

## Appendix 13

# Tools and Application Development

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# Tools and Application Development

## Theme Subcommittee Members

The Flood-MAR Tools and Application Development (TAD) Subcommittee is a multi-disciplinary group of academic experts and practitioners representing universities, state and federal agencies, environmental groups, and other non-governmental organizations. The subcommittee consists of 2 co-chairs, 19 subcommittee members, and a theme coordinator. The State co-chair, Rich Juricich, changed professional affiliation during the research and data development plan (R&DD) implementation and Glen Low with Earth Genome substituted Rich Juricich as the acting co-chair for the remaining activities and finalization of the Flood-MAR Research and Data Development Plan. Subcommittee members are listed by name, title, and affiliation below.

Position	Name and Title	Affiliation	Email
State Co-Chair	Rich Juricich, Assistant Division Chief for DIRWM	California Department of Water Resources (DWR)	<a href="mailto:Rich.Juricich@water.ca.gov">Rich.Juricich@water.ca.gov</a>
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Sub-committee Member	Abdul Khan, Supv. Engineer	DWR-Statewide Integrated Water Management	<a href="mailto:Abdul.Khan@water.ca.gov">Abdul.Khan@water.ca.gov</a>
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<b>Position</b>	<b>Name and Title</b>	<b>Affiliation</b>	<b>Email</b>
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<b>Position</b>	<b>Name and Title</b>	<b>Affiliation</b>	<b>Email</b>
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Sub-Committee Member	Matt Reiter, Principal Scientist	Point Blue	<a href="mailto:mreiter@pointblue.org">mreiter@pointblue.org</a>
Theme Coordinator	Francisco Flores-Lopez, Water Resources Engineer	DWR	<a href="mailto:Francisco.FloresLopez@water.ca.gov">Francisco.FloresLopez@water.ca.gov</a>

## Engagement Process

The State and non-State co-chairs were proposed by the DWR Flood-MAR team. Both co-chairs were selected based on their leadership skills and well-known expertise and experience in the corresponding fields and institutions.

The co-chairs, in collaboration with the DWR Flood-MAR team, identified a list of potential members to integrate the subcommittee. The identified candidates were experts, practitioners, researchers, and modelers with experience and expertise on tools and applications. The final list of members who accepted to participate in the theme as subcommittee members is presented in the above table.

The subcommittee members held a half-dozen meetings, each lasting about two to four hours. Similarly, the co-chairs and the theme coordinator participated in several phone calls to prepare meetings, and organize, process, and review the theme's contribution to the RAC.

Initially, the TAD leadership group proposed a list of work activities that were the foundation to develop the TAD's contribution to the R&DD plan. Those work activities are listed below.

1. The subcommittee will understand the data and tools landscape to ensure new Flood-MAR tools are additive and interoperable.
  - A. Identify the most recent available data and tools for Flood-MAR.
  - B. Understand (identification) existing data/tools/models being used by decision-makers.
  - C. Identify current and desired input/output factors for each of the three scales above that are needed for improved decision-making.
  - D. Create detailed list of data inputs, to ensure research themes can be structured efficiently. For example, information on water availability, infrastructure/conveyance capacities, soils, subsurface properties, land use types, must be coordinated across all three spatial/temporal scales above.
  - E. Create matrix to map how each data source would inform each scale (ensuring appropriate resolution is gathered).

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- F. Create table showing how well existing tools and applications meet desired input and outputs.
  - G. Identify data gaps related to the required/desired inputs and outputs.
  - H. Prioritize and sequence data gaps consistent with sequenced tool development (e.g., version 1, version 2, and so forth) and research themes. Also, identify linkages across the different Flood-MAR research themes.
2. The subcommittee will focus on evaluating necessary tools and applications at three primary scales:
    - A. System-wide planning for long-term analysis.
    - B. Watershed scale for analysis of short duration flood events. (Should the groundwater basin be considered as another scale or it is included somehow in the watershed scale?)
    - C. Project- and location-specific analysis.
  3. Prioritize decision contexts that can be informed at each scale.
    - A. Who are the targeted end users for the tool ("decision-makers" that Flood-MAR team wants to support)?
    - B. What type of questions the tools have to answer ("questions" define the tools to be used)?
    - C. At what scale (spatial or temporal) will decisions be made?
  4. System scale:
    - A. Spatial – Optimizing across the full system, potentially the entire state.
    - B. Temporal – Possibly monthly/annual/multi-year.
  5. Watershed scale:
    - A. Spatial – Optimizing across one river system, groundwater basin, or watershed.
    - B. Temporal – Investigate hourly/daily/weekly/monthly/annual scales.

