustrate the basic concept used to determine the surface water available for replenishment in the WAFR report (it should be noted that diversion capacity and minimum instream flows are variable, and not static based on several factors, including watershed, upstream reservoirs, and water year type).

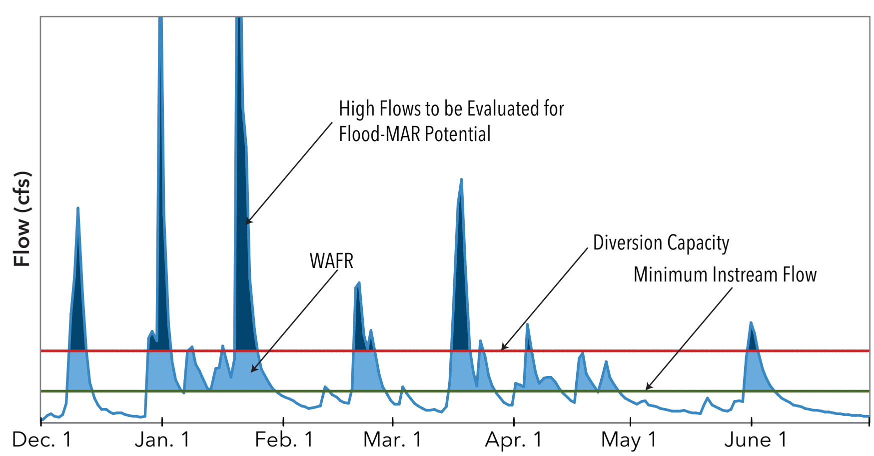
**FIGURE 7.** *Surface Water Available for Replenishment*




This white paper uses the term *flood water* to designate the flows in a channel that are above regulatory instream flow requirements (the combination of regulatory environmental/water quality flows and water required to satisfy water rights) and are resultant from high precipitation or snowmelt events in a given year. The WAFR analysis generally considered surface water "available" when streamflow exceeded existing water demands and minimum instream flow requirements, and provided some opportunity for additional beneficial use; and "available" water in the WAFR analysis was further limited by the potential division capacity.

Building on the WAFR analysis, identifying the potential water available for Flood-MAR projects goes beyond using current infrastructure and diversion capacity. In the example hydrograph illustrated in Figure 8, flood waters are considered those highlighted in dark blue. These high-flow events can be evaluated as a potential water source for Flood-MAR strategies, but their ability to be used for Flood-MAR purposes will be dependent on many regulatory and legal factors. Further, tradeoffs and risks must be considered when evaluating the potential water available for managed aquifer recharge. For example, the importance of high-flow events to aquatic communities is becoming better understood and a demonstration that diversion of flows does not degrade habitat quality or adversely affect aquatic and riparian species will be required.

**FIGURE 8.** *Flood Water to be Evaluated for Replenishment*




*Note: Peak flows are anticipated to increase with climate change (see Figure 3).*

When considering flows available for groundwater recharge, quantity, and timing are important factors. The quantity represents how much water is potentially available for groundwater recharge. The timing represents when it is available, which is of particular importance if the recharge is to occur on active farmland. Timing is also important for instream aquatic species. It is understood that high-flow events can provide environmental benefits, such as bypass flows for pulse protection designed to protect important species, and not all high-flow events should be used for groundwater recharge. Additionally, for many ecological and functional benefits, minimum instream flows may be dynamic. It is important to note that quantity and timing of flow in the future is expected to change because of the effects of climate change. Analyzing how hydrographs may change because of climate change will be essential in project development.

Hydrographs are anticipated to have higher flood peaks that occur earlier in the rainy season because of climate change. Further, quantity and timing for many waterways is controlled by upstream reservoirs. Current operations and potential reoperation of reservoirs are critical considerations for determining water available for managed aquifer recharge.

Not only are river flows expected to change because of climate change but changes in water management are expected. These changes would be motivated by the reduction in water storage available from snowpack, and the potential strategies in system and reservoir operation to better integrate aquifer storage into California's water management portfolio. Changes in water management as a result of climate change should be considered in any analysis.

## Conveyance to Recharge Areas

An important consideration for managed recharge projects is how to get the water to detention basins and/or recharge area. In some cases, such as properties adjacent to rivers, channels, and irrigation canals, existing conveyance is sufficient. But areas that currently rely on groundwater may lack surface water conveyance facilities. In many areas of the state, lack of sufficient conveyance facilities is a constraint for Flood-MAR projects. Also, many critically overdrafted basins do not have sufficient infrastructure for managed aquifer recharge.

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

## Determining Suitability of Potential Recharge Areas

Several physical parameters determine the suitability of a potential site for providing groundwater recharge benefits. Some parameters may require significant research to determine suitability or suitable methods. Not all physical parameters are important for every recharge mechanism (e.g., the requirements for recharge basins are different than those for *in-lieu* recharge). Important physical parameters include the following:

***Suitability of Soils*** – For most direct recharge methods, recharge volume is controlled by the rate at which water can infiltrate into the soil and the underlying geologic sediments. Infiltration rates will be faster for sandy soils, and much slower for soils with higher amounts of clay. Infiltration capacity is a measure of the volume of water that can be recharged per unit of time. It is determined by multiple factors. Recharge suitability indices are available that help determine potential areas where groundwater recharge is feasible.

Currently, there are a few recharge suitability tools or indices recently developed for California:

1. University of California, Davis (UC Davis) Soil Agricultural Groundwater Banking Index (SAGBI) is a suitability index that uses five major indicators for evaluating soil suitability (O'Geen et al, 2015). This tool is fundamentally based upon the Natural Resources Conservation Service's (NRCS) soil surveys, with additional assumptions governing its interpretation and use. UC Davis has identified 3.6 million acres of agricultural land in the state that have excellent or good potential for recharge. https://casoilresource.lawr.ucdavis.edu/sagbi/

2. Recharge Suitability Index developed by Land IQ and the Almond Board of California builds on SAGBI with subsurface geology characteristics from the U.S. Geological Survey, and depth-to-groundwater information from DWR, to provide greater information about site suitability for intentional groundwater recharge.

3. University of California, Santa Cruz has developed methods for identifying shallow and deep integrated mapping that incorporates vegetation, soils, underlying geology and available runoff. http://www.rechargeinitiative.org/

4. AquaCharge is a planning tool developed by Stanford University that helps urban water utilities develop efficient and cost-effective systems to replenish aquifers.

5. Almond Board of California and Lawrence Berkeley National Laboratory partnered to develop a better understanding of subsurface water storage, quality, and movement in relation to almond orchard groundwater recharge test sites. This partnership expands work to identify which orchards are suitable for recharge, and gauge groundwater recharge effects on almond trees, among other efforts.

