# Flood-MAR
# Using Flood Water for Managed Aquifer Recharge to Support Sustainable Water Resources

White Paper - Discussion Draft

November 2017

## Discussion Draft – White Paper Reviewer's Guide

This white paper on using flood water for managed aquifer recharge (Flood-MAR) to support sustainable water resources is presented as a discussion draft. Comments received on this draft by December 8, 2017, will be used to inform the final white paper.

In August 2017, DWR released the Phase 3 report for the System Reoperation Study. A recommendation of this report was to "evaluate potential for using flood water for managed groundwater recharge on farmland and working landscapes for flood protection, drought preparedness, aquifer remediation, and ecosystem restoration. DWR will work with flood managers, land owners, and Groundwater Sustainability Agencies to determine opportunities to implement managed groundwater recharge projects that use excess flood flows as the source water." This white paper represents an early effort to gather existing information on Flood-MAR opportunities, benefits, challenges, information gaps, and next steps. A Plan of Study for Flood-MAR will be released in early 2018.

### Where to Find This Draft

The discussion draft white paper will be posted online in PDF format at:

http://water.ca.gov/system_reop/

### What to Review

Prior to the publication of the final version, this white paper will be edited for grammar, punctuation, style, consistency, accuracy, or other issues relating to readability or quality. The current graphics are draft. Photographs will be inserted into the final version.

Recommendations for what to focus on during your review:

- **Completeness of information:** In general, does the text say all it should say? Is all information present that an average reader might need and is the information presented appropriately?
- **Organization of information:** Does any portion of the text cause readability issues because information is presented in a confusing sequence or because it is difficult to tell what section of text is a subsection of another?
- **Factual accuracy**: Is anything in the text incorrect? Does any information need additional attribution to a specific source?
- **Logical consistency:** Does the narrative build in a logical way and effectively tell the right story?
- **Clarity/Comprehensibility:**. Are there any holes/gaps in information that make the text difficult to understand? Is there jargon the average reader would not be able to

understand? Are there ways to improve clarity and make the text/graphics more meaningful and effective?

## How to Comment

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

## 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 utilize flood water for managed aquifer recharge (Flood-MAR) because DWR recognizes the need to rehabilitate and modernize water and flood infrastructure in California. DWR also wants to demonstrate the type of infrastructure investment needed to allow the delivery of water-related public services in the state that will foster long-term sustainability and adaptation to climate change. In addition, DWR has observed a steady rise in local studies and pilot projects of this type, research, and interest by water managers.

This white paper:

- Explores past efforts and future opportunities to utilize 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, a plan of study needed to fill information gaps and support a more comprehensive and expansive program, and the partnerships needed to successfully implement this type of strategy.

**The R's of Groundwater**

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

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

*Remediation – The process of improving groundwater quality, such as extracting contaminated groundwater from an aquifer, treating it, and then either returning it to the aquifer or using it for agricultural or municipal purposes.*

*Replenishment – To recharge an aquifer by supplying what has been formerly withdrawn from storage. 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 and increase groundwater levels. In other words, there is a State interest in healthy groundwater basins and an indicator of health is groundwater level.*