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6. Project location scale:
  - A. Spatial – Optimizing across one agency or subbasin, possibly down to individual parcel.
  - B. Temporal – Possibly weekly/monthly, or, perhaps, eventually daily (or hourly?).
7. Identification of factors that can define new Flood-MAR projects (e.g., public benefit analysis, cost-benefit analysis) with the deployment of tools.
8. Create a specific list of decisions (e.g., management actions, possible investments) that will be better informed.
9. Identify strategies to implement these new tools and applications (e.g., funding opportunities).
10. Make sure that local entities are able to use and implement these tools (e.g., facilitate access to tools and funding).

## Available Research, Data, and Tools

The tables below summarize the available research, data, and tools related to the Tools and Application Development theme. This information presented is based on subcommittee members suggestions.

**Table 1 IWFM Demand Calculator (IDC)**

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Category: [Tool](#)

Scale: [State, Local](#)

Availability: [Available](#)

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Other Themes That Will Benefit:

1. Hydrology Observation and Prediction
  5. Soils, Geology and Aquifer Characteristics
  6. Land Use Management
- 

Public Benefits Informed By: [Drought preparedness; climate change adaptation.](#)

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Description, including Connection to Flood-MAR: IDC is a climate and land-use driven model that can be used at any basins at local and regional scales. It simulates crop water demands as well as movement of water through land surface and root zone in agricultural, urban, and native vegetation lands. It can be used to calculate the timing of flooding and the amount of diversions to maintain a certain flood depth through a certain time period.

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Website: <https://water.ca.gov/Library/Modeling-and-Analysis/Modeling-Platforms/Integrated-Water-Flow-Model-Demand-Calculator>

Contact: [Emin C. Dogrul](#)

Email: [can.dogrul@water.ca.gov](mailto:can.dogrul@water.ca.gov)

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**Table 2 Integrated Water Flow Model (IWFM)**

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Category: Tool

Scale: State, Local

Availability: Available

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Other Themes That Will Benefit:

1. Hydrology Observation and Prediction
  5. Soils, Geology and Aquifer Characteristics
  6. Land Use Management
  8. Recharge and Extraction Methods & Measures
  13. Tool and Application Development
- 

Public Benefits Informed By: Drought preparedness, aquifer replenishment, subsidence mitigation, climate change adaptation.

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Description, including Connection to Flood-MAR: IWFM is a climate- and land use-driven integrated hydrologic model that can be used at any basins at local and regional scales. It can simulate flooding operations through surface water diversions, drainage of the flooded fields and ultimately its impact on the recharge of the aquifer system as well as the stream-aquifer interaction.

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Website: <https://water.ca.gov/Library/Modeling-and-Analysis/Modeling-Platforms/Integrated-Water-Flow-Model>

Contact: Emin C. Dogrul

Email: [can.dogrul@water.ca.gov](mailto:can.dogrul@water.ca.gov)

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**Table 3 Water Resources Integrated Modeling System (WRIMS)**

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Category: Tool

Scale: State

Availability: Available

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Other Themes That Will Benefit:

1. Hydrology Observation and Prediction
  2. Reservoir Operation
  3. Infrastructure Conveyance and Hydraulics
  5. Soils, Geology and Aquifer Characterization
  6. Land Use Planning and Management
  7. Water Quality
  8. Recharge and Extraction Methods & Measures
  9. Environment – Riparian/Aquatic; Economic Analysis
  13. Tool and Application Development
- 

**Public Benefits Informed By:** Flood risk reduction, drought preparedness, aquifer replenishment, ecosystem enhancement, subsidence mitigation, water quality improvement, climate change adaptation, recreation and aesthetics.

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**Description, including Connection to Flood-MAR:** WRIMS is a generalized water resources modeling system for evaluating operational alternatives of large, complex river basins. It is a flexible system that can not only simulate multi-purpose reservoirs and conveyance system operations but also integrate with other specialty models including groundwater, rainfall-runoff, water demand, flood operation and channel routing, water quality, economic analysis, and ANN/AI, that may apply to Flood-MAR.