It must be noted that these tools are generalized planning tools. Implementation at a site requires ground truthing of these data sources including discussions with land owners, engineers, scientists, and irrigation specialists familiar with the area.

Traditional MAR strategies have focused on highly permeable sites, limited to soils with excellent infiltration conditions. Flood-MAR on agricultural lands is not limited to selection of high infiltration rate-lands, but may be suitable for and implemented at low infiltration rates over very large areas of land (e.g., winter irrigation with micro-irrigation systems).

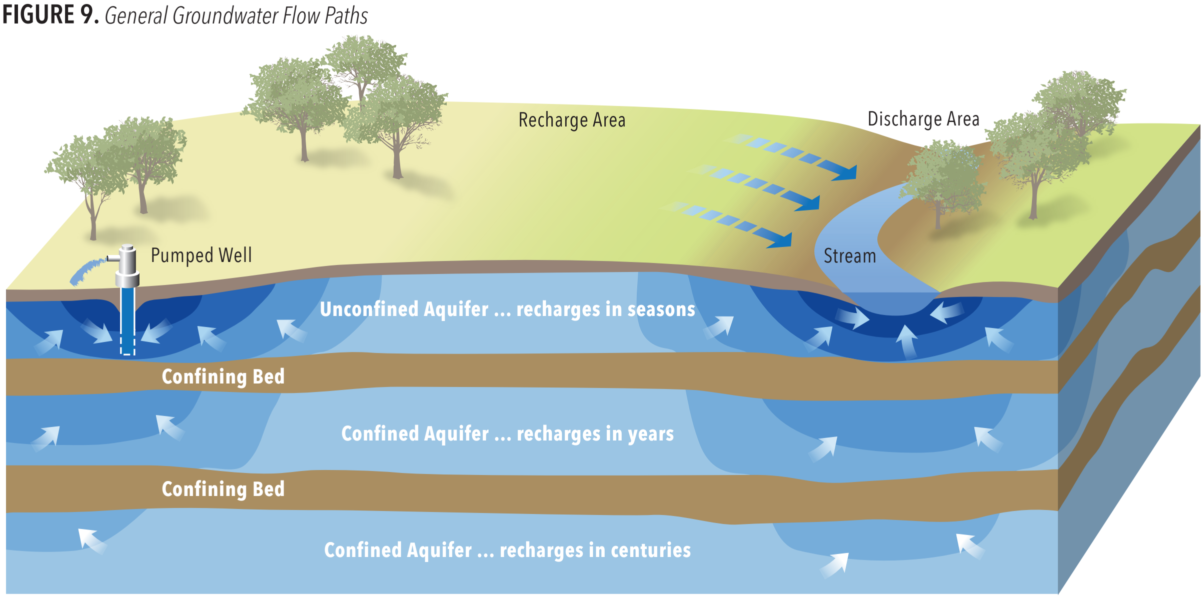
***Land Use and Crop Compatibility*** – Current or proposed land use is an important consideration for determining the suitability of potential recharge areas. Traditionally, groundwater recharge occurs through direct injection using wells or infiltration via dedicated recharge basins. Flood-MAR includes expanding recharge on agricultural and working landscapes. There are specific challenges associated with planted agricultural land uses. Crop compatibility with interim flooding or off-season irrigation must be determined, specifically the ability of the crop's root zone to tolerate saturated conditions for necessary durations or wet conditions during off-season irrigation. This is particularly important for perennial crops and vines, because of the risk of root damage, disease, and crop loss. Further, for trees and vines the timing of ground saturation before or after budbreak affects the crop's tolerance to saturation. Areas planted with annual crops and fallowed land have less risk related to crop damage and disease, but timing of saturation is important for next season planting. In addition, crop-type considerations are also important based on the types of fertilizers and pesticides that may be applied and the potential for transporting those chemicals into the aquifer.

For agricultural land uses, the type of infrastructure used for irrigation, such as conveyance facilities for flood irrigation, can facilitate Flood-MAR projects. Some farmers have already installed, or are evaluating the installation of, dual drip and flood irrigation systems that allow for the flooding of land when water is plentiful, and the use of drip irrigation when water is scarce and needs to be conserved.

***Aquifer Suitability*** – Water must not only migrate through the soil surface, but from there it must travel into and through the aquifer system that is used for regional or local groundwater supply. Underlying geology and depth to groundwater are important characteristics for potential recharge areas, and can vary significantly across the state. In the various depositional systems found in the Central Valley, there are locations where surface soils with high-infiltration capacities overlie less-permeable aquifer units. These less-permeable units impede the flow of infiltrated water and limit the amount of water that may reach the target aquifer. In those environments, water may move laterally to downgradient aquifer areas of higher permeability or to surface water bodies. If these are not available, lack of infiltration into the aquifer will limit the available infiltration rates at the land surface.

A schematic of general groundwater flow paths is shown in Figure 9. The less-permeable confining beds tend to be laterally discontinuous, but are abundant in most of California's groundwater basins. Because of California's geologic history, including mountain glaciation in the Sierra Nevada, there exist relatively deep, coarse channel deposits that locally incise through these confining beds, providing ideal 'avenues' for accomplishing shallow and deep recharge (Weissmann et al., 2004). These "incised valley-fill" deposits exist on nearly every major river system on the east side of the Central Valley, yet very few of them have been discovered and mapped. An essential part of augmenting recharge will be the improved characterization of the subsurface geologic architecture that strongly controls where, how, and how fast, groundwater exits and enters these multi-aquifer systems.

**FIGURE 9.** *General Groundwater Flow Paths*



*Available Groundwater Storage Capacity* – For shallow unconfined aquifers, available storage capacity is defined as the volume of a basin that is unsaturated and capable of storing additional groundwater. In general, aquifers in the San Joaquin Valley Groundwater Basin are more depleted and have larger storage capacities than those in the Sacramento Valley Groundwater Basin.

*Water Quality* – Vadose zone and groundwater water quality are important concerns for recharging groundwater. Constituents of concern will vary based on the intended end use of the water, but can include total dissolved solids, nitrate, lead, arsenic, boron, and organics, such as pesticides. Constituents may be anthropogenic or naturally occurring. Taste of extracted water is also an important concern for municipal use. Water quality must be considered for both the groundwater within the aquifer and the surface water being used to recharge the aquifer. Recharging aquifers can have positive and negative impacts on an aquifer. For example, recharging groundwater can dilute an already contaminated aquifer and have beneficial impacts on groundwater quality. Conversely, recharge water can mobilize surface or near surface nitrates or salinity into the aquifer causing negative groundwater quality affects. Even so, there may be long-term improvements in groundwater quality because of recurring recharge with flood waters that are low in salts and nitrates (Bachand et.al. 2014). Short- and long-term groundwater water quality affects will be site specific and an important factor for site suitability.