*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.*

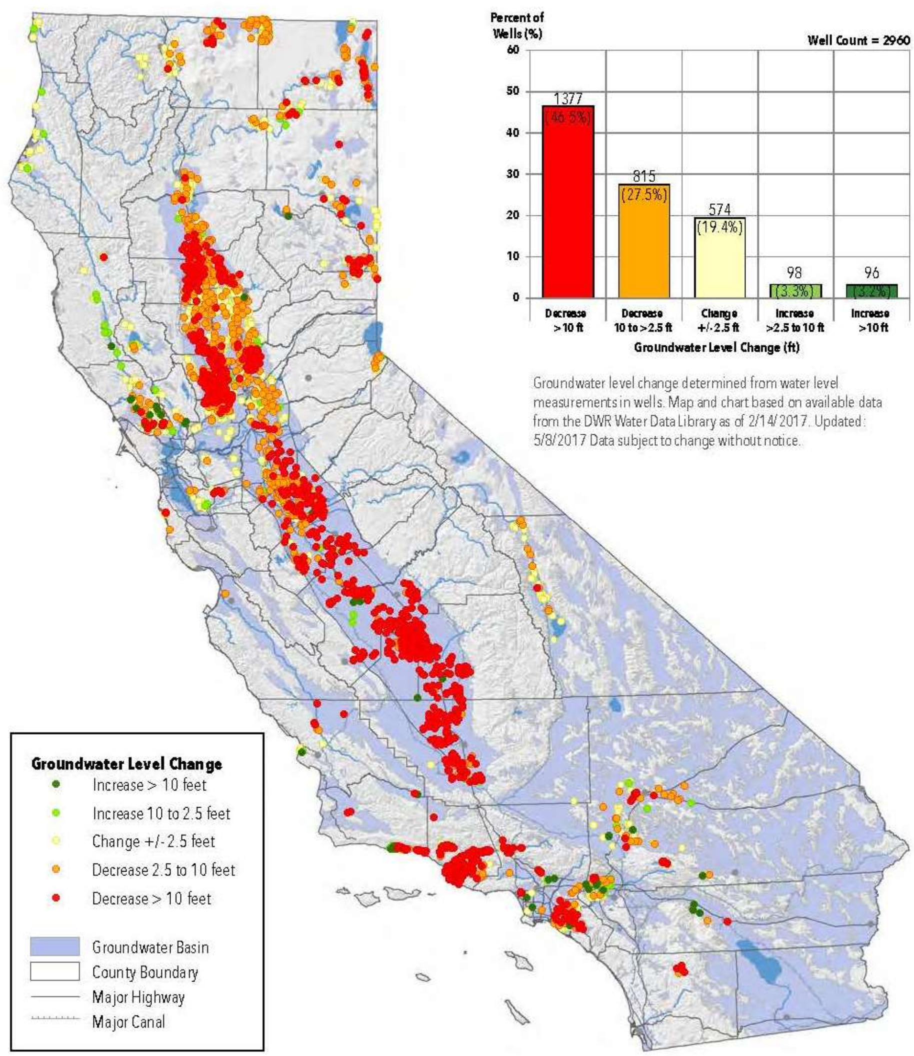
High demands for water across water use sectors, a limited and variable water supply, and complex regulatory framework have always made planning for water resources sustainability challenging. Planning for water resources sustainability is more challenging now than ever because drought and flood events 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 will exacerbate flood risks, add challenges for water supply reliability, and increase stressors on ecosystems. This white paper presents the need for Flood-MAR to be an important part of California's portfolio of water resource management strategies, now and in the future, to significantly improve water resources sustainability and climate resiliency throughout the state.

## California Water – A Tale of Two Extremes

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

Most recently, 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 in 2012-2015. 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.

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

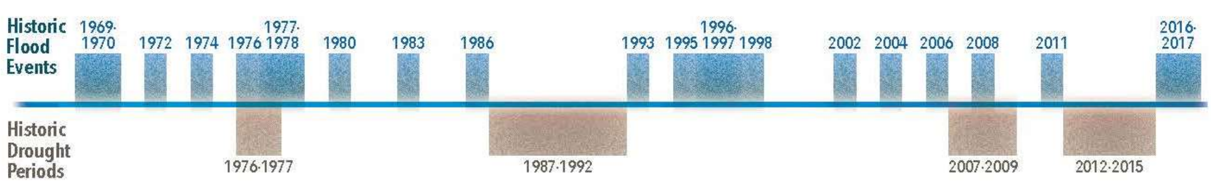


During this drought, the Sustainable Groundwater Management Act (SGMA) went into effect, establishing a new State framework and local tools for managing California's groundwater—forever changing how groundwater is managed in the state.

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.

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 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 were reported by the State-Federal Flood Operations Center (FOC) by mid-March 2017, including boils, seepages, sloughing, bank erosion, overtopping, slippage, levee breaks, and local flooding. 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. Climate change impacts related to flooding are expected to be particularly severe in the San Joaquin River Basin because it is a high-elevation, snow-melt driven watershed.