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**Website:** N/A

**Contact:** Hongbing Yin

**Email:** [hongbing.yin@water.ca.gov](mailto:hongbing.yin@water.ca.gov)

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#### **Table 4 Soil Water Assessment Tool (SWAT)**

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Category: Tool

Scale: State

Availability: Available

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##### Other Themes That Will Benefit:

1 .Hydrology Observation and Prediction

2. Reservoir Operations

7. Water Quality

9. Environment

Climate Change

Flood Management

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**Public Benefits Informed By:** Flood risk reduction, drought preparedness, ecosystem enhancement, preservation and stewardship of working landscapes, water quality improvement, and climate change adaptation.

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**Description, including Connection to Flood-MAR:** The SWAT (Soil Water Assessment Tool) model, is a small watershed-to-river basin-scale model that simulates the quality and quantity of surface and groundwater and predicts the environmental impacts of land use, land management practices, and climate change. The water balance, or the flow of water in and out of a hydrologic system, informs all processes in the SWAT model because of its impact on plant growth, sediment, nutrients, pesticides and pathogens. To model hydrologic processes, the SWAT model first divides basin of interest into subbasins, and then further into hydrologic response units (HRUs) based on land use, management and soils. SWAT estimates runoff for each HRU separately, and then the total runoff for the entire basin. The SWAT model is widely used for hydrologic studies, climate change studies, and water quality studies including nutrient loading, total daily maximum loads, pesticides, and bacteria.

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**Website:** <http://swat.tamu.edu/>

**Contact:** <https://swat.tamu.edu/contact/>

**Email:** [mike.white@ars.usda.gov](mailto:mike.white@ars.usda.gov)

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## Table 5 GSFLOW

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Category: Tool

Scale: State

Availability: Available

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### Other Themes That Will Benefit:

1. Hydrology Observation and Prediction
  5. Soils, Geology, and Aquifer Characterization
  7. Water Quality
  8. Recharge and Extraction Methods & Measures
  9. Environment
- 

**Public Benefits Informed By:** Drought preparedness, aquifer replenishment, subsidence mitigation, ecosystem enhancement, water quality improvement, climate change adaptation.

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**Description, including Connection to Flood-MAR:** GSFLOW is a coupled groundwater and surface-water FLOW model based on the integration of the USGS Precipitation-Runoff Modeling System (PRMS) and the USGS Modular Groundwater Flow Model (MODFLOW and MODFLOW-NWT). GSFLOW was developed to simulate coupled groundwater/surface-water flow in one or more watersheds by simultaneously simulating flow across the land surface, within subsurface saturated and unsaturated materials, and within streams and lakes. Climate data consisting of measured or estimated precipitation, air temperature, and solar radiation, as well as groundwater stresses (such as withdrawals) and boundary conditions are the driving factors for a GSFLOW simulation. GSFLOW operates on a daily time step. GSFLOW uses internal daily stress periods for adding recharge to the water table and calculating flows to streams and lakes. GSFLOW can be used to evaluate the effects of factors such as land-use change, climate variability, and groundwater withdrawals on surface and subsurface flow for watersheds that range from a few square kilometers to several thousand square kilometers, and for time periods that range from months to several decades.

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**Website:** <https://water.usgs.gov/ogw/gflow/>

**Contact:** N/A **Email:** N/A

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**Table 6 Hydrus 2D/3D (Version 3.x), Hydrus-1D (Version 4.xx)**

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Category: Tool

Scale: State

Availability: Available

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Other Themes That Will Benefit:

- 5. Soils, Geology, and Aquifer Characterization
  - 7. Water Quality
  - 8. Recharge and Extraction Methods & Measures
  - 9. Environment
- 

Public Benefits Informed By: Site suitability, risk analysis, high likelihood of project success; aquifer replenishment; water quality improvement.