Groundwater quality information can be found through multiple sources, including local monitoring efforts, DWR's Water Data Library, State Water Boards Groundwater Ambient Monitoring and Assessment Database, and the U.S. Geological Survey's groundwater quality programs.

*Regional Considerations* – Much of the focus on implementing Flood-MAR has been associated with the Central Valley, in large part because of SGMA. Yet, Flood-MAR projects are being considered in other areas as well, such as the Sierra Nevada and coastal areas. In these applications, other considerations become evident, such as topography, more layered or heterogeneous soils, temperature effects on soils and frost lines, and fewer opportunities for managing upstream flows. Regional considerations also include regional infrastructure and water management, as well as potential impacts on disadvantaged communities that may be reliant on groundwater.

## Methods of Recharge

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.

Two methods are often used to replenish groundwater:

1. *Active Recharge* includes direct spreading recharge and aquifer injection.

*Direct spreading* is accomplished by ponding water in dedicated percolation basins, or spreading across confined land-scapes where it infiltrates downward into unconfined aquifers. Direct spreading in areas with highly permeable geologic materials can result in a rapid, efficient, and economical way to recharge the aquifer. This recharge method usually requires large, dedicated land areas. Some recharge also occurs with the use of unlined water conveyance facilities.

***Aquifer injection*** is another active recharge technique. Water is injected into aquifers using injection wells. Aquifer injection has the advantage of working in many geologic conditions, and in relatively small areas, where direct spreading recharge is less suitable. But, this technique is prone to clogging and some degree of maintenance is needed to sustain well-injection performance. Aquifer injection has a higher energy requirement for maintaining adequate water pressure for injection.

*2. In-Lieu Recharge*

In some areas, recharge may be accomplished by providing an alternative source of water to users who would normally use groundwater, leaving groundwater in place and increasing the potential to improve the groundwater levels, or for later use. In-lieu recharge is not being considered in this white paper.

## Capacity for Recovery of Recharged Groundwater

To be considered a water supply benefit, recharged water must be recoverable. To recover the water, enough wells must be present near the sites to extract water from the target aquifers. Some portion of recharged water will not be recoverable. Determining the percentage of recharged water that can be considered recoverable requires development of accounting tools, groundwater monitoring networks, and groundwater modeling tools. Water that is not recoverable for water supply is still beneficial for aquifer replenishment. Also, groundwater that supplements surface water flow (i.e., flows from the aquifer to provide streamflow benefit) is not recoverable from the aquifer for other uses.

Costs to recover recharged water must also be considered in project planning. The cost to install and operate extraction wells can be prohibitive.

## Pilot Projects and Feasibility Analysis

Robust pilot projects and feasibility studies will be required to test and illustrate the potential benefits and impacts of Flood-MAR projects. The economic, environmental, and operations aspects of Flood-MAR projects need to be well understood to ensure successful partnerships and leverage multiple funding sources. Project proponents will need to understand:

- Water resources operations and socioeconomic, ecosystem, and water quality conditions, with and without the project.
- Physical changes caused by the project and if changes are beneficial or detrimental.
- How benefits and impacts can be monetized.
- Costs to construct, as well as operate and maintain, projects.
- How to allocate costs to beneficiaries and compare benefits to costs.

6

# OPPORTUNITIES FOR USING FLOOD WATER FOR MANAGED AQUIFER RECHARGE

DWR plans to consolidate and build on the knowledge and lessons from past and on-going studies and programs to expand integration of flood and groundwater management.

This section provides an overview of past and current studies from federal, State, and local agencies, and academia identifying potential opportunities for this strategy.

In 2000, the CALFED Record of Decision (CALFED 2000) identified a need to expand groundwater storage by 500 thousand acre-feet (taf) to 1 million acre-feet (maf); and specifically identified 250 taf to 700 taf of additional storage in the Upper San Joaquin River watershed. Two years later, the U. S. Army Corps of Engineers Hydrologic Engineering Center (U. S. Army Corps of Engineers 2002) published findings of a study related to improving conjunctive use and minimizing flood risk. This study demonstrated flood protection improvements by exercising a conjunctive use pool in existing reservoirs and integrating flood releases and groundwater recharge. The study found that as much as 740 taf of additional flood protection space could be created, and as much as 1 maf of new annual yield could be generated in the Central Valley.

Since SGMA was passed, the number of studies related to managed aquifer recharge sharply increased. In 2015, UC Davis developed SAGBI and showed the potential to increase groundwater levels by using some of California's 3.6 million acres of farmland with suitable topography and soil conditions to recharge aquifers during winter months without disrupting agricultural production (O'Geen et al. 2015). The same year, a study from RMC Consultants, Inc. identified the opportunity of capturing winter flows on agricultural lands as favorable to groundwater recharge in the San Joaquin Valley. The study identified between 80 taf and 130 taf of average annual potential recharge (RMC Consultants, Inc. 2015). Two years later, DWR released the draft WAFR report, which estimated the water available for replenishment throughout the state. The estimates indicated a range of opportunities, investments, and innovations that may provide a foundation, or starting point, for local planning to recharge groundwater basins (California Department of Water Resources 2017c). UC Davis evaluated the availability of high-magnitude flows from the Sacramento and San Joaquin watersheds and reported that, in an average year, 2.6 maf of water would be available from flood flows to recharge groundwater (Kocis and Dahlke 2017).

Within the state, at least 89 agencies are currently engaging in conjunctive use programs; including 32 in the South Coast, 37 in the lower San Joaquin Valley (the Tulare Lake Hydrologic Region), and a handful in several other hydrological regions (California Department of Water Resources 2015b). The following are some examples of locally led studies and projects:

