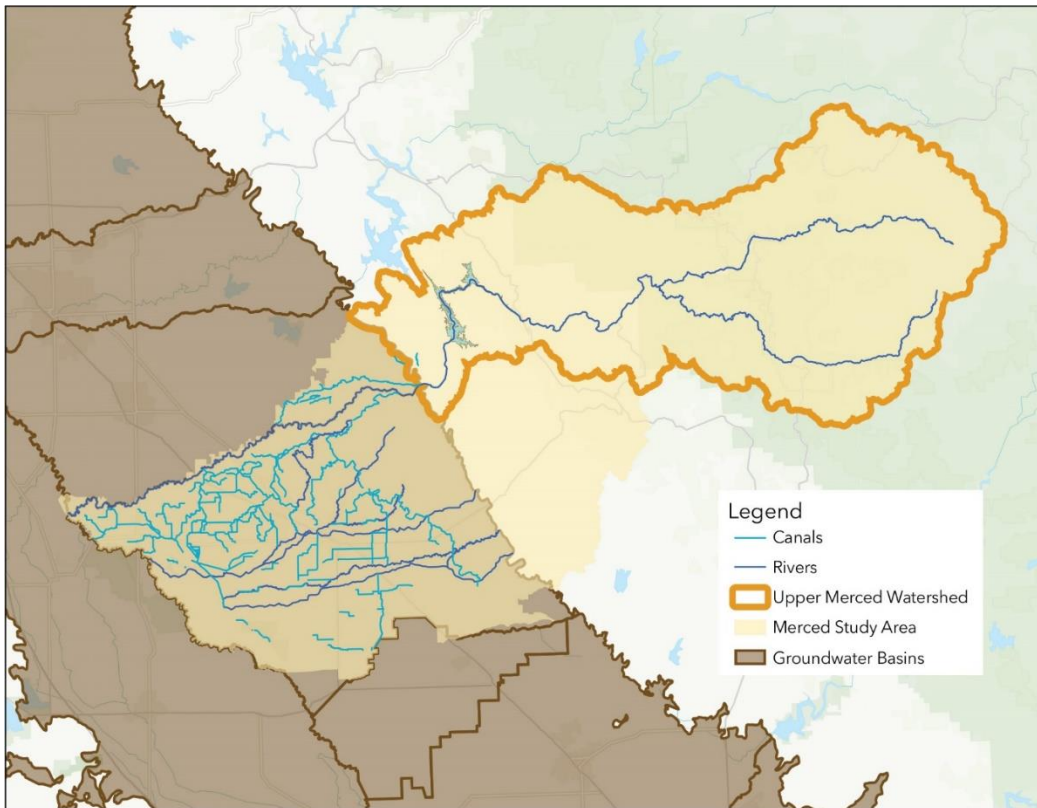State of California
California Natural Resources Agency
Department of Water Resources

Merced River Watershed Flood-MAR Reconnaissance Study

Plan of Study

Technical Information Record

November 2023

Acknowledgements

Contents

List of Figures

Acronyms and Abbreviations

C2VSim-FG	California Central Valley Groundwater-Surface Water Simulation Model, Fine-Grid
cfs	cubic feet per second
CVFPP	Central Valley Flood Protection Plan
DWR	California Department of Water Resources
FERC	Federal Energy Regulatory Commission
Flood-MAR	using floodwater for managed aquifer recharge
GRAT	Groundwater Recharge Assessment Tool
LiDAR	light detection and ranging
study	Merced River Reconnaissance Study
MID	Merced Irrigation District
SAGBI	Soil Agricultural Groundwater Banking Index
SGMA	Sustainable Groundwater Management Act
taf	thousand acre-feet
TIR	technical information record

Chapter 1. Introduction

On the heels of the driest four consecutive years of statewide precipitation in the historical record (2012 through 2015) and the second wettest year on record (2017), the California Department of Water Resources (DWR) initiated the Flood-MAR Program. These extreme precipitation seasons are hallmarks of the effects of climate change and significantly stressed the state's natural and managed water systems. DWR recognized the need for creative solutions to these extreme events, and in late 2017, released a draft white paper, *Flood-MAR: Using Flood Water for Managed Aquifer Recharge to Support Sustainable Water Resources* (California Department of Water Resources 2018), to explore opportunities to use floodwater for managed aquifer recharge.

Large-scale implementation of Flood-MAR can fundamentally change how flood and groundwater management are integrated and how water is stored for use. Since the passage of the Sustainable Groundwater Management Act (SGMA) in 2014, DWR has observed a steady rise in interest in using excess winter season water application on agricultural lands from the agricultural community, groundwater sustainability agencies, and elected officials. This increased interest in Flood-MAR includes studies, pilot projects, and new research. DWR would like to facilitate expansion of Flood-MAR implementation throughout California. To broaden Flood-MAR implementation, many of the questions, barriers, and challenges identified in the Flood-MAR white paper must be explored in depth. This technical information record (TIR) lays out the plan of study for investigating Flood-MAR opportunities and ways to overcome barriers and challenges for Flood-MAR project implementation within the Merced River Basin.

Chapter 2. Flood-MAR Concept

Flood-MAR is an integrated and voluntary resource management strategy that uses floodwaters resulting from, or in anticipation of, rainfall or snowmelt events for groundwater recharge on agricultural lands, working landscapes, and managed natural lands, including refuges, floodplains, and flood bypasses. Figure 2-1 illustrates example elements of Flood-MAR.

Figure 2-1 Example Components of Flood-MAR Projects
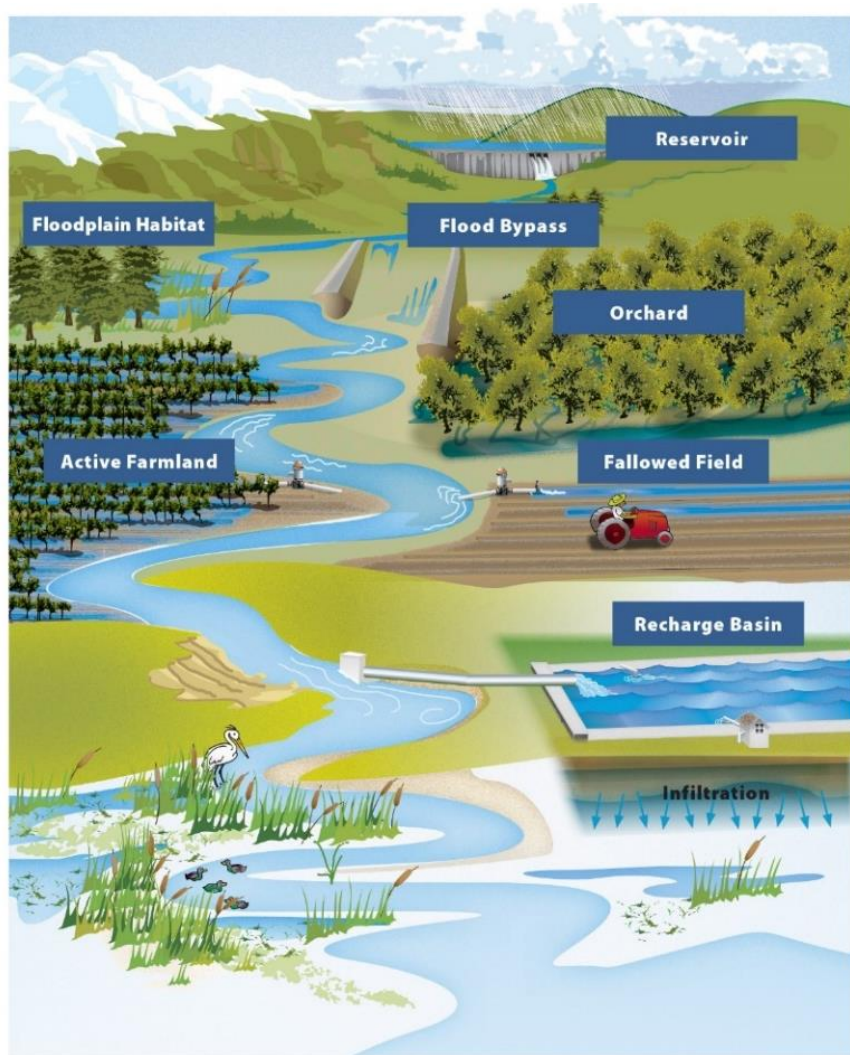
Flood-MAR epitomizes integrated water management. The concept is designed to be multi-beneficial—providing water supply reliability, flood risk reduction, drought preparedness, aquifer replenishment, ecosystem enhancement, subsidence mitigation, and other potential benefits. Flood-