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Description, including Connection to Flood-MAR: Hydrus 2D/3D Version 3.x is a Microsoft Windows-based physical modeling environment for analysis of water flow and solute/colloid transport in variably saturated porous media with and without vegetation cover. The model simulates growth of vegetation (crop) roots in the root zone and water and solute uptake into the plant cover from the root zone. The software package is based on two- and three-dimensional finite element method for solving partial differential equations. The model includes a parameter optimization algorithm for inverse estimation of a variety of soil hydraulic and/or solute transport parameters. The model is supported by an interactive graphics-based interface for data-preprocessing, generation of a structured mesh, and graphic presentation of the results. Software licenses are obtained from the developer. A public domain, one-dimensional version, HYDRUS-1D, is also available (free of charge) from the same vendor (PC Progress). The software is suitable to determine site-specific flow and transport processes underneath and adjacent to recharge sites, given information about the local climate, soils, geology, hydrogeology, existing contaminants in the soil profile, and land use management (irrigation, fertilizer and pesticide use, recharge). The software tracks the fate and transport of pollutants. It tracks the fate and transport of recharge water, alerts to ponding that may occur in the unsaturated zone because of the presence of lower permeable layers and can be used to predict the rise in water table in response to recharge. Because of its ability to capture important site and project conditions, this software is well suited to evaluate various recharge project designs for long-term benefits (amount of water that can be recharged, quality of receiving groundwater) and risks at or nearby the site (contamination, extended periods of saturation in crop root zone).

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Websites: <https://www.pc-progress.com/en/Default.aspx?hydrus-3d>

<https://www.pc-progress.com/en/Default.aspx?hydrus-1d>

Contact: Jirka SImunek, University of California, Riverside

Email: [j.slmunek@ucr.edu](mailto:j.slmunek@ucr.edu)

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**Table 7 Groundwater Recharge Assessment Tool (GRAT)**

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Category: Tool

Scale: Regional

Availability: Available

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Other Themes That Will Benefit:

- 3. Infrastructure Conveyance and Hydraulics
  - 4. Crop Systems Suitability
  - 5. Soils, Geology, and Aquifer Characterization
  - 6. Land Use Planning and Management
  - 8. Recharge and Extraction Methods & Measurement
  - 11. Economic Analysis
- 

**Public Benefits Informed By:** Flood risk reduction, drought preparedness, aquifer replenishment, ecosystem enhancement. In the future, GRAT upgrades may address also subsidence mitigation, climate change adaptation and others.

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**Description, including Connection to Flood-MAR:** GRAT is a GIS decision support tool that can be localized to any groundwater sustainability agency or water district. It allows an end user to estimate the optimal amount of recharge that can be done across multiple recharge types (on-farm, dedicated, fallow) given estimated water available for recharge, existing conveyance, and soil suitability information. GRAT is meant to be used by water managers to test unlimited number of scenarios to see impact of possible recharge volumes. Spatial scale is sub-acre (usually APN or field level). Temporal scale is weekly (52 weeks for 20 years), although some datasets are daily.

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**Website:** <https://grat.earthgenome.org/>

**Contact:** Glen Low or Daniel Mountjoy (Sustainable Conservation)

**Email:** [jack.sieber@sei.org](mailto:jack.sieber@sei.org)

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**Table 8 Water Evaluation And Planning System (WEAP)**

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Category: Tool

Scale: Regional

Availability: Available

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Other Themes That Will Benefit:

1. Hydrology Observation and Prediction
  2. Reservoir Operations
  3. Infrastructure Conveyance and Hydraulics
  5. Soils, Geology And Aquifer Characterization
  6. Land Use Planning and Management
  7. Water Quality
  8. Recharge And Extraction Methods & Measures
  9. Environment – Riparian/Aquatic
- 

Public Benefits Informed By: Flood risk reduction, drought preparedness, water quality improvement, aquifer replenishment, ecosystem enhancement, and climate change adaptation.

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Description, including Connection to Flood-MAR: WEAP is a climate-driven, integrated water resources management decision support tool. It can be built to any scale from a single farm to a basin. Model time step can be from daily to annual. Flood management aquifer recharge processes can be represented in WEAP, as recently demonstrated in Yolo County. Climate-driven hydrologic simulation is integrated with water systems infrastructure (dams, canals, hydropower) and instream flow requirements. Water allocation routines distribute water available to each demand at each time step. Three levels of groundwater integration are provided, including linking to MODFLOW. A graphical user interface makes the model user friendly.

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Website: <https://www.weap21.org>

Contact: Jack Sieber

Email: [jack.sieber@sei.org](mailto:jack.sieber@sei.org)

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**Table 9 Variable Infiltration Capacity (VIC) Model**

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Category: Tool

Scale: State

Availability: Available

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Other Themes That Will Benefit:

1. Hydrology Observation and Prediction
  2. Reservoir Operations
  9. Environment
- 

Public Benefits Informed By: Flood risk reduction, drought preparedness, ecosystem enhancement, preservation and stewardship of working landscapes, climate change adaptation.