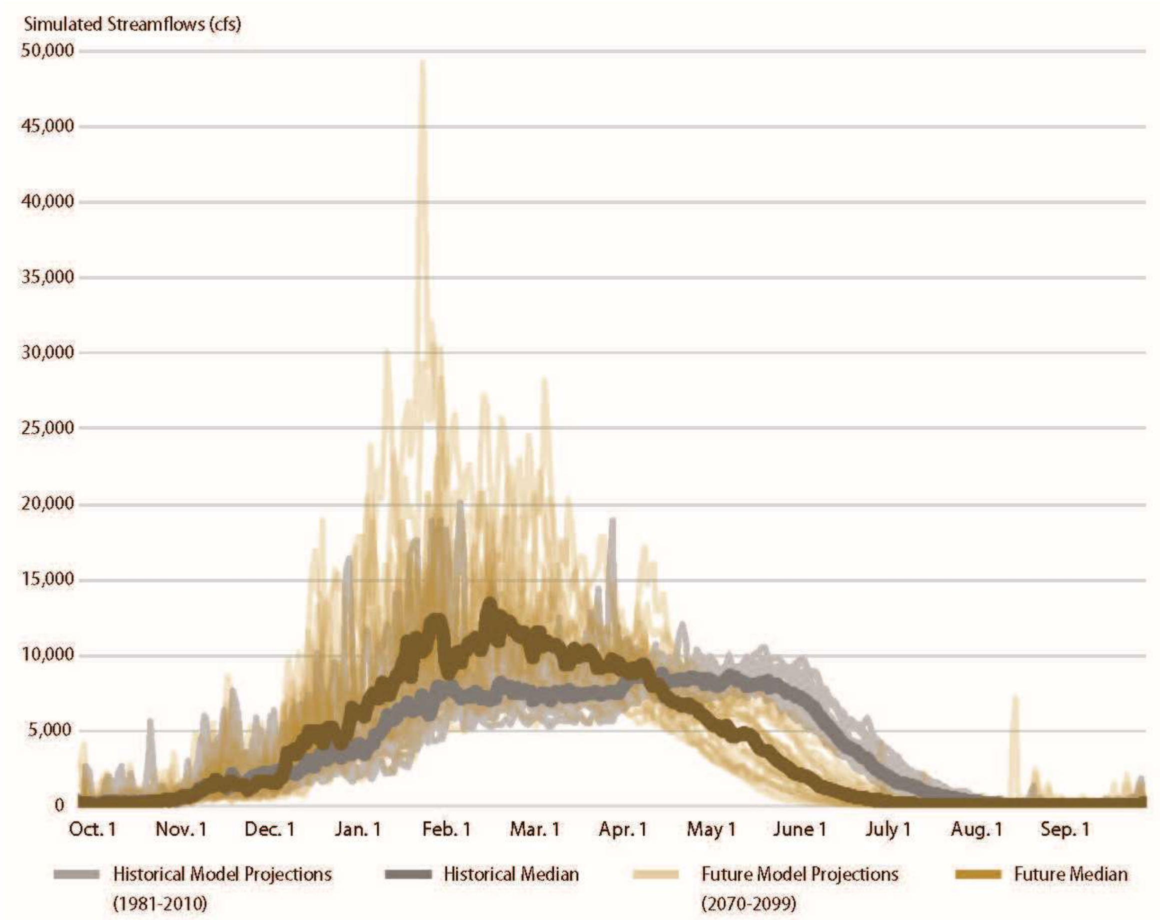
**Figure 2. California Flood and Drought Timeline**




The state will continue to experience recurring extreme weather events, which will be 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 (Figure 3). Climate change is also expected to result in more variable weather patterns throughout

California. More variability can lead to longer and more severe droughts. This potential change in weather patterns will exacerbate flood risks and add additional challenges for water supply reliability.

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




Source: California Department of Water Resources, 2017a

In response, the State must use more integrated and sustainable water management to simultaneously prepare for longer and deeper droughts, and more severe flooding. This recent cycle of drought and flood, and the passage of SGMA, has provided a unique opportunity to discuss and inform long-term State policies related to the nexus between flood management, land use, and groundwater management.

DWR, and other State, federal, regional, and local entities, 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 expanded, integrated program implementation.

For example, after enduring four years of drought followed by the 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. What if mechanisms had been in place to take high flows during, or make reservoir releases ahead of, precipitation events onto agricultural lands and working landscapes? Doing this on a large scale can reduce flood risks and recharge groundwater in some shallow aquifers. Compensating landowners for easements to flood their lands could support a larger scale, public-private implementation effort that helps reduce flood risks on a system scale and recharges depleted shallow aquifers in many locations.

## 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 significant 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 contribute toward sustainable 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 support the sustainable use of water.

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 2013). 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. Sustainability is not an end point but an ongoing, resilient, and dynamic balance between four societal values — public health and safety, a healthy economy, ecosystem vitality, and opportunities for enriching experiences. Dynamic balancing is necessary because the relative importance of societal values changes over time, often expressed through political processes.

To prepare for longer droughts and more severe flooding, the state must engage in strategic and integrated water management planning. 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, regional, and local levels, can ensure a sustainable future for California. DWR believes Flood-MAR can significantly improve water resources sustainability throughout the state.

## Benefits of Using High-Flow Events for Managed Aquifer Recharge

The ability to integrate flood and groundwater management by actively managing high-flow events to recharge aquifers could provide multiple benefits.

### Public Benefits

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

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

#### *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 river flow and stage, during and before high-flow events, reducing downstream flood risk. The reduction of flow and stage also provides reservoir operators with additional flexibility to manage flood space and control flood releases, providing greater potential for flood-risk reduction benefits.

Through Flood-MAR, flood benefits (i.e., flood-risk reduction) could be attained in two ways:

1. By taking water off the channel during high-flow events (i.e., skimming peak flows) and purposefully flooding lands to promote groundwater infiltration. This methodology requires a significant amount of land area to achieve flood-risk reduction benefits downstream of the diversion point.
2. By lowering reservoir storage levels prior to the flood season, or ahead of discrete events, to vacate storage for anticipated precipitation/snowmelt, which can reduce flood risks below the reservoir. The vacated water is transferred to groundwater storage.