MAR 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: floods and droughts. Shifting climate patterns have introduced more flash floods and intense flood flows, and longer and deeper droughts; Flood-MAR focuses on managing and reducing the adverse consequences of these events.

With the passage and implementation of SGMA, in combination with climate change-induced extreme events, it is clear and imperative that groundwater and flood management communities partner and integrate. This partnership will help reduce the impacts of future swings of high and low water availability periods and support meeting their communities' objectives of groundwater sustainability and flood protection. This cooperation will also lead to multi-water sector benefits like improving floodplain ecosystems, preserving working landscapes, and engaging California's agricultural community in needed solutions, among other benefits.

Flood-MAR can be implemented across multiple scales, from individual landowners diverting floodwater with existing infrastructure, to using extensive detention/recharge areas and modernizing flood protection infrastructure and operations. Many landowners are considering Flood-MAR on a small scale to achieve local groundwater sustainability and improved water supply reliability, but there is still much to be learned about Flood-MAR's potential at agency, watershed, and inter-watershed scales. It is at these larger scales that Flood-MAR can achieve its full potential and value for California by integrating into the broader water system.

Chapter 3. Study Purpose

DWR, in partnership with the Merced Irrigation District (MID), is conducting a preliminary study using flood waters for managed aquifer recharge that can reduce flood risk, increase surface and groundwater supply reliability, and enhance ecosystems in the Merced River Basin. This Merced River Reconnaissance Study (study) is exploring the potential, feasibility, and effectiveness of Flood-MAR concepts, testing theories, and assessing strategies in overcoming barriers and challenges to project planning and implementation. The study will assess current conditions of the Merced River watershed and the vulnerability of these watershed management characteristics to a range of potential climate change futures. The study will also describe the public and private benefits that may be achieved through Flood-MAR strategies and quantify a range of benefits that Flood-MAR could provide in or adjacent to the Merced River watershed.

This study incorporates and applies concepts from DWR's Flood-MAR white paper (California Department of Water Resources 2018). The study expands on previous studies of system (e.g., reservoir) reoperation and conjunctive use in the Merced River Basin conducted under the System Reoperation Study Phase III Report (California Department of Water Resources 2017). When completed, the study will include a preliminary analysis of the implementation factors and barriers and challenges discussed in the white paper and listed below:

- Source water, including reservoir operations.
- Conveyance.
- Site suitability.
- Recharge methods.
- Groundwater fate, extraction, and use.
- Feasibility analysis.
- Governance and coordination.
- Funding and incentives.

The study will also explore Flood-MAR opportunities under a range of conditions; identify best practices for analyzing and documenting the

planning, modeling, and analysis of Flood-MAR projects on a watershed scale; and identify the barriers and constraints to implementing Flood-MAR projects in the Merced River Basin and make recommendations on how to overcome them.

Last, the study will quantify and describe the potential public and private benefits that may result from Flood-MAR projects, such as:

- Water supply reliability.

- Flood risk reduction.

- Aquifer replenishment.

- Ecosystem enhancement.

- Subsidence prevention.

- Water quality improvement.

- Working landscape preservation and stewardship.

- Climate change adaptation.

- Recreation and aesthetics.

The study will also, to the degree possible, consider and describe potential negative effects associated with Flood-MAR actions, using a similar but negative effect listing as compared to the benefits listing above (e.g., increased flood risk is the negative effect opposite of the flood risk reduction benefit).

Chapter 4. Geographic Scope

The Merced River is a 145-mile-long tributary of the San Joaquin River, flowing from the Sierra Nevada into the San Joaquin Valley (Figure 4-1). The Merced River watershed encompasses 1,726 square miles and is bordered to the north by the Tuolumne River watershed, to the south by the headwaters of the San Joaquin River, and to the east, the watershed of Mono Lake. The headwaters of the Merced River are at 8,017 feet. The river famously flows through the Yosemite Valley and irrigated lands of the San Joaquin Valley. It joins the San Joaquin River a few miles south of Turlock.

The Merced River above Lake McClure is free-flowing and unobstructed by dams. Large-scale irrigation began in the late nineteenth century and led to the construction of several dams. New Exchequer Dam (Lake McClure) is the largest dam on the river. Downstream of New Exchequer Dam is McSwain Dam (which serves as a regulating afterbay for New Exchequer Dam and generates hydroelectric power), Merced Falls Dam, an irrigation diversion dam, and Crocker-Huffman Diversion Dam.