- The Farmington Groundwater Recharge Program was developed in 2001 and created a successful partnership between the Stockton East Water District and U.S. Army Corps of Engineers. The program's goal is to store as much as 35,000 acre-feet per year of flood flows in local aquifers via direct recharge methods. In 2016, more than 11,000 acre-feet per year were contributed (http://www.farmingtonprogram.org/).
- The McMullin On-Farm Flood Capture and Recharge Project in the Kings Basin was initiated under a NRCS grant investigating flooding agricultural lands to mitigate regional flood risks and offsetting groundwater overdraft. The 1,000-acre pilot project studied the infiltration rate of floodwater diverted from the Kings River, potential recharge of groundwater and farm scale logistics (Bachand et al 2011, 2014). Based upon a 30-year historical record of Kings Basin surplus flood flows, the project estimated 30,000 acres operated for on-farm flood recharge would have had the capacity to capture 80 percent of available flood flows and potentially offset overdraft rates in the Kings Basin (Bachand et al. 2016). The project was expanded to a regional scale under a DWR Flood Corridor Grant being implemented by the Kings River Conservation District, and with local matching funds from Terranova Ranch (Bachand et al. 2015). This Phase 1 project included approximately 5,000 acres and was the first phase of a three-phase project to eventually enroll approximately 20,000 acres to divert 500 cfs of flood flows from the Kings River when available. Most recently, a U.S. Department of Agriculture's Regional Conservation Partnership Program award was awarded to Raisin City Water District for the next phase, enrolling approximately 5,000 more acres and implementing the needed infrastructure. Terranova Ranch is a 2017 Governor's Environmental and Economic Leadership Award (GEELA) winner for the McMullin On-Farm Flood Capture and Recharge Project under Ecosystem and Land Use Stewardship.
- The Recharge Initiative is an effort by the University of California, Santa Cruz to protect and improve groundwater resources through education and outreach in collaboration with academia; federal, State, and local agencies; municipalities; and stakeholder groups. The initiative has conducted research for the Pajaro Valley groundwater basin on managed aquifer recharge and its ability to increase groundwater recharge and reduce sea water intrusion. Continued research on incentivizing groundwater recharge through net metering is yielding promising public-private partnerships for recharge opportunities (http://www.rechargeinitiative.org/; http://ucwater.org/).
- The Ag-Recharge project team is a UC Davis initiative that seeks to collaborate with farmers, water districts, conservation districts, and managers to assess the feasibility, risks, and costs associated with opportunistic agricultural groundwater banking. The team is currently collaborating with the Scott Valley Irrigation District in Siskiyou County and the Orland-Artois Water District in Glenn County (http://recharge.ucdavis.edu/).
- The UC Water Security and Sustainability Research Initiative (http://ucwater.org/) is a University of California multi-campus initiative that includes whole-watershed (from headwaters to groundwater basin) integrated water stores management to maximize water storage in both surface and subsurface reservoirs. A project in the American-Cosumnes basin is demonstrating how diversion of American River flood flows, partly through reoperation of Folsom Dam, and conveyance to strategic recharge locations and farmlands in central and southern Sacramento County, could significantly increase groundwater and total system water storage (http://ucwater.org/sites/default/files/UCWater_Integrated_American_Cosumnes.pdf; http://ucwater.org/info).

- The Groundwater Recharge Assessment Tool (GRAT) developed by Sustainable Conservation and Earth Genome is an interactive platform that integrates publicly-available hydrologic, agronomic, and geologic data with best available data from local, state, and federal sources to help practitioners determine where, when, and how much water to use for recharge (http://www.groundwaterrecharge.org/)

All these studies and projects illustrate that using available flood water for groundwater recharge is feasible, cost effective, provides multiple benefits, and is a promising strategy. At the same time, expanding the implementation of Flood-MAR comes with limitations, concerns, costs, and regulatory constraints that need to be fully considered and studied. Agencies that successfully implemented a long- or short-term groundwater recharge program using flood water identified the following issues:

- Determining the quantity and timing of flows available for diversion.
- Understanding crop suitability.
- Willingness of local landowners to participate.
- Accounting and reporting of replenished water.
- Developing explicit agreements for operations and use of water.
- Making funding available for studies, projects, and compensation of landowners.
- Collaboration between academia, the State Water Resources Control Board, and local agencies to provide proof-of-concept and ease of permitting.

In 2017, the Public Policy Institute of California Water Policy Center surveyed 81 local water districts (64 agricultural and 17 urban districts) in the San Joaquin Valley about their groundwater recharge efforts. Survey respondents indicated an increased interest in recharge efforts to support SGMA and groundwater sustainability. The survey indicated smaller agencies were interested in increasing recharge activities; about 75 percent of respondents said they were actively recharging in 2017. Survey respondents indicated barriers to implementation very similar to the list above, but also mentioned infrastructure (72 percent of respondents), regulatory issues (30 percent), challenges of expanding recharge on croplands because of farm-related issues (42 percent), and difficulties raising funds for recharge projects (23 percent). The survey highlighted the potential opportunity for expanding recharge in the San Joaquin Valley. The complete survey findings were released in April 2018 (http://www.ppic.org/wp-content/uploads/r-0417ehr.pdf). (Hanak 2017)

There is a strong interest across the state in understanding the benefits, limitations, concerns, costs, and funding opportunities for the Flood-MAR resource management strategy.

## Preliminary Study on Merced River

As part of the System Reoperation Study, DWR recently completed a preliminary study on the Merced River and New Exchequer Dam to determine the potential to capture high flow events for groundwater recharge. Merced Irrigation District (MID) operates both New Exchequer Dam and the downstream Crocker-Huffman Diversion Dam, which diverts water for delivery to MID customers. MID's Main Canal and other existing infrastructure provide an opportunity to divert flood flows to agricultural land within MID's boundaries. Initial estimates indicate as much as 25,000 acres of land within MID's boundaries are suitable for groundwater recharge. The initial analysis focused on opportunities within MID, but could be expanded to other areas within the Merced and Turlock groundwater sub-basins.

The goal of this preliminary analysis was to determine the volumes of potential water available to be diverted off the Merced River, which could provide multiple benefits, including flood protection (risk reduction), aquifer replenishment (an environmental/public benefit), and drought preparedness (supply augmentation). Conveyance and recharge parameters were applied using historical hydrology and operations to determine the volume of excess water that could have been diverted for each potential benefit. Analyses were completed using reservoir data for New Exchequer Dam, and streamflow data for the Merced River, local creeks, and the MID Main Canal.

Given current conveyance capacity, land use, and historical hydrology (1970-2017), this analysis indicates that an annual average of 29.3 thousand acre-feet (taf) to 35.3 taf of water could be recharged annually. Of that amount, approximately 19.2 taf to 24.5 taf could also provide a potential flood protection benefit. Flood protection benefits from diverted water are also seen in peak flow and stage reductions of as much as approximately 2,000 cubic feet per second (cfs). Stage reductions also help maintain flows in the Merced River below the downstream channel capacity of 6,000 cfs, while providing reservoir operators with additional flexibility to manage their flood control pool. While most of this water would be captured during wet years, such a volume of water would also provide aquifer replenishment and drought preparedness benefits, especially for groundwater sustainability agencies attempting to improve the sustainability of their groundwater basin.