It should be noted, changes in reservoir operations will have effects beyond flood management, including potential impacts on water supply, water quality, environmental flow requirements, and contracted water delivery requirements. Although this strategy has significant merit, it will require the analysis of benefits and impacts and coordination agreements with numerous parties. The analysis must also consider how those benefits and impacts will change over time (e.g., how resilient are 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. In some areas, groundwater levels are so depressed they are causing subsidence, or the permanent lowering of ground surfaces. High flows represent another source of water that can be used to replenish aquifers and reverse declining groundwater levels. Recharged groundwater may be extracted for beneficial use, but a water agency may choose to leave water in the basin for the purpose of aquifer replenishment, or increasing or maintaining groundwater levels.

### *Ecosystem Enhancements*

Flood-MAR can provide ecosystem benefits by reconnecting and inundating floodplains; creating floodplain habitat (e.g., riparian), marsh, and wetlands; and supporting groundwater dependent ecosystems. 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. 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. Not much is known about below-surface ecosystems and organisms, or how aquifer replenishment may provide ecosystem benefits below the surface. Research is needed in this area.

### *Subsidence Mitigation*

Flood-MAR has the potential to reduce groundwater overdraft and stop or slow land subsidence. Land subsidence has been an issue for decades and areas of the San Joaquin Valley have been particularly hard hit, 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, reducing their water storage and carrying capacities. Land subsidence can also permanently reduce the water storage capacity of an aquifer.

### *Aquifer Remediation/Water Quality*

Flood-MAR can improve groundwater quality by increasing the amount of water in storage and potentially diluting impaired or contaminated aquifers. This resource management strategy can also help prevent or slow seawater intrusion into aquifers. But, flooding recharge areas could mobilize surface/soil pollutants from current or past land uses and contaminate aquifers. Increasing recharge could also mobilize contaminated groundwater plumes by increasing pressure gradients. Potential benefits and impacts will be site specific (this is true for all benefit categories).

### *Working Landscape Preservation and Stewardship*

Flood-MAR strategies could compensate landowners for keeping their lands in their current use while allowing periodic flooding. This strategy relies upon 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. This strategy allows farmland to stay in production rather than retiring lands to create recharge basins.

### *Climate Change Adaptation*

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 changed climate. Flood-MAR adds flexibility to system operations that will be needed to compensate for earlier snow melt runoff and potential changes in water demand. Both groundwater use and flood risks are projected to increase as the climate changes. Flood-MAR could help address these two major challenges in an integrated way.

### *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 could improve bird watching or creation of wetlands. Reconnection on floodplain habitat could improve the natural beauty of a landscape over non-vegetated, dedicated recharge basins.

## Private/Local Benefits

### *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 has the potential to significantly increase water supply reliability for users. The consumer water-supply benefits of this strategy are considered a private benefit.

### *Reduced Groundwater Pumping Costs*

Elevated groundwater levels will help groundwater users reduce their groundwater pumping costs, and could potentially prevent the need for wells to be deepened (another cost saving to groundwater users).

## Description of Flood-MAR

Flood-MAR is an integrated and voluntary resource management strategy that uses high flows resulting from, or in anticipation of, rainfall or snowmelt for groundwater recharge on agricultural lands, working landscapes, and open space.

This strategy epitomizes integrated water management. It is inherently multi-benefit—providing flood risk reduction, drought preparedness, aquifer replenishment, ecosystem enhancement, and other potential benefits. It is also an effective climate change adaptation strategy that would take an integrated approach to 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.

Flood-MAR can be implemented at multiple scales, from individual landowners taking on flood water with existing infrastructure, to using extensive detention/recharge areas and modernizing flood protection infrastructure/operations.

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. In a post-SGMA world, with climate-induced extreme events, the logic for these communities to partner and integrate is becoming clear and imperative. This partnership would take the edge off 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.

Figure 4 describes the fundamental factors for implementing this resources management strategy. Figure 5 illustrates the basic concepts of Flood-MAR.