Figure 4-1 Study Area
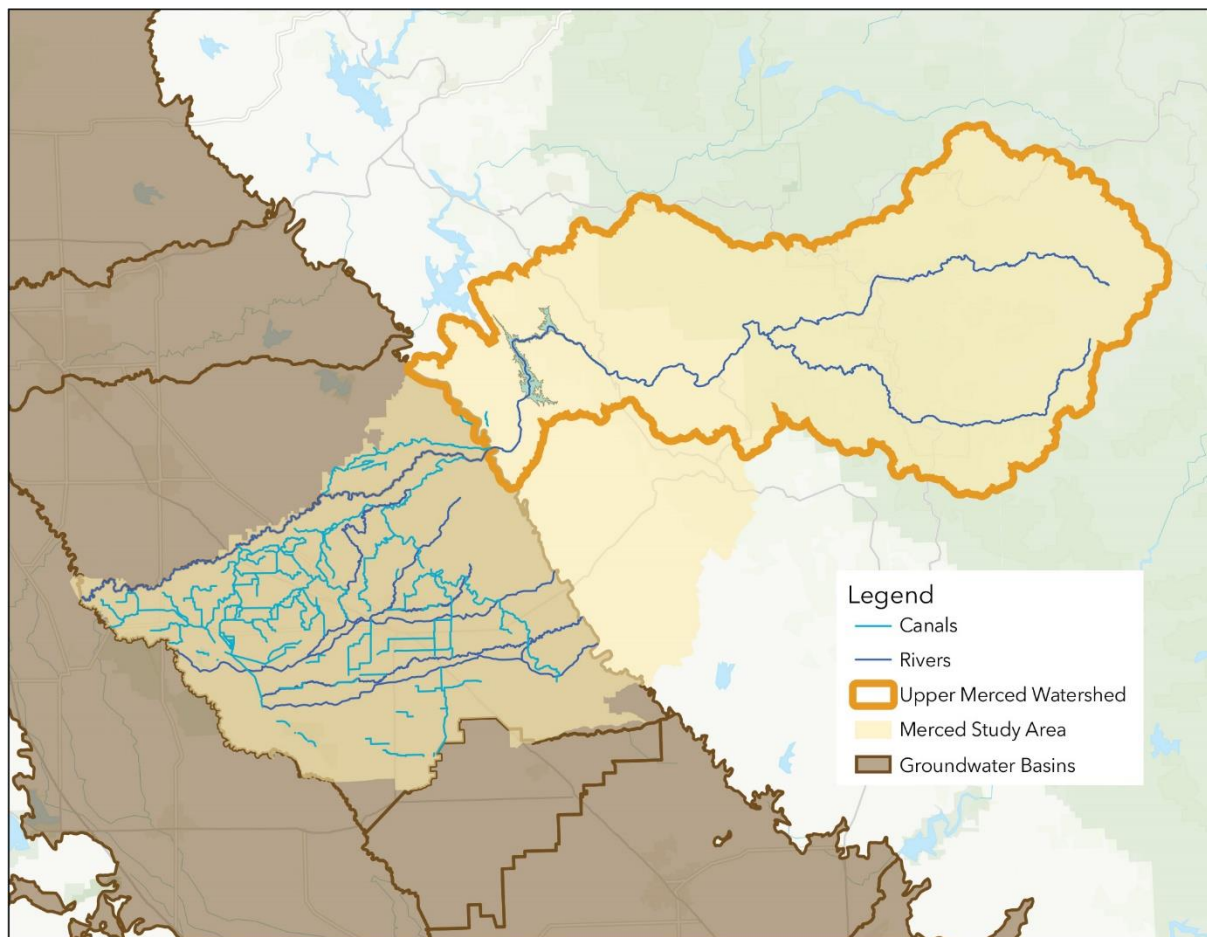
MID owns, operates, and maintains the New Exchequer and McSwain dams, reservoirs, and hydroelectric facilities. Lake McClure has a storage capacity of 1,024,600 acre-feet, and Lake McSwain has a storage capacity of 9,730 acre-feet. The New Exchequer Dam Project provides water for domestic and irrigation uses, flood control, hydroelectric power generation, recreation, and the environment.

MID operates New Exchequer Dam for flood control and the U.S. Army Corps of Engineers' Water Control Manual mandates a maximum flood space of 350 thousand acre-feet (taf). Water is also released to meet water rights settlement agreements with riparian water users along the Merced River, for deliveries to Stevinson Water District, and to the Merced National Wildlife Refuge. New Exchequer Dam is also operated to meet instream flow requirements contained in MID's Federal Energy Regulatory Commission (FERC) license.

Within MID are approximately 150,000 acres of irrigable lands and 825 miles of water canals and pipelines. MID also maintains 4,100 delivery gates, as well as 1,500 check structures. In addition to providing irrigation water, MID uses its existing irrigation distribution system for local flood control by routing runoff and floodwaters away from populated areas.

MID also owns, operates, and maintains 239 deep irrigation wells of which 170 are active. Most of the MID service area overlies groundwater basins of the San Joaquin Valley Groundwater Basin, which provides groundwater as a major source of water supply for agricultural and municipal uses. MID actively practices conjunctive use by delivering more surface water when available to reduce groundwater pumping and by relying more on groundwater during dry conditions. However, the San Joaquin Valley has experienced varying degrees of groundwater level decline. Where groundwater pumping exceeds recharge, groundwater overdraft remains a recurring problem in certain areas of Eastern Merced County. During the past four decades, the Merced Subbasin has been experiencing significant decrease in groundwater storage, with a cumulative decrease in storage of approximately 2.4 million acre-feet, from 1996 to 2015, or approximately 120,000 acre-feet per year on average. In addition, the area has been experiencing land subsidence resulting from high groundwater pumping in the southern part of the basin as well as the neighboring basins. DWR has ranked the Merced Subbasin as a critically overdrafted basin.

The largest city in the Merced River Basin is the City of Merced with an estimated population of 86,750 as of 2018. Merced is also home to the University of California, Merced, which had a student population of 8,554 during the 2018–2019 academic year. Cities within the study area rely significantly on groundwater for water supply.

Chapter 5. Initial Assessment of Flood-MAR Potential

Before work began on the study, an initial assessment of the Flood-MAR potential was completed to determine the viability of a Flood-MAR project within the Merced River watershed. A spreadsheet model was set up using historical Merced River flows, canal operations, information about flood flows, and minimum instream flow requirements. A 48-year period of historical hydrology (1970 through 2017) was analyzed. This assessment included evaluating the impact of several flood events and extended droughts.

A range of Flood-MAR trigger conditions were identified. A "Lower Flood-MAR" scenario used a Merced River flow exceeding 4,500 cubic feet per second (cfs) as the point when Flood-MAR operations would trigger. MID considers the Merced River to be at flood conditions at this flow. A "Higher Flood-MAR" scenario used a flow exceeding 700 cfs as the point when Flood-MAR operations would trigger. This flow is several hundred cfs more than the minimum instream flow requirements and ensures minimum instream flow requirements are maintained. For both scenarios, Flood-MAR operations were analyzed from November through February, the time of year that MID does not provide irrigation flows through their canal system. The initial assessment focused on quantifying floodwater available for recharge and was not constrained by recharge area or recharge capacity rates.

Figure 5-1 presents results of the spreadsheet model. Depending on the scenario, Flood-MAR operations occur in above-average and wet years and can provide a large range of water available for recharge. For example, in 1997, Flood-MAR operations could have provided between 230–320 taf of water for recharge. In a more recent flood event, such as the 2017 event, 73–180 taf of floodwater could have been available for Flood-MAR purposes. Cumulatively, the 48-year historic amount of floodwater available for recharge was between 700–2,200 taf (or 15–46 taf/year average annual recharge). Results of this analysis show a significant potential for Flood-MAR water management in the Merced River watershed.