This analysis was at a proof of concept level based on historical operations. Further refinement and analysis would examine actual operational and conveyance constraints, refinement of recharge suitability, surface water-groundwater interaction, and risks such as localized flood control problems and potential crop damage. Further analysis of ecosystem function benefits is also required to evaluate potential ecosystem enhancement benefits.

7

# BARRIERS AND CHALLENGES TO USING FLOOD WATER FOR MANAGED AQUIFERS RECHARGE

Complex technical, legal, and institutional barriers and challenges affect the planning and implementation of Flood-MAR.

This section provides an overview of barriers and challenges to implementation of Flood-MAR strategies. The barriers and challenges were discussed during the November 8, 2017, public forum on Managed Groundwater Recharge to Support Sustainable Water Management and subsequent MAR events and meetings. This section also reflects comments received on the November 2017 discussion draft white paper. Barriers and challenges are organized by the following themes:

- Cooperation and Governance.
- Policy.
- Legal.
- Implementation.

## Cooperation and Governance

Potential considerations related to cooperation and governance:

- Willingness of landowners to flood their property.
- Water infrastructure in California is owned and operated by many federal, tribal, State, and local agencies.
- Flood and groundwater managers have not historically coordinated their activities.
- Better integration of water and flood management planning with local land use and urban planning.
- Federal, tribal, State, and local agency authorities may be limited, or in conflict, with this strategy.
- Local control of resources is splintered geographically, and within and across resources (e.g. flood, irrigation, municipal vs. rural).
- Under SGMA, different approaches for local and regional cooperation and governance are being developed. Some of these approaches will be more effective than others.

- Contractual arrangements and operations plans will be required among the appropriate flood and water agencies, reservoir operators, landowners, and end-users to deliver, store, and recover managed waters – this will be a challenging process.
- Trust and understanding of goals, needs, priorities, and unique concerns are needed by all parties. This will take time to develop.
- Lack of statewide leadership to facilitate multi-agency, regional programs has been a challenge.
- Third party impacts need to be considered and could be barriers to implementation.
- Developing cooperative relationships with local agencies will be critical because land use decisions are made at the local level and may affect Flood-MAR implementation.
- Managing water at the watershed-scale (headwaters to outflows) for all uses, with understanding of surface and groundwater interactions, will be required.

## Policy

Potential considerations related to policy:

- Replenishment of overdrafted aquifers is not currently considered a beneficial use and/or a public benefit, and is ineligible for receiving State grant funding.
- There are no State incentives for the development of infrastructure needed to increase recharge opportunities.
- Landowners are not compensated for use of land, such as through floodplain protection easements programs that allow agricultural uses.
- The impact of the Irrigated Lands Regulatory Program requirement that farmers ensure that water does not unnecessarily pass the root zone because of concerns of nitrogen migration.

## Legal

### WATER RIGHTS

Potential considerations related to water rights:

- Landowners need to have water rights in terms of both the quantity of water and ability to divert at the right time of year.
- The process to obtain new water rights can be slow and difficult for landowners to navigate.
- Complications for implementers will increase if there is no extension to the provisions of the Governor's Executive Order B-36-15 of November 2015 that provide an expedited process for temporary water rights permits.
- State water-rights system treats surface water and groundwater separately.

- Storage rights of importers, and water rights of landowners/groundwater agencies, create challenges.
- Area of origin may be a source of concern for determining river flows available.
- Pursuit of managed aquifer recharge projects may require change in defined beneficial uses. There is disagreement if a change is necessary.
- A water availability analysis is needed to ensure that there is no harm to existing rights and that environmental water needs are appropriately considered.

### REGULATORY

Potential considerations related to other regulations:

- Complications for implementers could increase if there is no extension to the provisions of the Governor's Executive Order B-36-15 of November 2015 that provide a California Environmental Quality Act exemption for temporary water rights permits.
- A permanent and appropriate regulatory process for groundwater replenishment projects needs to be established.
- The process for obtaining permits can be difficult for landowners to navigate and cost prohibitive.
- Depending on the water source and the intended use of the water, water developed for replenishment will be subject to specific water quality standards, which may limit its use.
- Flood-MAR projects may expose landowners to greater risk under environmental laws for creating certain conditions or habitats (e.g. wetland protection, endangered species habitat, water quality). Safe harbor agreements should be considered to encourage landowners to implement Flood-MAR projects.
- There are concerns that flooding working lands could create conditions that may subject landowners to restrictions under State or federal wetland regulations.

## Implementation

Potential considerations related to strategy implementation:

### LAND USE

- Determine how well crops will tolerate inundation. Namely, if the method damages or kills permanent crops, reduces yield, or increase disease risks.
- Determine what types of crops and soils are ideal for this strategy.
- Determine if projects will increase the amount of nitrate and other pollutants entering the groundwater, and if there is a net dilution of nitrates or other pollutants over time.
- Determine guidelines, practices and land uses, including crop types, that can protect or improve groundwater quality.

### RECHARGE/RECOVERY

- Determine the quality of recharged and recovered water, how the project impacts water quality, and if a project mobilizes dissolved pollutants into aquifers.
- Determine water available for recharge and climate change effects on water available for recharge.
- Identify methods to account and report on replenished water, where the water goes, if it reaches the water table, and if it moves laterally out of the basin.
- Need better understanding of subsurface geology.

### CONVEYANCE

- The spatial and temporal connectivity between potential water sources and groundwater are important considerations.
- Conveyance of water will have specific physical characteristics (e.g., conveyance capacity) and system operations that may limit the amount, or affect the timing, of water available at a specific site.
- Federal, tribal, State, and local conveyance facilities are essential to convey water to either direct groundwater recharge or to existing groundwater users for in-lieu recharge.
- These systems require complex operations that must be coordinated between water users/suppliers and ecosystem, flood, and power requirements. Facilities and requirements (both operational and regulatory) limit capacity throughout the year.
- The maintenance and restoration of existing, and construction of new, infrastructure that can facilitate Flood-MAR needs to be evaluated.

### RESERVOIR REOPERATION

- Federal, State, and local reservoirs are essential to store water. These systems require complex operations that must be coordinated between water users/suppliers and ecosystem, flood, and power requirements. Facilities and requirements (both operational and regulatory) limit capacity throughout the year.
- Many reservoir rule curves and operations are outdated and need to be updated to reflect the effects of current conditions and climate change.
- There is a need to evaluate the potential for additional flood risk reduction benefits from reservoir reoperation, modification of flood rule curves (as prescribed by the U.S. Army Corps of Engineers in reservoir water control manuals), and/or forecast-informed operations.
- Improved weather forecasting will be required to confidently reoperate reservoirs to maximize flood risk reduction benefits and minimize potential impacts to water supply reliability. Forecasting ability is also important for knowing when flood peaks are expected to occur to maximize flood risk reduction benefits, which includes managing the peaks of high-flow events.