Figure 4. Factors for Implementing Flood-MAR

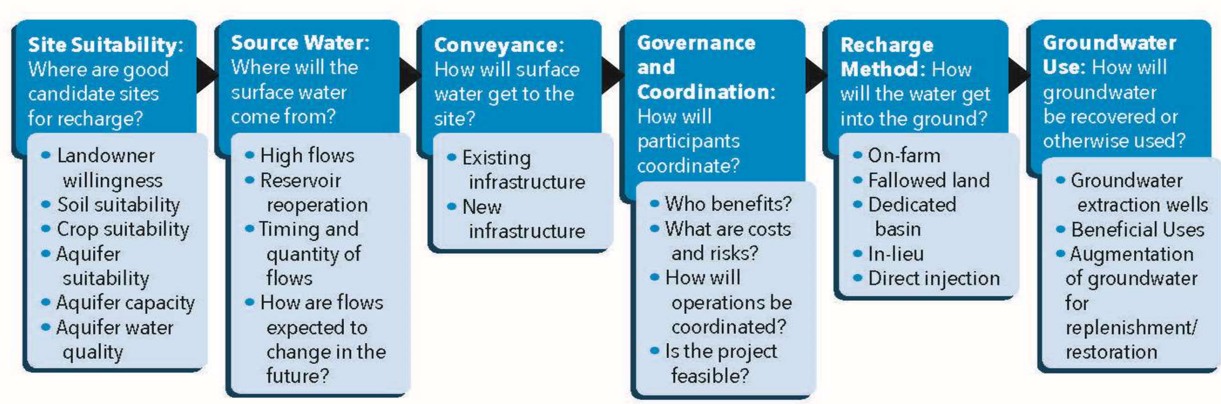
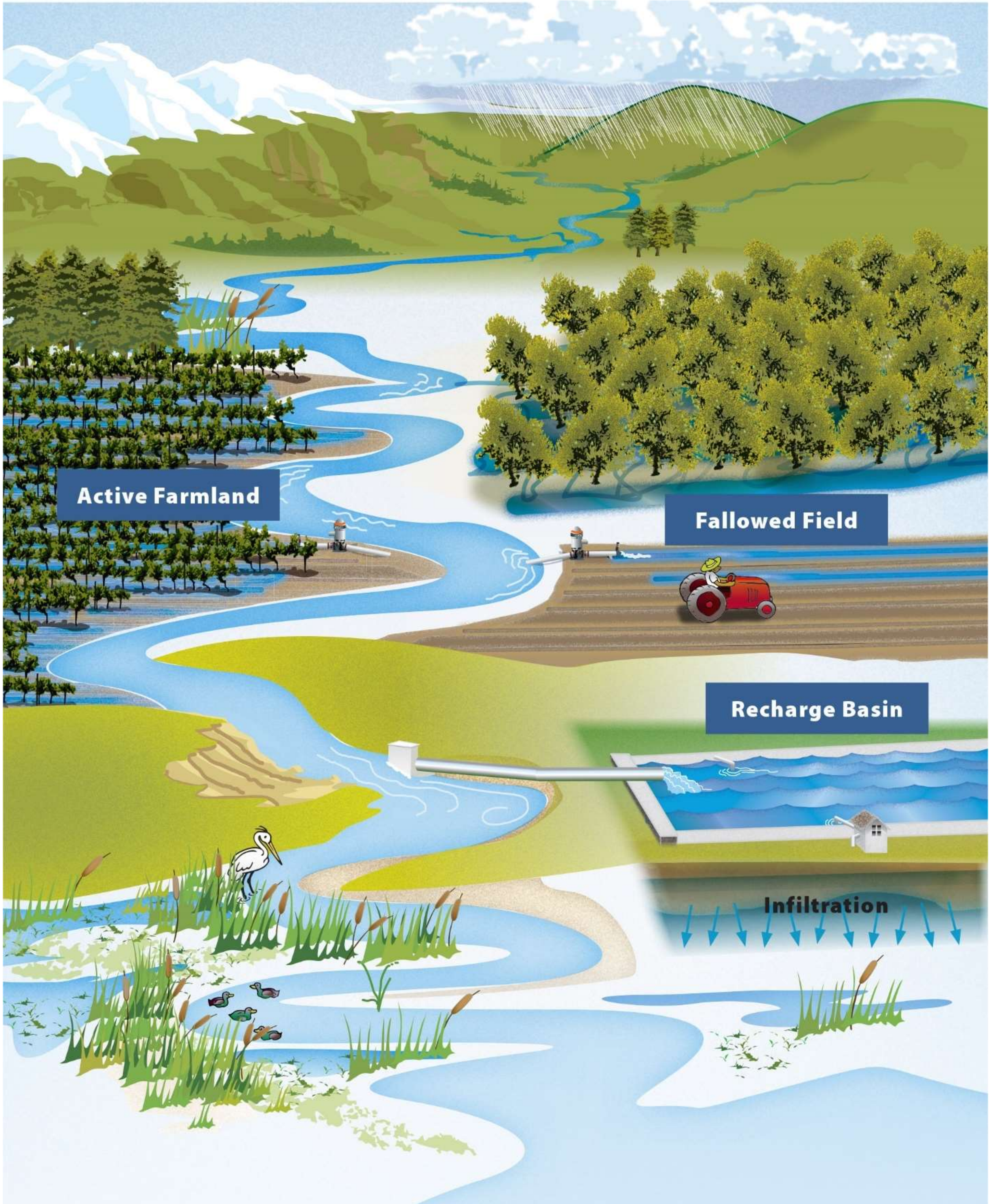


**Figure 5. Concepts of Flood-MAR**



## Determining Suitability of Potential Recharge Areas

First and foremost, Flood-MAR will require the voluntary participation (and compensation) of landowners. Several physical parameters determine the suitability of a potential site for providing groundwater recharge benefits. 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. Infiltration capacity is a measure of the volume of water that can be recharged per unit of time, and is determined by multiple factors. Recharge suitability indices are available that help determine potential areas where groundwater recharge is feasible.