Figure 5-1 Merced River Flood-MAR Assessment Results
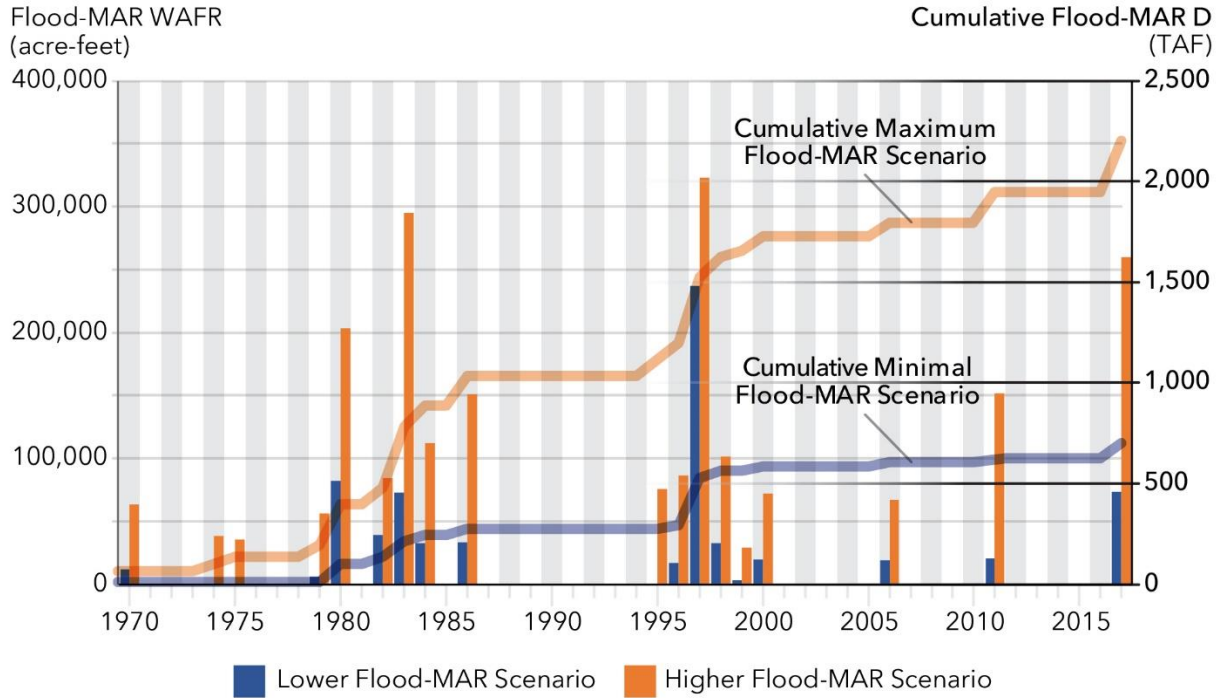
Chapter 6. Study Plan Overview

Initially, the study will assess and describe potential vulnerabilities to climate change in three water resource management areas of the Merced River watershed – water supply, flood, and ecosystems. This vulnerability description will provide a foundation for considering resilience needs for the watershed. The study will then analyze Flood-MAR strategies in the Merced River Basin under a range of assumptions to understand the variety of public and non-public benefits possible with various levels of participation and investment in Flood-MAR projects. The analysis will include comparing baseline conditions (no Flood-MAR actions), to three levels of Flood-MAR actions, including a range of assumptions for reservoir and canal operations and conveyance and recharge capacities. The study will also examine how Flood-MAR benefits and impacts may change under a broad range of operational, infrastructure, and climate scenarios.

Analyses will be conducted sequentially by level with knowledge gained from each level informing strategies and analysis for the next level (e.g., Level 2 analyses will provide information on potential infrastructure limitations that can be expanded in Level 3 analyses). Three scenarios will be evaluated for each level of Flood-MAR operations and projects. An initial scenario will attempt to create benefits while minimizing the risk of impacts. An intermediate scenario will attempt to balance Flood-MAR benefits with risks. A robust scenario will attempt to maximize Flood-MAR benefits while assessing the associated risks of the overall strategy. Each scenario has different assumptions or triggers to define the water available for replenishment.

- **Baseline —** The study will assess current conditions of the Merced River Basin including water supply resources, flood risk, and ecosystems, as well as the vulnerability of these watershed management characteristics to a range of potential climate change futures.

- **Level 1: Existing Reservoir Operations and Infrastructure —** Level 1 will evaluate potential Flood-MAR benefits with existing facilities and infrastructure under existing operations. Level 1 analysis assumes existing infrastructure to divert, convey, and recharge flood waters, assuming all permits are in place and there is adequate participation in a Flood-MAR program. Level 1 Flood-MAR operations and projects are expected to have relatively lower risks, costs, implementation challenges, and benefits.

- **Level 2: Modified Reservoir Operations and Existing Infrastructure** — Level 2 will evaluate how changing operations of upstream reservoirs or conveyance canals can expand Flood-MAR benefits. Operational changes are intended to increase the volume of water available for Flood-MAR, shift the period when water is available, and expand the flood control benefits of Flood-MAR. Operational strategies may include expanded conjunctive management, expanded flood reservation space through releases for recharge, and forecast-informed reservoir operations. Level 2 operations and projects likely will increase potential benefits, costs, implementation challenges, and risks.

- **Level 3: Modified Reservoir Operations and Expanded Conveyance and Recharge Infrastructure** — Level 3 will evaluate how new or modified infrastructure to expand conveyance capacity of flood flows, coupled with operational changes, can increase Flood-MAR benefits. New or expanded infrastructure may include canals and pipelines to convey flood flows, dedicated recharge ponds, or dam modifications. Level 3 operations and projects may provide the greatest benefits but come with infrastructure costs and additional implementation challenges.
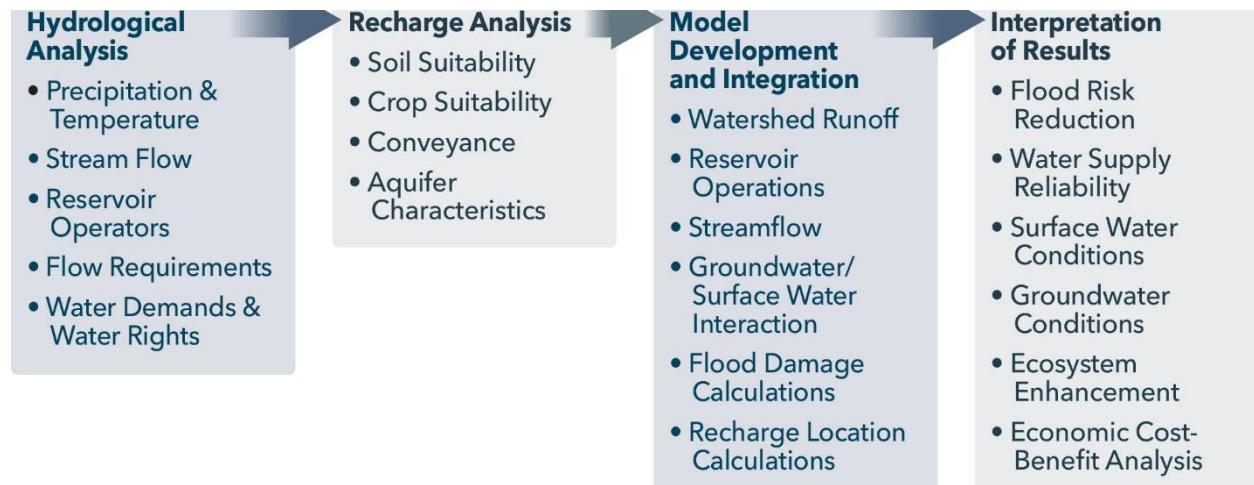
Chapter 7. Analytical Tools and Methods

Integrating surface and groundwater management is challenging in practice because there are few analytical tools that can support decision-making for coordinated management of surface water, reservoirs, and groundwater, particularly at a watershed scale. Sufficient data sets, tools, and analysis methods do not exist in many areas of the state. This study is innovative, where new and creative thinking will be used to identify, develop, and integrate the analysis of Flood-MAR projects and develop in-house expertise in the development and application of those tools to better provide local technical assistance. This analysis will help inform and guide an understanding of the necessary tools and how to apply them to other potential Flood-MAR concepts and projects throughout the state.