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Description, including Connection to Flood-MAR: The VIC model is a macroscale hydrologic model used to solve full water and energy balances. In addition to hydrologic processes, VIC models land-surface interactions and flow routing. The model simulates land-atmospheric fluxes, and water and energy balances on the land for each grid independently, and then routes estimated surface flows and base flows to produce streamflows from the network of grids. The model can be used for a variety of applications, for example, streamflow simulation and forecasting, water and energy balance calculations, reservoir water management, and climate change studies.

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Website: <https://vic.readthedocs.io/en/master/#variable-infiltration-capacity-vic-macroscale-hydrologic-model>

Contact: Bart Nijssen

Email: [nijssen@uw.edu](mailto:nijssen@uw.edu)

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# Research Needs and Gaps

This section presents a list of the identified gaps for the Tools and Application Development theme. This list of identified gaps was determined by the co-chairs, a subcommittee member, Glen Low, and the team coordinator, Francisco Flores-Lopez, during different work meetings. The list is not intended to be final but represents what the lead team was able to identify as current gaps or needs in the TAD's arena; this information is presented below as a non-prioritized list.

## **1. Spatial Coverage (Gap type: Tools, Data)**

There is a wide disparity in the spatial coverage within California of analytical tools that could be used to support Flood-MAR analysis at the needed resolution. Gaps below are described for inside and outside of the Central Valley.

### Inside the Central Valley

There is good spatial coverage of analytical tools for some aspects needed for Flood-MAR analysis. For example, the C2VSIM model developed and maintained by DWR and CVHM model developed and maintained by the United States Geological Survey (USGS) each can describe important watershed-scale surface water and groundwater conditions for the entire Central Valley. However, these two integrated hydrologic models are not of sufficient resolution to assess small-scale Flood-MAR projects within a water district. And these two models do not capture all the important Flood-MAR factors including flood routing, environmental benefits, detailed agricultural processes, economic and other factors that may be necessary for assessment of Flood-MAR potential. Some water districts and regional water management groups have created local or regional models that may be better suited to Flood-MAR analysis, but there is not a publicly available catalog of these tools.

There is a general need to create and catalog available information that can be used to develop and calibrate existing and new analytical tools. This includes information on land use, surface and groundwater use, soil properties, hydrogeological parameters, stream flow, stream aquifer connections, and many other factors. There is a need to access improved technologies like remote sensing to capture and update these factors on a wide scale. Along with this data, there is a need for improved geospatial analysis tools that can effectively make use of remote sensing and other spatial information.

### Outside the Central Valley

Some water districts and regional water management groups have created localized models, but there is not a publicly available catalog of these tools. In some cases, the USGS has created local-scale integrated hydrologic models in partnership with local and regional water management agencies. As with the Central Valley, there is a need to create and catalog available information that can be used to develop and calibrate existing and new analytical tools.

### **2. Temporal Coverage (Gap type: Tools, Data)**

To effectively evaluate the timing and volume of water for Flood-MAR projects, there is a need to more effectively integrate between analytical tools that capture daily or sub-daily peak-flow water movement and tools used for longer-term planning by aggregating flows at weekly or greater time scales. There are different tools suited to these different time scales, but there is no easy way to effectively link these two for an integrated analysis of Flood-MAR constraints and opportunities.

### **3. Decision Support Tools (Gap type: Tools)**

As stated above, many independent tools and models exist that represent different functional aspects involved in a typical Flood-MAR project. Today, a gap exists to seamlessly integrate these models to fully represent the required system, and to effectively share technical results in a manner that is accessible to decision-makers. There is a need to link data inputs and outputs between tools, at comparable spatial/temporal scale, so that models can be connected as needed. In a similar way, there also lacks the ability to know what are required common assumptions to ensure consistency of what is being modeled. Filling this gap would benefit from a use case-driven approach, ideally with simplified visualization in a cloud-based spatial optimization tool, that will allow decision-makers to implement Flood-MAR projects without having expertise in all coupled models. Addressing these gaps would dramatically expand the effectiveness of the tools for communicating with decision-makers (e.g., local water agencies, groundwater sustainability agencies [GSAs]) who may implement a Flood-MAR project. Note: Creation of decision support tools for Flood-MAR would hopefully leverage the ongoing Assembly Bill 1755 process that is helping establish water data infrastructure for California.