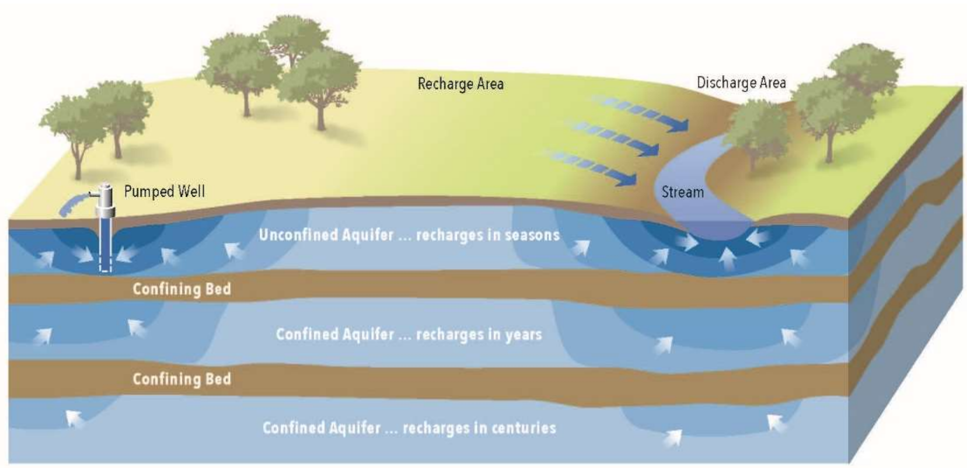
Currently, there are two recharge suitability indices:

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. 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 of site suitability for intentional groundwater recharge.

*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, on dedicated recharge basins. This resource management strategy looks at expanding recharge onto agricultural and working landscapes. There are specific challenges associated with planted agricultural land uses. Crop compatibility to interim flooding must be determined, specifically the ability of the crop's root zone to tolerate saturated conditions for necessary durations. 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 being 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. Lastly, crop-type considerations are also important based on the types of fertilizers that may be applied and the potential for moving fertilizers into the aquifer.

*Aquifer Suitability* – Water must not only migrate through the surficial soils, as described earlier, but it must also travel to the aquifer system that is used for regional or local groundwater supply. 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 prevent the water from reaching the target aquifer. In those cases, water infiltrates to relatively shallow depths and then moves laterally, often discharging to downgradient surface water bodies. Or, for less permeable aquifers, the infiltration to the aquifer may be the controlling recharge rate. A schematic of general groundwater flow paths is shown in Figure6.

**Figure 6. 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, unconfined aquifers in the San Joaquin Valley Groundwater Basin have larger storage capacity than those in the Sacramento Valley Groundwater Basin.

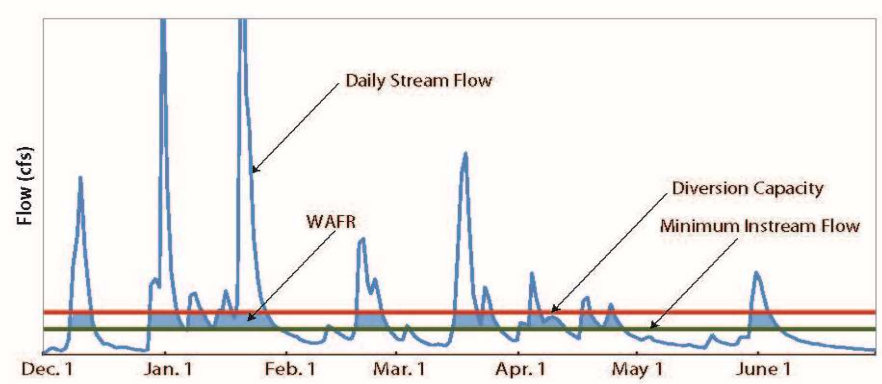
*Water Quality* – Groundwater basin water quality is an important concern for recharging groundwater that can be used later. Constituents of concern will vary based on the intended end use of the water, but can include total dissolved solids, lead, arsenic, boron, and organics. Constituents may be anthropogenic or naturally occurring. Taste of extracted water is an important concern for municipal use.

## Determining High Flows Available

In January 2017, DWR released the draft Water Available for Replenishment (WAFR) report as required by SGMA. The WAFR report summarized estimates of surface water available for replenishment that were determined using a synthesis of information—monthly simulated Water Evaluation and Planning model outflows, historical daily gage data, regulatory environmental flow requirements, water rights, and existing storage and conveyance facilities.

Figure 7 illustrates the concept used to determine the surface water available for replenishment in the WAFR report.