Many different models and tools will be used in the analysis of Flood-MAR to understand each project component, quantify potential benefits, and evaluate risks. Figure 7-1 provides a process flowchart for the technical considerations of the Merced study Flood-MAR analysis, with some examples provided. For simplicity, the process is separated into four categories: hydrologic analysis, recharge analysis, model development and integration, and interpretation of results. As noted previously, this approach and analytical framework may be useful in other areas and watersheds.

Hydrologic analysis focuses on the potential water available for recharge and determining what data sets and tools are needed to support this analysis. Recharge analysis focuses on identifying the best recharge areas based on soil and aquifer characteristic, land use, and land management. Recharge analysis also includes determining how to convey water available for recharge to the recharge site. Model development involves identifying and setting up available models, developing any additional tools that may be needed, integrating the models, and calibrating and running the models. The last step in the analysis — interpretation of metrics and model results — brings together all the information developed in the previous steps to develop a set of indicators to track performance of Flood-MAR strategies in providing flood risk reduction, water supply reliability, and ecosystem enhancement. In addition to quantifying public and private benefits, results will be processed to determine the cost of implementation and economic value of benefits realized through the implementation of Flood-MAR strategies. Collectively, performance metrics and economic cost-benefit analysis will help with the comparison of alternatives and decision-making.

Figure 7-1 Considerations for the Technical Analysis

Hydrological Analysis

- Precipitation & Temperature
- Stream Flow
- Reservoir Operators
- Flow Requirements
- Water Demands & Water Rights

Recharge Analysis

- Soil Suitability
- Crop Suitability
- Conveyance
- Aquifer Characteristics

Model Development and Integration

- Watershed Runoff
- Reservoir Operations
- Streamflow
- Groundwater/ Surface Water Interaction
- Flood Damage Calculations
- Recharge Location Calculations

Interpretation of Results

- Flood Risk Reduction
- Water Supply Reliability
- Surface Water Conditions
- Groundwater Conditions
- Ecosystem Enhancement
- Economic Cost- Benefit Analysis

Chapter 8. Hydrologic Analysis

The hydrologic analysis quantifies the surface water available for aquifer recharge under different operational strategies. The hydrologic analysis will also provide information to the recharge, groundwater, and flood models, facilitating evaluation of recharge, groundwater, and flood management effects. Variations in temperature and precipitation will also be evaluated as part of the climate change analysis. This study will be employing a decision-scaling framework for climate change vulnerability and adaptation planning analyses, as described in *Decision Scaling Evaluation of Climate Change Driven Hydrologic Risk to the State Water Project* (California Department of Water Resources 2019). All Flood-MAR scenarios will be analyzed under current conditions hydrology and a range of potential future climate hydrologies to understand their expected performance and evaluation of benefits. Overall, the climate analysis will seek to determine and generally describe:

- The vulnerabilities of the existing water supply, ecosystem, and flood management systems.

- Flood-MAR actions' ability to mitigate the effects of climate change on water supply, ecosystem, and flood management.

- The benefits of Flood-MAR and whether they are robust and exist under a range of potential future climates.

- A broad understanding of potential future climates that may suggest different operational strategies or investment decisions.

Specifically, available flows under Level 1 operations will be quantified based on existing demands, requirements, and operation of the Merced River project. A subset of available flows, such as flows above the flood monitor stage, will be defined as flood flows that, when used for Flood-MAR, will provide a flood control benefit. Under Level 2 and Level 3 operations, reservoir operation of New Exchequer with the use of a forecast-informed reservoir operations, conjunctive use pool, or other strategies will be analyzed to understand the potential increase in Flood-MAR benefits. Analysis may include multiple strategies or a range of operations for a specific strategy (e.g., various sizes of a conjunctive use pool).

For the hydrologic analysis, existing water rights must be understood to

determine the flexibility of what may be possible under those rights in the context of a Flood-MAR program. An appropriative water right is necessary for the diversion of water from a stream and storage of water in aquifers. Location, timing, and rate of diversion, place of use, and beneficial uses must be appropriate for a Flood-MAR strategy. For the study, the ability to utilize existing rights for Flood-MAR, needs for modifications, or new rights will be considered and discussed.

The study will also assess opportunities and challenges for Flood-MAR in conjunction with predictable future climate conditions. Both temperature and precipitation patterns are expected to change in the future, affecting the timing and volumes of Merced River runoff. Analysis of climate-changed conditions will recognize the uncertainty in predicting the future climate and hydrology through the use of multiple, potential future conditions. Analysis will include assessment of water available for Flood-MAR under each level (Levels 1 through 3) and how changes in climate and future water availability affect benefits and risks. Although climate change may potentially affect agricultural activities, cropping patterns and irrigation practices are assumed to be driven by markets and technology. As such, the current irrigation practices and cropping patterns are in place over the entire study period and for each potential climate future. Flood-MAR operation strategies under Levels 2 and 3 will be evaluated and adjusted, if necessary, depending on the magnitude of future changes in runoff.

Chapter 9. Recharge Analysis

Recharge analysis will identify promising recharge locations through consideration of site and aquifer suitability, recharge methods (e.g., in-lieu, spreading basins, recharge using working landscapes), conveyance to recharge sites, and recharge capacity (Figure 9-1).

Several recent research efforts have focused on assessing suitability of soils for groundwater recharge, including University of California, Davis' Soil Agricultural Groundwater Banking Index (SAGBI) and a recharge suitability index developed by Land IQ. Existing information will be compiled to develop maps and a database of known soil characteristics within the study project area. Additionally, outreach efforts will consolidate local knowledge on soils and recharge suitability to understand areas most suitable to recharge.