#### **4. Water Quality Processes (Gap type: R, D and T)**

Water quality is an important factor in assessing the feasibility of Flood-MAR projects. Surface water quality, mobile constituents in soils, quality of urban or agricultural runoff, and groundwater quality must all be considered. There is often limited information available on site-specific water quality conditions. There is a need to include water quality considerations in the analytical tools used for Flood-MAR analysis. This may include the fate and transport of chemical constituents in urban or agricultural runoff and the leaching potential and transport of chemical constituents from flooded agricultural fields into the underlying soils and aquifers. Analytical tools are available to perform some of these analyses but are seldom developed for specific Flood-MAR locations under consideration.

#### **5. Hydrologic / Hydrogeologic Processes (Gap type: R, D and T)**

Some gaps have been identified for precise representation of some hydrological processes that are driven by Flood-MAR practices. These identified gaps are those which cannot simulate for example the effects of specific processes such as maximizing the use of runoff from atmospheric rivers or determining how much flood flow is safe to divert for MAR from a water rights point of view. There is a need to estimate how inundated areas for a Flood-MAR project relate to flood impact analysis, ecosystem restoration, agricultural production, and water quality. Those specific processes are particular to Flood-MAR practices that have not been studied prior to the Flood-MAR concept.

#### **6. Agricultural Processes (Gap type: Research, Data)**

Research is needed to understand agricultural processes that determine the site and crop suitability. For example, there is a need to understand how different crops and their root systems respond to high groundwater levels and flooded winter conditions and the subsequent impacts (if any) on yields and crop quality. This implies to determine the tolerance to flooded conditions such as flooding time and duration to ensure agricultural systems continue to be economically viable and sustainable. Until these processes are well understood, a correct simulation of them can be developed.

## **7. Environmental Processes (Gap type: Research, Data)**

There are gaps related to tools and methods for quantifying environmental benefits related to Flood-MAR, such as benefits related to sustain groundwater dependent ecosystems, increase groundwater storage and reduce pressure to meet instream flow requirements from surface water sources, improve water temperature during summer because of higher groundwater levels and groundwater contributions to rivers, reconnecting floodplains now occupied by other land use (e.g., agriculture) with river water.

## **8. Policy Linkages and Governance Structure (Gap type: Research)**

There are gaps related to defining the legal (e.g., California Water Code) and regulatory framework (e.g., water right permits) of Flood-MAR, its linkages with other regulations and policies (e.g., the Sustainable Groundwater Management Act [SGMA]), and the ability to simulate different policy (e.g., state incentives) and regulatory scenarios to define Flood-MAR governance structures for funding, implementation, operation and coordination among individuals landowners, irrigation districts, and multiple agencies (e.g., individual landowners vs. group of landowners).

## **9. Stakeholder Preferences (Gap type: Research, Data)**

Implementing Flood-MAR projects requires understanding of which strategies are acceptable or preferred by local stakeholders. For example, whether on-farm recharge is acceptable for any specific farmer is likely a result of crop type, soil, underlying geology, and other weather-related conditions. Today, there is a gap in knowing and cataloging which strategies can be implemented in any specific region for any specific stakeholder, which hampers exploration of the full potential for Flood-MAR. Filling this gap would ideally create a system where local stakeholders can voluntarily input their own preferences on Flood-MAR strategies so other local authorities can further explore these opportunities as needed.

## **10. Cost/Benefit Analysis, Including Multi-Benefit (Gap type: R, D, and T)**

There are gaps related to quantifying the cost and benefits of implementing Flood-MAR strategies. On the cost side, there is a need for more spatially explicit estimates on costs to implement (capital expenditures, plus ongoing operating costs) across all Flood-MAR strategies. Likewise, there lacks a way to estimate the

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benefit of actions along financial/economic terms, including economic impacts of flooding (avoidance). This would require sophisticated models that include time value of money, discount rate, and other cash flow implications of understanding when and how Flood-MAR strategies are implemented. Importantly, this kind of financial analysis would help identify Flood-MAR funding gaps (e.g., capital investments needed) and, likewise, possible incentives for implementing Flood-MAR by local stakeholders. Ideally, this quantification of cost and benefits would be inherently multi-benefit, including non-monetary considerations such as impacts on local communities, environmental/ecological benefit, and other hydrological/geological benefits consistent with avoiding the undesirable results stated in SGMA.