## ECONOMICS

- Calculating economic and financial benefits and costs associated with projects.
- Determining economic value of public benefits and avoided costs.
- Landowner compensation mechanisms.
- State incentive programs.
- Consistent standards for economic analysis, including how recharge is accounted.

## ENVIRONMENTAL CONSIDERATIONS

- Determine how diversion of surface water for groundwater recharge affects environmental flows.
- Determine if benefits outweigh risks of diversion during high-flow events. For example, if bypass (pulse protection) flows can be maintained to avoid stranding important aquatic species.
- For projects designed for benefits to rearing native fishes, challenges include minimizing fish stranding and predation while optimizing residence time.
- For projects designed for benefits to terrestrial species, challenges include maximizing residence time and associated food web benefits in recharge areas, and balancing competing needs of current land uses.
- Determine how groundwater recharge/aquifer replenishment can be used to augment base stream flows, particularly in dry years.
- Determine if a project contributes to the recovery and stability of native species, biological diversity, and ecological function.
- Determine if Flood-MAR projects increase groundwater pumping and energy demands – link to the state's greenhouse gas reduction efforts.

## DATA AND CAPACITY BUILDING

- Water budget and recharge accounting methods.
- Data and information exchange and sharing.
- Indicators for monitoring and tracking of project outcomes
- Subsurface geologic characterization, including hydrogeology and knowledge of aquifers targeted for recharge.

*Mark Tos uses a tablet computer to monitor and control water levels on his Hanford, California, farm Thursday, November 8, 2012.*

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# NEXT STEPS

There is significant State government interest in the potential public benefits and water supply reliability improvements associated with Flood-MAR.

DWR recommends the following next steps:

## Engagement

DWR will continue to work with stakeholders and other programs pursuing this strategy, collect relevant existing literature, and assess available tools. Because there are many past and current efforts to study different aspects of this type of resource management strategy, the compilation of existing literature that is relevant, and that will support formulation and evaluation of strategies, is an important effort.

There is significant opportunity to integrate with, and leverage, elements of major ongoing water resources planning efforts. Close coordination with existing and proposed water resources planning and research efforts are critical for the effective and efficient development and implementation of Flood-MAR, such as Sustainable Groundwater Management, the Central Valley Flood Protection Plan (CVFPP), and its Conservation Strategy. For example, DWR, the Central Valley Flood Protection Board, and many stakeholders have been working for years to develop two cycles of the CVFPP and the Conservation Strategy. There is much to be gained and leveraged from the significant level of technical expertise and commitment to multiple benefit projects.

Coordination with some programs has already begun, and additional early engagement is expected over the coming months to help coordinate Flood-MAR actions. Once a State program is developed and funded, continuous and close coordination will be required among landowners, stakeholders, academia, non-governmental organizations, tribes, and applicable federal, State, and local agencies. DWR is committed to supporting and facilitating this coordination.

Contingent on available funding, DWR will develop a program communication strategy to identify venues to allow efficient and effective means to exchange Flood-MAR ideas and practices. The program communication and engagement strategy will help develop statewide expertise and provide a common forum for sharing ideas and encouraging collaboration.

Additionally, DWR will encourage practitioners to develop Flood-MAR projects by providing planning, technical, and facilitation assistance, while supporting robust implementation of pilot projects in the near-term.

## DWR Flood-MAR Planning

DWR is currently developing a Flood-MAR Implementation Plan to guide the formulation and implementation of a State program. DWR has also developed a Research and Data Development Framework (R&D Framework, available on the Flood-MAR website https://www.water.ca.gov/Programs/All-Programs/Flood-MAR) to guide future research and piloting of Flood-MAR opportunities for any entities with interest in implementing this strategy. The R&D Framework will be a major component of the Implementation Plan. These documents are being developed as part of the System Reoperation Study.  Full implementation of the Flood-MAR Implementation Plan and R&D Framework will require authorization and funding from the Legislature.

## Flood-MAR Research and Data Development Framework

The purpose of the R&D Framework is to identify and categorize Flood-MAR relevant research themes, and coordinate ongoing and future research and pilot studies around a common research plan. The R&D Framework will identify gaps in data, information, and knowledge, and outline methods for developing, reviewing, and distributing information among stakeholders. It will also help inform the development of Flood-MAR reconnaissance studies. The intended outcomes of the R&D Framework are:

- Develop a body of knowledge and a living inventory of technical research needs for the Flood-MAR resource strategy.
- Inventory, develop, and coordinate technical expertise related to research needs.
- Matrix technical expertise among participating groups and stakeholders to develop and communicate within the Flood-MAR interest communities a clear, concise, and consistent message.
- Ensure availability of research and technical expertise for all stakeholders.
- Promote long-term and continued research and development.
- Provide guidance to stakeholders to support implementation of the Flood-MAR projects.

Establishing a Flood-MAR Research Advisory Committee will be an early priority for implementing the R&D Framework. The activities of the Research Advisory Committee include but are not limited to:

- Develop a repository and literature review for the body of knowledge and technical research related to the Flood-MAR resource management strategy. The repository would catalogue available information, data, and studies and share those with stakeholders.
- Facilitate the creation of an extensive network of collaborators and advisors organized and led by DWR to communicate and train using the best available science and technical capacity across State, local, federal, academic, non-governmental, private experts, extension advisors, firms, and stakeholders.

- Provide guidance to develop and support multi-agency technical and scientific activities, plans, and programs such as common standards, data-based information, modeling capabilities, testing, and documentation.
- Oversee and provide recommendations to technical and policy-informing studies with responsible independence, transparency, credibility, and competency to address controversies in a non-advocacy way.
- Foster and provide independent technical reviews to better inform discussions of controversial topics.
- Lead and develop an integrated training and education program for staff and scientific outreach and engagement for stakeholders, industry, regulators, planners, decision makers, and academic experts.

## Scoping Process

Scoping will include continued outreach and coordination efforts, such as workshops, brainstorming sessions, and meetings, to implement the Flood-MAR R&D Framework and identify initial study areas for Flood-MAR. The scoping process will help DWR identify the ideal locations for analyzing opportunities and find ways to overcome barriers to provide guidance to others trying to implement Flood-MAR.

## Study Execution

Study execution includes full implementation of the Flood-MAR R&D Framework and Implementation Plan. Reconnaissance and feasibility assessments will be conducted throughout the state in coordination with local agencies, academia, non-governmental organizations, tribes, and federal and State partners.