Figure 9-1 Example Recharge Potential in Study Area
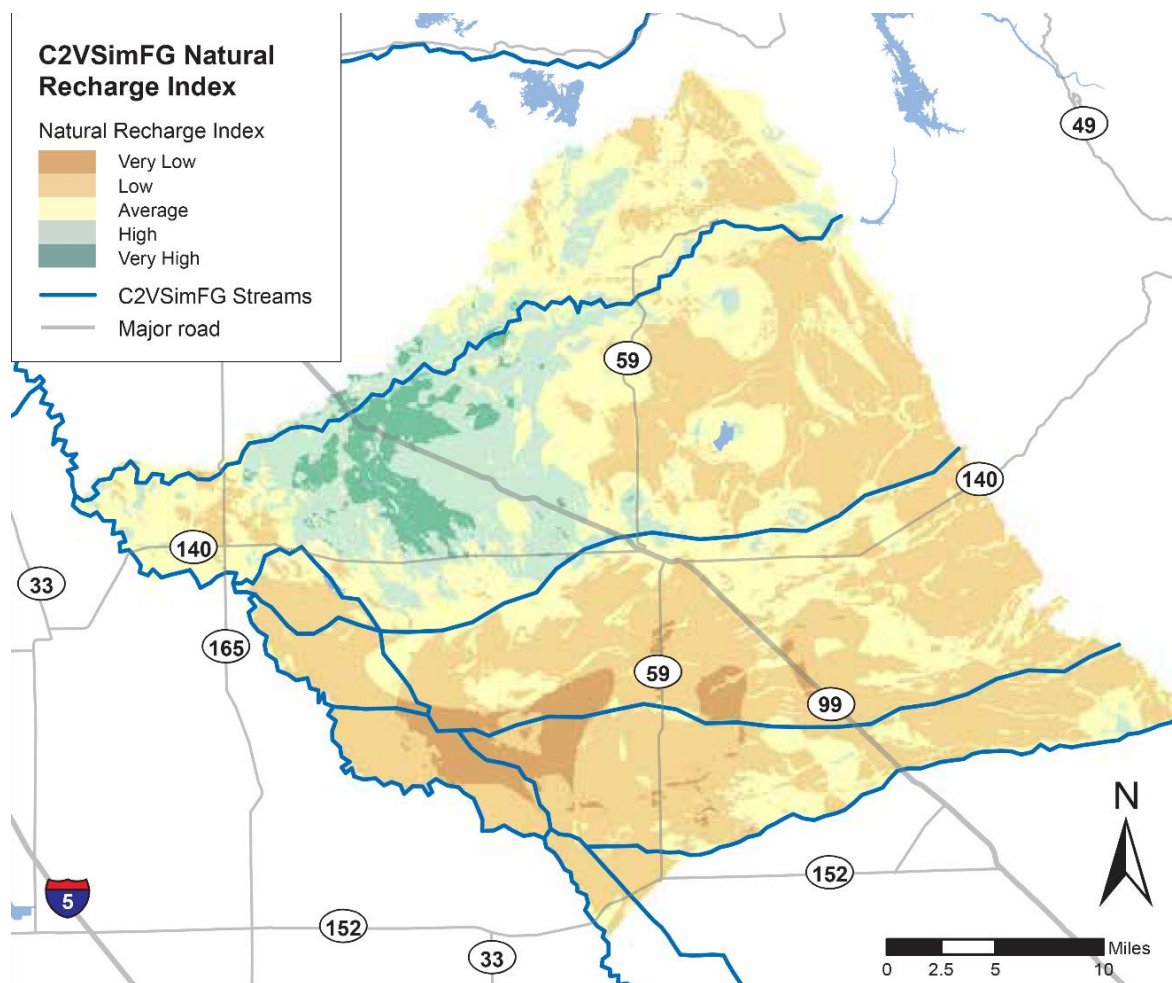
The use of agricultural fields for aquifer recharge is an emerging concept in California as water managers and landowners look for multiple benefits from existing land uses. This study will include a review of the project area suitability through identification of crop and soil types, land ownership, and details related to specific crops to include response to recharge, root zone saturation, effects on yield, periods of dormancy, agricultural practices, and other relevant factors. Ongoing research on the effects of recharging agricultural fields will be reviewed and incorporated into the project analysis. The Groundwater Recharge Assessment Tool (GRAT), developed by Sustainable Conservation, will support this analysis. An essential key to the use of agricultural lands for Flood-MAR is willingness of landowners to participate.

An understanding of underlying aquifers and geology is necessary to determine the effects of recharge and extraction on the aquifer system, as shown in Figure 9-2. Figure 9-2 also shows the MID service area, delivery systems (i.e., conveyance), and the geographic relationship to the represented aquifer subregions of the California Central Valley Groundwater-Surface Water Simulation Model, Fine-Grid (C2VSim-FG) groundwater model. There are multiple sources of information on geology and aquifer systems, including DWR Bulletin 118 information and several existing groundwater models including DWR's C2VSim-FG, the U.S. Geological Survey's Central Valley Hydrologic Model, and local models. Existing information will be reviewed and summarized for the project area. A local groundwater model, Flood-MAR Merced Groundwater-Surface Water Simulation Model (FM2Sim), has been developed for this study from the C2VSim-FG and supplemented with local data. C2VSim-FG is a DWR tool for conducting groundwater analyses in the Central Valley and is an integrated groundwater and surface water model. FM2Sim will analyze the effects of both climate change and Flood-MAR actions on the aquifer system, such as stream/aquifer interaction and the fate of recharged water, including water extractions, remaining in storage, or flowing out of the local aquifer system. Groundwater analysis will help refine understanding of surface water-groundwater interaction in the project area.

The study and analysis will identify and discuss promising recharge methods, such as in-lieu recharge, spreading basins, and recharging agricultural lands, and estimate the recharge capacity of different methods. Recharge capacity will be based on the method and include assumptions for the recharge area and rate.

Level 1 analysis will include an assessment of existing conveyance capacity, considerations for maintenance of facilities, and the existing use of facilities to convey flood flows and water supply. A key outcome of the analysis will be understanding the limiting components for Flood-MAR benefits (available water, recharge capacity, or conveyance capacity), and the interaction between components to understand where future investments could be made to maximize benefits.

Analysis of Level 2 will include modifications to reservoir operations that would support expansion or effectiveness of recharge potential. Level 3 analysis will include options to modify or add infrastructure, including increasing conveyance capacity, to expand benefits. Increased conveyance capacity may include expanding capacity in existing facilities to take advantage of available water, and new facilities to convey water to areas with recharge potential that currently lack conveyance facilities. Analysis of Level 3 will also consider the potential to expand recharge capacity through inclusion of additional areas or recharge methods that may be possible with investment in recharge programs and conveyance capacity.