# Prioritization Process

To define the prioritization process of the TAD gaps, the subcommittee looked at Figure 6 provided in *Factors for Implementing Flood-MAR* in the Flood-MAR White Paper (*Flood-MAR. Using Flood Water for Managed Aquifer Recharge to Support Sustainable Water Resources*. California Department of Water Resources. June 2018.) In Figure 6, the team identified the coverage that the 10 gaps listed in the previous section (List Research Needs and Gaps) have on the *Factors for Implementing Flood-MAR*. The identified gaps have been placed in Figure 6 with the corresponding factors, and a color scale has been added describing the coverage type (good, fair, and significant gap) for each bullet point in each factor.

This exercise allowed the subcommittee to get a sense of the priorities to be addressed based on the identified gaps. The gaps identified are Feasibility Analysis, Governance and Coordination, and Funding and Incentives Factors.

Flood-MAR: TAD Subcommittee Identified Gaps  
Gaps and how they relate to Figure 6  
February 22<sup>nd</sup>, 2019

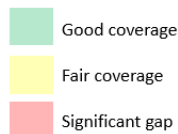
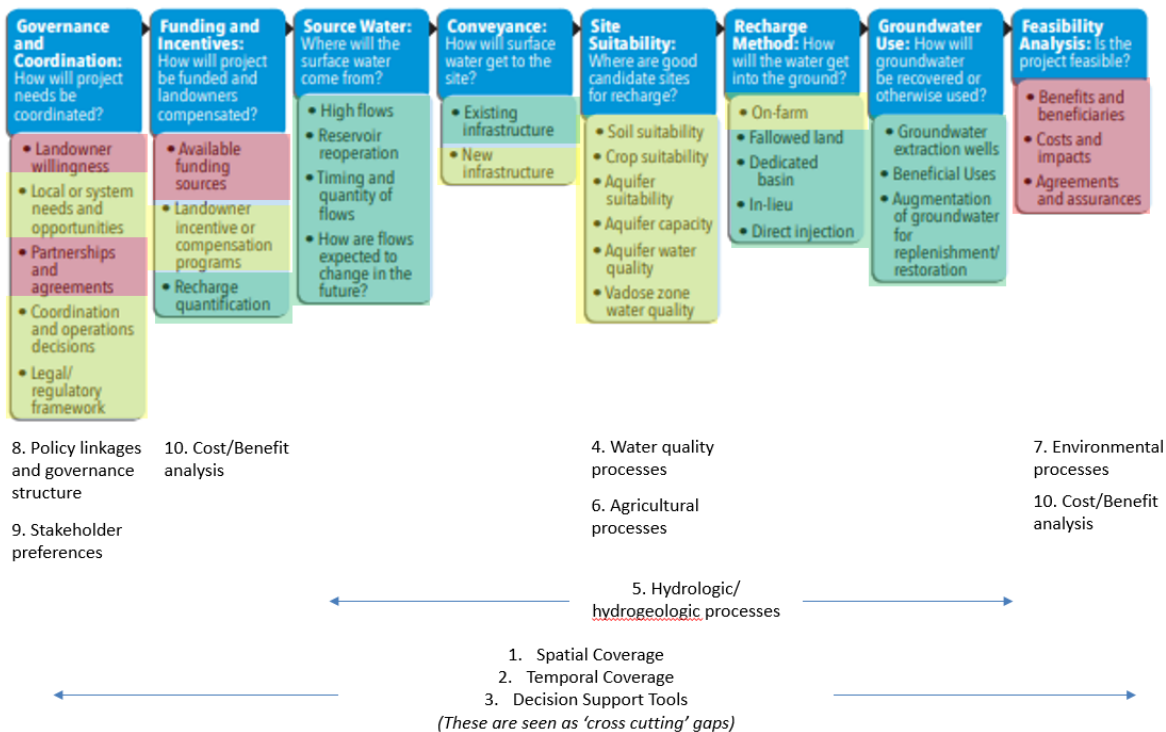


FIGURE 6. Factors for Implementing Flood-MAR



The next step was to convert the identified gaps into actions items that can be persuade at the RAC level. Those action items are presented below in order of priority.