As part of the System Reoperation Study, DWR is developing a Flood-MAR Conceptual Study that will expand on the Preliminary Study on Merced River to better frame the Flood-MAR concept. This conceptual study, through initial technical analysis, will investigate the Flood-MAR concepts presented in this white paper. Contingent on available funding, DWR will perform reconnaissance studies on multiple watersheds and reservoirs. These reconnaissance studies will incorporate strategies and research themes from the R&D Framework, and will explore in finer detail the types of analyses that could be accomplished and the benefits that could be attained by a Flood-MAR project.

## Schedule

Contingent on available funding, DWR plans to initiate a Flood-MAR program and, in partnership, implement the R&D Framework with the following phases:

1. Year 1 – initial outreach, scoping, and review of past efforts (including what was started in 2017 through preparation of this white paper); development of key partnerships and technical expertise; review of relevant existing literature, related programs, and available tools to explore opportunities, best practices, and how to overcome obstacles; and initiation of conceptual level studies.

2. Year 2 – continued outreach, evaluation of preliminary Flood-MAR and reoperation strategies and opportunities, and initiation of reconnaissance level assessments and pilot projects.

3. Year 3, and beyond – capitalize on developed partnerships and information gathered to conduct feasibility studies and implement projects.

DWR is developing partnerships and preparing to provide long-term technical assistance to local agencies exploring and implementing Flood-MAR projects. But, DWR's participation in, and development of, Flood-MAR studies and projects will require additional authorization and funding from the Legislature.

# REFERENCES

## Resources Cited


Bachand, Philip A.M.; Roy, Sujoy B.; Stern, Nicole; Choperena, Joseph; Cameron, Don; and Horwath, William R., 2016. On-farm Flood Capture Could Reduce Groundwater Overdraft in Kings River Basin. California Agriculture. Volume 70, Number 4. October-December.

Bachand P, Dahlke H, Horwath W, et al. 2015. Capturing El Niño for the underground. California Water Blog, Oct.13, 2015. http://californiawaterblog.com/2015/10/13/capturing-el-nino-for-the-underground/

Bachand, Phillip A.M.; Roy, Sujoy B.; Choperena, Joe; Cameron, Don; and Horwath, William R., 2014a. Implications of Using On-Farm Flood Flow Capture to Recharge Groundwater and Mitigate Flood Risks Along the Kings River, CA. ACS Publications. Environmental Science & Technology 48 (23), 13601-13609. Published November 13, 2014. http://aquadoc.typepad.com/files/bachand-et-al-2014-on-farm-flow-cap.pdf

Bachand P.A.M., Trabant S, Vose S, Mussetter B. 2013. McMullin On-Farm Flood Capture and Recharge Project: Hydraulic and Hydrologic Analyses (H & H). Final report, TO# 01, prepared for Kings River Conservation District for submittal to California DWR.

Bachand, P.A.M., WR Horwath, SB Roy, J. Choperena and D. Cameron. 2011. CIG Agreement No. 68-9104-0-128 Fact Sheet: On-Farm Flood Flow Capture – Addressing Flood Risks and Groundwater Overdraft in the Kings Basin with Potential Applications throughout the Central Valley. http://aquaticcommons.org/11289/1/CIG%20On%20Farm%20Flood%20Capture%20Fact%20Sheet.pdf

California Department of Water Resources, 2018. California Water Plan Update 2018. Chapter 3. Working Draft for Public Webathon. January 9, 2018. http://www.water.ca.gov/waterplan/docs/cwpu2018/workshops/jan2018/Update2018_DRAFT_Ch03_Jan09_Webinar.pdf

California Department of Water Resources, 2017a. Climate Change Analysis Technical Memorandum. Central Valley Flood Protection Plan 2017 Update. March. http://www.water.ca.gov/cvfmp/docs/CC_DraftClimateChangeSummary_March2017.pdf

California Department of Water Resources, 2017b. Central Valley Flood Protection Plan 2017 Update. August. http://www.water.ca.gov/cvfmp/docs/2017/2017CVFPPUpdate-Final-20170828.pdf

California Department of Water Resources, 2017c. Water Available for Replenishment. Draft Report. January. http://water.ca.gov/groundwater/sgm/wafr.cfm

California Department of Water Resources, 2015a. Sustainable Groundwater Management Program Draft Strategic Plan. March 9. http://www.water.ca.gov/groundwater/sgm/pdfs/DWR_GSP_DraftStrategicPlanMarch2015.pdf

California Department of Water Resources, 2015b. California's Groundwater Update 2013. A Compilation of Enhanced Content for California Water Plan Update 2013. April.

California Department of Water Resources, 2013a. California Water Plan Update. Volume 4 Reference Guide. Glossary. http://www.water.ca.gov/waterplan/docs/cwpu2013/Final/vol4/background/08CWP_2013_Glossary_Final.pdf

California Department of Water Resources, 2013b. California's Flood Future: Recommendations for Managing the State's Flood Risk. Final. November. http://www.water.ca.gov/sfmp/resources/California_Flood_Future.pdf

CALFED Bay-Delta Program, Programmatic Record of Decision, August 28, 2000. http://www.calwater.ca.gov/content/Documents/ROD.pdf

California Natural Resources Agency, California Department of Food and Agriculture, and California Environmental Protection Agency. California Water Action Plan 2016 Update.

Dahlke et al. Managed winter flooding of alfalfa recharges groundwater with minimal crop damage. California Ag: 1 – 11.

Farmington Groundwater Recharge Program, 2017, http://www.farmingtonprogram.org/

Faunt et al. 21016. Water availability and land subsidence in the Central Valley, California, USA. https://www.researchgate.net/profile/Claudia_Faunt/publication/284244408_Water_availability_and_land_subsidence_in_the_Central_Valley_California_USA/links/570ff50e08ae74cb7d9efe34.pdf

Hanak, Ellen 2017. The State of Groundwater Recharge in the San Joaquin Valley. Viewpoints the PPIC Blog. November 10, 2017. http://www.ppic.org/blog/state-groundwater-recharge-san-joaquin-valley/

Kocis, TN; & Dahlke, HE. 2017. Availability of high-magnitude streamflow for groundwater banking in the Central Valley, California. ENVIRONMENTAL RESEARCH LETTERS, 12(8). doi: 10.1088/1748-9326/aa7b1b. UC Davis: oa_harvester:2212536. Retrieved from: https://escholarship.org/uc/item/57f3790g

O'Geen AT, Saal MBB, Dahlke HE, et al. 2015. Soil suitability index identifies potential areas for groundwater banking on agricultural lands. http://calag.ucanr.edu/Archive/?article=ca.v069n02p75

RMC Consultants, Inc., 2015. A New Opportunity – Groundwater Recharge through Winter Flooding of Agricultural Land in the San Joaquin Valley. October.