Figure 9-2 MID Service Area, Conveyance, and C2VSim-FG Subregions
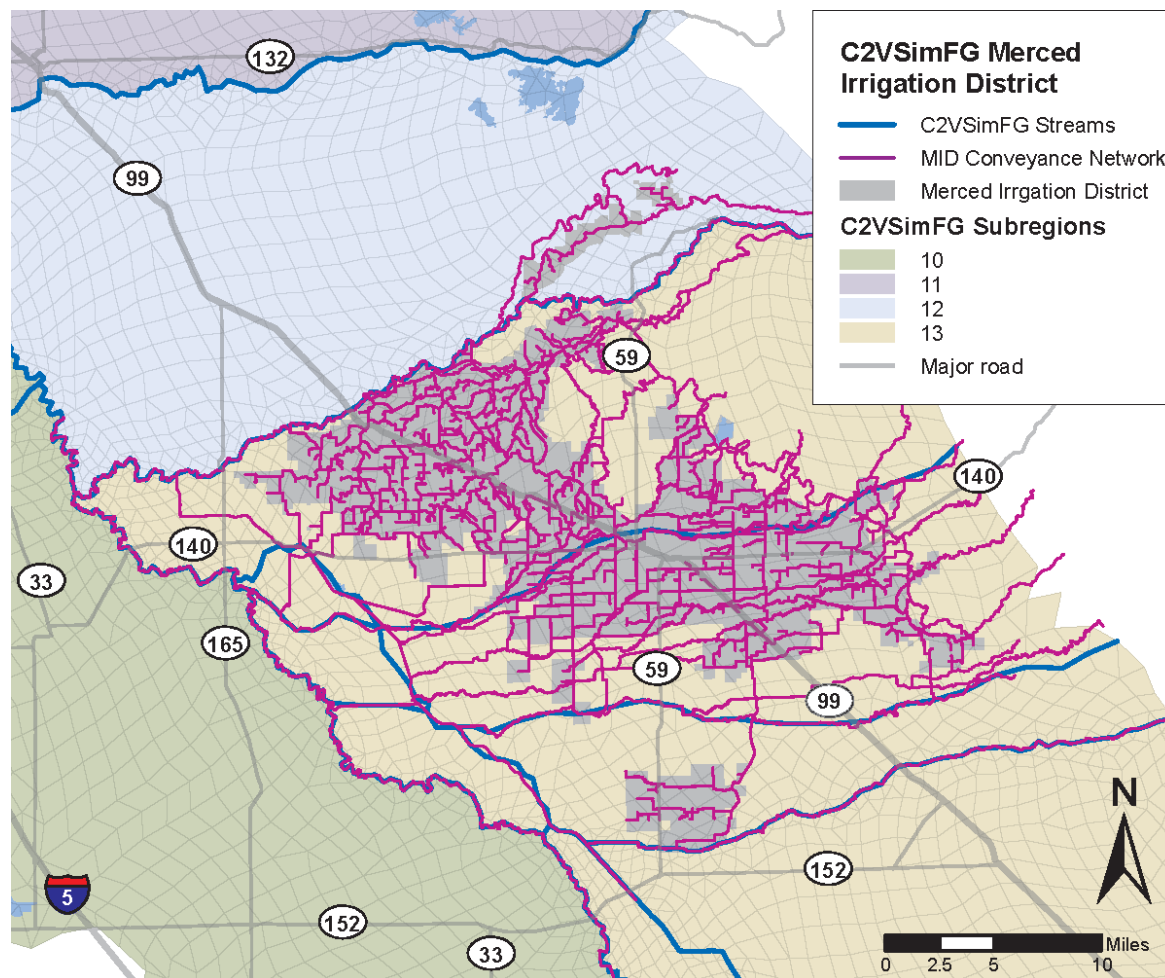
This analysis will also produce information and collect data to inform an analysis of potential environmental benefits and impacts, as well as to evaluate economic considerations. There are numerous potential environmental effects of a Flood-MAR project. Environmental impacts may occur from diversion of additional flows, even during high flow events, and changes in reservoir operations that may affect downstream flows and temperature. Flood-MAR projects have the potential to provide environmental benefits through the enhancement of water supplies to wetland areas when water is recharged, improving groundwater conditions that may support groundwater dependent ecosystems, and increasing groundwater discharge to streams and improving base flow. Ecosystem benefits may be considered using the Central Valley Flood Protection Plan (CVFPP) Conservation Strategy and the Groundwater Dependent Ecosystem tool developed under SGMA.

After benefits are determined, the economic value of those benefits will be evaluated. Potential economic benefits may include flood damage reduction or reduced cost for flood control programs, increased water supply reliability, contributions to groundwater sustainability, improved groundwater conditions, reduced pumping costs, and ecosystem benefits. Available economic models, such as California's Statewide Agricultural Production Model and GRAT, may be utilized to quantify economic benefits for comparison with expected program costs or risks at each level. The recharge analysis combined with hydrologic analysis may also help identify positive and negative effects on rural, urban, and disadvantaged communities from a Flood-MAR project.

Chapter 10. Model Development and Integration

Model development includes selecting and applying the best available tools, processes, and models based on the goals of the analysis and information available. This effort also includes the collection of data, setting up and running the models, and integrating model inputs and outputs.

Several models and innovative tools will be used in the analysis of Flood-MAR to understand each component and quantify potential benefits. Analysis of New Exchequer Dam operations for water supply and flood control will be performed with available models and tools, including CVFPP modeling tools, MIDH2O (Merced Irrigation District's hydrologic and hydraulic operations model), FM2Sim, and tools from the Hydrologic Engineering Center's modeling suite. Surface water processes are simulated to analyze the current and future runoff, reservoir operations for flood control and water supply, and downstream hydraulic models for river stage and flood management. Several of these modeling tools may be developed during this or other studies and refined or integrated with models developed for this analysis.

Flood-MAR analysis will also include studying the effects of recharge on the aquifer systems. The groundwater analysis will provide information on the effects of recharge on groundwater conditions, an understanding of the volume of water that remains in the aquifer, and a method to quantify the changes in the aquifer storage through time. As previously described, groundwater analysis will be performed using a location-clipped version of the C2VSim-FG model. Groundwater analyses will be performed for each of the three levels of Flood-MAR. The analyses also may be used to assess a range of assumptions on the location, capacity, or timing of recharge and inform the refinement of Level 2 and 3 Flood-MAR scenarios.

Additional technical tools may be developed or utilized in the analysis, including SAGBI and the recharge suitability index developed by Land IQ, to identify potential recharge locations. A root zone model, Integrated Water Flow Model Demand Calculator will be used to define the root zone saturation levels in different crop-soil combinations to determine the

acceptable recharge duration and dry down intervals and maintain acceptable soil oxygen conditions for crops. Other tools may simulate available conveyance or recharge capacity and existing economic models. Availability and need for technical tools will be coordinated with local agencies. The study may include development of a Flood-MAR decision support tool to assist local agencies in understanding how decisions related to operations and infrastructure investments affect the benefits and impacts of using Flood-MAR to consider a range of future climate projections.

The study will follow these simplified descriptions of tasks:

1. Develop/locate available datasets (e.g., precipitation, flow gages, land use, soil type, crop types and compatibility, reservoir operating rules, LiDAR, among others).

2. Develop inflow hydrographs using a watershed runoff model for hydrologic and hydraulic routing and operations models (e.g., reservoir models, delivery models, and streamflow/conveyance models).

3. Refine the real-time reservoir operations model for planning and develop outflow hydrographs and canal deliveries.

4. Develop a root zone model for determining acceptable recharge application and frequency for various crop and soil type combinations.

5. Determine floodwater allocation for recharge optimization. Using inputs from the root zone model and estimates of Flood-MAR deliveries from reservoir operations model, the floodwater allocation and recharge model will optimize the spatial and volume distribution and timing of the Flood-MAR water allocation.