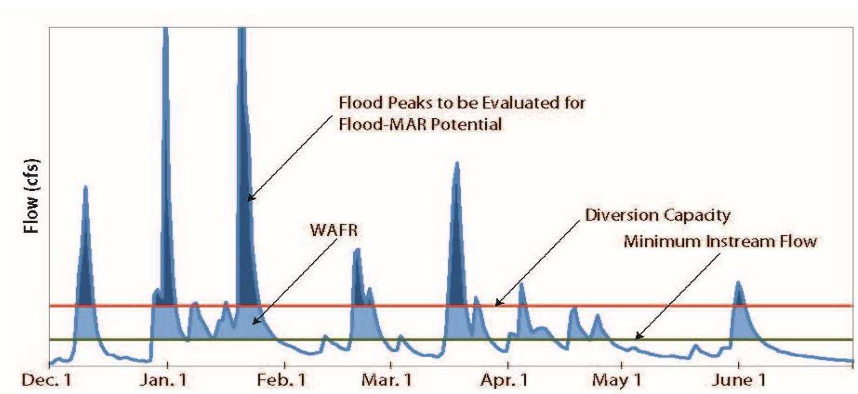
Figure 7. Surface Water Available for Replenishment




This white paper uses the term *high flows* 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). A similar designation was used in the WAFR analysis conducted for SGMA. It generally considered surface water *available* when streamflow exceeded existing water demands and minimum instream flow requirements, and provided some opportunity for additional beneficial use.

In Figure 8, high flows are considered those highlighted in blue. The term high flows used in this report is considered synonymous with unappropriated flows. Flood peaks can be evaluated for as a potential water source for Flood-MAR strategies. Tradeoffs and risks must be considered when evaluating the potential water available for managed aquifer recharge. Hydrographs are anticipated to have higher flood peaks that occur earlier in the rainy season due to climate change.

Figure 8. High Flows




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 needs. It is understood that high flows 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. 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.

## Conveyance to Recharge Areas

An important consideration for managed recharge projects is how to get the water to the recharge area. In some cases, such as properties adjacent to rivers, channels, and irrigation canals, existing conveyance is sufficient. But areas that currently rely solely on groundwater may do so because they lack surface water conveyance facilities.

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, will be required to maximize managed aquifer recharge statewide.

## Governance and Coordination

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 a myriad of local, regional, State, federal, 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 way surface water and groundwater is managed across the state. It has just been during the last few years that surface water and groundwater interactions, and the need to manage both resources in an integrated manner, are really being understood and embraced (with the help of the SGMA legislation).

Cooperation of many entities is required for this resources management strategy to be successful. Cooperation among the owners, operators, and maintainers of pertinent water management facilities; potential beneficiaries; and the land owners bearing impacts, is required for this resource management strategy to be successful. This 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.

## Methods of Recharge

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 percolation basins 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.

    Flood-MAR focuses on the ability to utilize direct spreading onto large acreages of active agricultural land, fallowed land, working landscapes, dedicated recharge basins, or open space. For active farmland, recharge water is typically applied during the non-irrigation season.

    *Aquifer injection* is another active recharge technique. Water is injected into confined 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.

## Opportunities for Using Flood Flows for Managed Aquifer Recharge

DWR plans to build on the knowledge from past studies and programs to pursue expanded flood and groundwater management integration.

This section provides an overview of past and existing 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, a study related to improving conjunctive use and minimizing flood risk was published by U. S. Army Corps of Engineers Hydrologic Engineering Center (U. S. Army Corps of Engineers 2002). This study improved flood protection 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.

Coincidentally, after SGMA was passed, the number of studies related to managed aquifer recharge has spiked. 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 potential 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). Finally, 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 et al 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 lead 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 (afy) of flood flows in local aquifers via direct recharge methods. In 2016, more than 11,000 afy were contributed (http://www.farmingtonprogram.org/).

- The Kings River Basin on-farm flood capture project is investigating methods of mitigating regional flood risks and offsetting groundwater overdraft. The 1,000-acre pilot project studied the infiltration rate of floodwater diverted from the Kings River and potential recharge of groundwater. 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 (Bacand et al. 2016).
- Under a DWR Flood Corridor Grant being implemented by the Kings River Conservation District, and with local matching funds from Terranova Ranch, the McMullin On-Farm Flood Capture and Recharge Project is expanding a pilot study to a regional scale (Bacand et al. 2015).
- 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 (http://www.rechargeinitiative.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/).

All the studies and projects illustrate that using available high flows for groundwater recharge is feasible, cost effective, provides multi -benefits, and is a promising strategy to pursue. But implementing such a strategy does come with limitations, concerns, costs, and regulatory constraints that need to be fully considered and studied. Agencies that have successfully implemented a long- or short-term groundwater recharge program using high flows identified the following common concerns:

- 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.

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

DWR recently completed a reconnaissance study on the Merced River and New Exchequer Dam to determine the potential to capture high flows 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 remediation (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 remediation 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.