U.S. Army Corps of Engineers, 2002. Conjunctive Use for Flood Protection. January.

Weissmann, G.S., Y. Zhang, Fogg, G.E., and Mount, J.F., 2004, Influence of incised valley fill deposits on hydrogeology of a glacially-influenced, stream-dominated alluvial fan. SEPM special publication on Hydrogeophysics and Hydrostratigraphy (edited by John Bridge and David Hyndman), p. 15-28.

Wood, Warren W. and David W. Hyndman. 2017. Groundwater Depletion: A significant unreported source of atmospheric carbon dioxide. Earth's Future. http://onlinelibrary.wiley.com/doi/10.1002/2017EF000586/full

## Resources Consulted

Ariayama, J., 2014. Nitrogen Leaching and Groundwater Recharge Modeling for the On-Farm Flood Flow Capture Project in Fresno, CA. https://search.proquest.com/openview/32067d9bc08e6b28619a31a18dd95f00/1?pq-origsite=gscholar&cbl=18750&diss=y

Association of Groundwater Agencies, 2000. Groundwater and Surface Water in Southern California – A Guide to Conjunctive Use.

California Department of Water Resources website. Groundwater Basins Subject to Critical Conditions of Overdraft. Sustainable Groundwater Management Program. http://www.water.ca.gov/groundwater/sgm/pdfs/COD-basins_2016_Dec19.pdf

California Department of Water Resources, 2016. San Joaquin Basin-Wide Feasibility Study Technical Appendix. Section 19 Groundwater Recharge. Stakeholder Review Draft. October.

California Department of Water Resources, 2012. Central Valley Flood Protection Plan 2012 Update. Attachment 8L Groundwater Recharge Opportunities Analysis. June. http://www.water.ca.gov/cvfmp/docs/2012CVFPP_Att8L_June.pdf

California Department of Water Resources, 2006. Conjunctive Management Opportunities in the San Joaquin Valley. Division of Planning and Local Assistance. August 16.

Kern Water Bank (KWB), 2017. http://www.kwb.org/index.cfm/fuseaction/Pages.Page/id/352

Land IQ 2017. Groundwater Recharge Suitability. http://www.landiq.com/water-resources

National Water Research Institute, et al, 1998. Conjunctive Use Water Management Program Workshop Report. May 27-29.

O'Geen, et al, 2015. April-June. Soil suitability index identifies potential areas for groundwater banking on agricultural areas. Research article. http://calag.ucanr.edu/

Rohde, Melissa, Choy, Janny, and McGhee, Geoff, 2014. Recharge: Groundwater's Second Act. Understanding California's Groundwater. Water in the West. July 31. http://waterinthewest.stanford.edu/groundwater/charts/recharge-interactive/index.html

Sustainable Conservation and Earth Genome. 2018. Groundwater Recharge Assessment Tool. http://earthgenomevm.cloudapp.net/GRATViewer/

U.S. Department of Agriculture. Natural Resources Conservation Service Soil Survey. https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/survey/

## Comments Received on the Working Draft

Bachand & Associates – https://www.water.ca.gov/-/media/FLOOD-MAR-Documents/Flood-MAR-White-Paper-Public-Comments/Flood-MAR_BachandAssociates.pdf?la=en&hash=A739316D1BA0294F7F4D3D3F7A55C5D9E0028D0F

California Farm Bureau Federation – https://www.water.ca.gov/-/media/FLOOD-MAR-Documents/Flood-MAR-White-Paper-Public-Comments/ZidarFlood--MAR-Comments-to-White-Paper--Discussion-Draft-November-2017Flood-MAR-Comment.pdf?la=en&hash=A6B9897847BBA974EA675A8C3183886277FCB724

California Central Coast Regional Water Quality Control Board – https://www.water.ca.gov/-/media/FLOOD-MAR-Documents/Flood-MAR-White-Paper-Public-Comments/Region-3-Groundwater-Recharge-Comments.pdf?la=en&hash=0D7247D1002B1C65DFCA852DECA48622FDAC68E9

California Sportfishing Protection Alliance – https://www.water.ca.gov/-/media/FLOOD-MAR-Documents/Flood-MAR-White-Paper-Public-Comments/CSPA-comments-Managed-Replenishment-White-Paper-120517.pdf?la=en&hash=34C6131721FEEE75D6B137125B5C3DA5A016A16F

Consultant - Strategic Groundwater Planning and Management – https://www.water.ca.gov/-/media/FLOOD-MAR-Documents/Flood-MAR-White-Paper-Public-Comments/ZidarFlood--MAR-Comments-to-White-Paper--Discussion-Draft-November-2017Flood-MAR-Comment.pdf?la=en&hash=A6B9897847BBA974EA675A8C3183886277FCB724

Environmental Science Associates – https://www.water.ca.gov/-/media/FLOOD-MAR-Documents/Flood-MAR-White-Paper-Public-Comments/Flood-MAR_Discussion-Draft_ESA.pdf?la=en&hash=171A952A2C4E2D1CA63EBF93B470CF50F569C219

Point Blue Conservation Science/Audubon California/Environmental Defense Fund/American Rivers/California Trout/River Partners/The Nature Conservancy/Sacramento River Preservation Trust – https://www.water.ca.gov/-/media/FLOOD-MAR-Documents/Flood-MAR-White-Paper-Public-Comments/NGO_Flood_MAR_comment_letter_8Dec2017.pdf?la=en&hash=321A7C602130DF1B9D477AD8102AC1EE1EE01CB9

Sustainable Conservation – https://www.water.ca.gov/-/media/FLOOD-MAR-Documents/Flood-MAR-White-Paper-Public-Comments/Flood-MAR-White-Paper_Sustainable-Conservation-comments.pdf?la=en&hash=95035FC87828C0CB1F8498D36332071026EDD1C8

UC Water/Groundwater Resources Association of California – https://www.water.ca.gov/-/media/FLOOD-MAR-Documents/Flood-MAR-White-Paper-Public-Comments/UC-Water-and-Groundwater-Resources-Association-Comments.pdf?la=en&hash=C733B7CAE39405C1584C7F3431AA5F401CAAC5E5

USACE Hydrologic Engineering Center – https://www.water.ca.gov/-/media/FLOOD-MAR-Documents/Flood-MAR-White-Paper-Public-Comments/HEC-Comments_-Groundwater-Recharge-with-Flood-MAR.pdf?la=en&hash=0AFFB3AD594FC0E73BBE199AD558417CBDB0CAF4

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