6. Develop a groundwater model. Using the spatial, volume, and timing optimization from the floodwater allocation and recharge optimization model, along with the irrigation, streamflow, and Flood-MAR deliveries from reservoir operations and delivery models, the groundwater model will estimate the relative aquifer conditions, including groundwater/surface water interaction.

7. Develop a routing/streamflow model for impacted rivers and creeks (e.g., the Merced River, Bear Creek, and Burns Creek

for this study) for flood risk analysis, including flood flow and stage frequency.

8. Input flood (stage and flow) information from routing and runoff models into economic flood risk model to calculate flood damage and life loss.

9. Use model outputs to inform economic analysis.

Figure 10-1 illustrates this process and shows the integration of models used in the study.

Figure 10-1 Model Development and Integration Process Flow
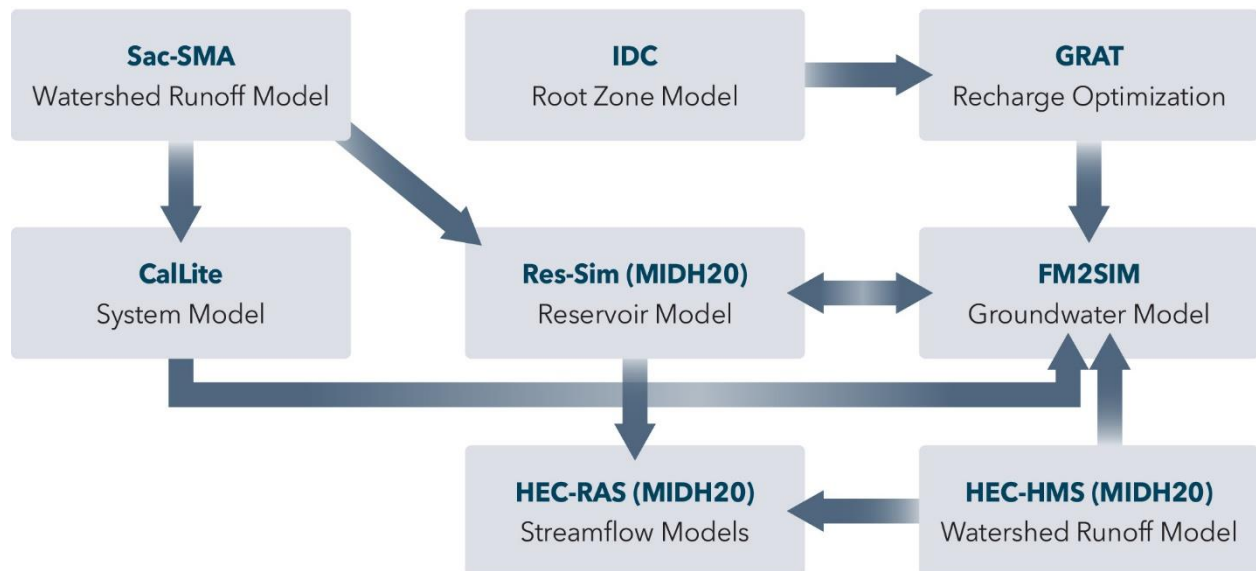
Chapter 11. Interpretation of Model Results

As described in previous sections, the study will utilize multiple integrated models in the analysis of the benefits and risks of the Flood-MAR strategies analyzed. Flood-MAR is a water management strategy conceived to uniquely provide integration of three distinct areas of water management: flood control, water supply, and ecosystem management. Results from multiple models will be interpreted, distilled, and presented using a set of metrics and indicators to provide meaningful information to water managers in each of the three areas. The tools and information are designed to inform how benefits in one area will affect the other areas, using an integrated hydrologic sequence. Water managers and users can use this information to select, plan, design, and implement Flood-MAR strategies that provide robust public and non-public benefits possible under a range of future climate projections.

The study will track the performance under four metric categories — flood risk, surface water conditions, groundwater conditions, and ecosystem management — with up to five indicators per category. These indicators will help ascertain the potential, feasibility, and effectiveness of implementing Flood-MAR in the Merced River watershed. Flood-MAR benefits for flood control will be evaluated by looking at specific, high-flow events, and reservoir storage conditions. Surface water supplies can be evaluated through analysis of water deliveries, reservoir carryover, and stream flow. Flood-MAR's contribution to groundwater management may be summarized through recharge volumes and resulting groundwater levels to understand Flood-MAR's potential to contribute toward meeting sustainability criteria. Effects of Flood-MAR strategies on ecosystem management can be determined by evaluating potential benefits and risks to downstream flows, groundwater conditions in ecologically significant areas, and surface water-groundwater interaction.

Additionally, results from the climate change assessment will help inform water managers about the vulnerabilities of watershed management characteristics in the Merced River basin and the robustness of Flood-MAR strategies in mitigating the risks posed by climate change. Lastly, because the analysis will be conducted sequentially by level, model results from each level will inform strategies and analysis for the next level. For example,

model results from Level 1 would help inform reservoir operational strategies, determine areas to target for recharge, and develop initial recharge schedules for implementation of a Flood-MAR project in Level 2.

Chapter 12. Study Schedule

The study is anticipated to take approximately one year to complete and will include outreach and coordination with local agencies, landowners, and stakeholders within the basin.

TIRs presenting technical results on multiple, feasible Flood-MAR scenarios for the Merced River watershed will be released throughout the next year, as indicated in the listing below. These TIRs will describe assumptions, analyses, findings, lessons learned, and include suggestions for potential implementation. The purpose of these TIRs is to provide a description and quantification of the benefits of Flood-MAR for different audiences, including policy and decision-makers, water agencies, including groundwater sustainability agencies, technical staff, and the public.

This Plan of Study is intended to be the first TIR in a series for the Merced River Flood-MAR Reconnaissance Study that will culminate in the *Merced River Flood-MAR Reconnaissance Study Report* and will include the following additional TIRs.

- TIR: Analytical Tools Integration – Detailed overview of all the models used for the study, including setup, calibration, inputs and outputs, and how models are integrated. Fall 2023.

- TIR: Baseline Performance and Climate Change Vulnerability – Assessment of current conditions and a climate change vulnerability analysis, including water supply, ecosystem, and flood. Fall 2023.

- TIR: Adaptation Strategy Performance – Analysis of Flood-MAR actions using existing and modified operations and facilities. Fall 2023.

- Merced River Flood-MAR Reconnaissance Study Report will summarize the study, including observations from the TIRs above. Fall 2023.

Chapter 13. Outreach and Partners

As stated previously, this study is being conducted in partnership with MID. This partnership is essential to the success of this study. Flood-MAR implementation must be led at the local level.

Throughout the study, DWR will engage other stakeholders to scope and share the analysis and consider potential Flood-MAR actions. DWR plans to engage with other State, federal, tribal, and local entities; academia; and landowners to build on the knowledge and lessons from past and ongoing studies and programs to identify strategies to expand the integration of flood and groundwater management within the Merced River Basin.

A strong interest exists across the state in understanding the benefits, limitations, concerns, costs, and funding opportunities for Flood-MAR projects. Pilot projects and studies are necessary 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. This Merced River Flood-MAR Reconnaissance Study will be a key step in developing that understanding.

Chapter 14. References and Resources

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