# Barriers and Challenges to Using Flood Flows for Managed Aquifers Recharge

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

The barriers and challenges are being discussed during the November 8, 2017 public forum on Managed Groundwater Recharge to Support Sustainable Water Management. This section will be expanded and updated with information discussed during the November forum and any subsequent events and meetings, as well as updated based on comments received on this discussion draft.

## Cooperation and Governance

Potential considerations related to cooperation and governance:

- Water infrastructure in California is owned and operated by many federal, State, and local agencies.
- Flood and groundwater managers have not historically coordinated their activities.
- Federal, State, and local agency authorities may be limited, or in conflict, with this strategy.
- Contractual arrangements and operations plans will be required among the appropriate 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 and 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.

## 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.
- Challenges if there is no extension to the provisions of the governor's executive order of November 2015 that provide expedited process for temporary water rights permits.
- 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.

### *Regulatory*

Potential considerations related to other regulations:

- Challenges if there is no extension to the provisions of the governor's executive order of November 2015 that provide a California Environmental Quality Act exemption for temporary water rights permits.
- 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.

## Policy

Potential considerations related to policy:

- Replenishment of overdrafted aquifers is not currently considered a beneficial use and/or a public benefit.
- There are no State incentives for the development of infrastructure needed to increase recharge opportunities.
- Landowners are not compensated for use of land through floodplain protection easements programs that allow agricultural uses.

## Implementation

Potential considerations related to strategy implementation:

### *Land Use*

- How well will crops tolerate inundation? Will the method damage or kill permanent crops? Reduce yield? Increase disease risks?
- What types of crops and soils are ideal for this strategy?
- Will it increase the amount of nitrate and other pollutants entering the groundwater?
- Is there a mix of annual and permanent crops?

### *Recharge/Recovery*

- Quality of recharged and recovered water.

### *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, 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.

### *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.

### *Economics*

- Calculating economic and financial benefits and costs associated with projects.
- Landowner compensation.
- State incentive programs.

### *Environmental Considerations*

- How would diversion of surface water for groundwater recharge impact environmental flows?
- Do benefits outweigh risks of diversion during high flows? For example, can bypass (pulse protection) flows 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.
- How can groundwater recharge/aquifer replenishment be used to augment base stream flows, particularly in dry years?

# Next Steps

DWR believes there is significant State interest in the potential public benefits associated with Flood-MAR and 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.

Coordination with some programs has already begun, but early engagement is expected for another six months to help formulate a State program. Continuous coordination will be required once a State program is developed.

## Plan of Study

As part of the System Reoperation Study, and a companion to this white paper, DWR is currently developing a Flood-MAR plan of study to guide the formulation and implementation of a State program. The purpose of the plan of study is to identify and describe data and knowledge gaps and recommend studies and pilot projects to fill these gaps. The plan of study will set a framework for the program; identify general tasks, roles, and responsibilities for the matrix program team; identify and prioritize desired outcomes and work activities; develop strategies for internal and external communications; and determine 10-year financial needs and resources. The plan of study describes potential work activities from scoping to project implementation.

Specific elements of the plan of study include how a State-led program and public-private partnership will:

1. Assess statewide potential for use of flood flows for recharge and prioritize locations based upon proximity and conveyance connections in the state with flood hazard reduction, groundwater sustainability, and ecosystem restoration needs.
2. Complete a pilot study of a priority location to demonstrate potential water resources management innovations to facilitate flood hazard reduction, aquifer replenishment, aquifer remediation, and ecosystem enhancements.

3. Identify and demonstrate use of analytical tools and innovative water management techniques to support development of available flood flows and recharge of groundwater basins.
4. Develop economic monetization techniques for groundwater recharge benefits, including avoidance of undesirable results, as described in SGMA.
5. Demonstrate application of DWR's climate change methodology to both water supply and flood management applications.
6. Provide technical assistance to groundwater sustainability agencies and local flood management agencies, as well as coordination with State and federal flood agencies.

## Scoping

Scoping will include outreach and coordination efforts, such as workshops, brainstorming sessions, and meetings, to 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 plan of study. Reconnaissance and feasibility assessments will be conducted throughout the state in coordination with local agencies, academia, and federal and State partners.

## Coordination with Other Plans and Programs

Flood-MAR will require close coordination and cooperation among landowners, stakeholders, academia, and applicable federal, State, and local agencies.

## Schedule

During the next several years, DWR would like to initiate a Flood-MAR program with the following phases:

1. Year 1 would include initial outreach, scoping, and review of past efforts (e.g., what was done in 2017) and relevant existing literature, related programs, and available tools to explore opportunities, best practices, and how to overcome obstacles.
2. Year 2 would include continued outreach, evaluation of preliminary Flood-MAR and reoperation strategies and opportunities, and initiation of reconnaissance level assessments and pilot studies.
3. Year 3, and on, would begin development of partnerships, feasibility studies, and implementation of projects.

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