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**Action Item 1 Conduct Cost/Benefit Analysis, Including Multi-Benefit**

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Category: Research, Data, Tool

Scale: State, Regional

Availability: Gap

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Other Themes That Will Benefit:

11. Economic Analysis

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Public Benefits Informed By:

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Implementation Factors:

2. Funding and Incentives

8. Feasibility Analysis

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**Description of Gaps and Connection to Flood-MAR:** There are gaps related to quantifying the cost and benefits of implementing Flood-MAR strategies. On the cost side, there is a need for more spatially explicit estimates on costs to implement (capital expenditures, plus any ongoing operating costs) across all Flood-MAR strategies. Likewise, there lacks a way to estimate the benefit of actions along financial/economic terms, including economic impacts of flooding (avoidance). This would require sophisticated models that include time value of money, discount rate and other cash flow implications of understanding when and how Flood-MAR strategies are implemented. Importantly, this kind of financial analysis would help identify Flood-MAR funding gaps (e.g., capital investments needed) and, likewise, possible incentives for implementing Flood-MAR by local stakeholders. Ideally, this quantification of cost and benefits would be inherently multi-benefit, including non-monetary considerations such as impacts on local communities, environmental/ecological benefit, and other hydrological/geological benefits consistent with avoiding the undesirable results stated in SGMA.

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Strategy for Gaps Implementation:

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Cost:

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## Action Item 2 Identify Policy Linkages and Governance Structure

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Category: Research

Scale: State, Regional

Availability: Gap

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Other Themes That Will Benefit:

12. Local, State, and Federal Policies and Legal Considerations

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Implementation Factors:

1. Governance and Coordination

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**Description of Gaps and Connection to Flood-MAR:** There are gaps related to defining the legal (e.g., California Water Code) and regulatory framework (e.g., water right permits) of Flood-MAR, its linkages with other regulations and policies (e.g., SGMA), and the ability to simulate different policy (e.g., state incentives) and regulatory scenarios to define Flood-MAR governance structures for funding, implementation, operation and coordination among individuals landowners, irrigation districts, and multiple agencies (e.g., individual landowners vs. group of landowners).

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Strategy for Gaps Implementation:

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Cost:

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### **Action Item 3 Create Decision Support Tools to Integrate Flood-MAR Disciplines**

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Category: Tool

Scale: State, Regional

Availability: Gap

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#### Other Themes That Will Benefit:

1. Hydrology Observation and Prediction ; 2. Reservoir Operations
  3. Infrastructure Conveyance and Hydraulics; 4. Crop Systems Suitability
  5. Soils, Geology, and Aquifer Characterization; 6. Land Use Planning and Management; 7. Water Quality; 8. Recharge and Extraction Methods & Measurement;
  9. Environment; 10. People and Water; 11. Economic Analysis;
  12. Local, State, and Federal Policies and Legal Considerations
- 

#### Implementation Factors:

Cross cutting over all eight factors:

1. Governance And Coordination; 2. Funding And Incentives; 3. Source Water;
  4. Conveyance; 5. Site Suitability; 6. Recharge Method; 7. Groundwater Use
  8. Feasibility Analysis
- 

**Description of Gaps and Connection to Flood-MAR:** As stated above, many independent tools and models exist that represent different functional aspects involved in a typical Flood-MAR project. Today, a gap exists to seamlessly integrate these models to fully represent the required system, and to effectively share technical results in a manner that is accessible to decision-makers. There is a need to link data inputs and outputs between tools, at comparable spatial/temporal scale, so that models can be connected as needed. In a similar way, there also lacks the ability to know what are required common assumptions to ensure consistency of what is being modeled. Filling this gap would benefit from a use case-driven approach, ideally with simplified visualization in a cloud-based spatial optimization tool, that will allow decision-makers to implement Flood-MAR projects without having expertise in all coupled models. Addressing these gaps would dramatically expand the effectiveness of the tools for communicating with decision-makers (e.g., local water agencies, GSAs) who may implement a Flood-MAR project. Note: Creation of decision support tools for Flood-MAR would hopefully leverage the ongoing Assembly Bill 1755 process that is helping establish water data infrastructure for California.

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#### Strategy for Gaps Implementation:

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Cost:

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## Action Item 4 Quantify Environmental Processes and Benefits

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Category: Research, Data

Scale: State, Regional

Availability: Gap

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### Other Themes That Will Benefit:

1. Hydrology Observation and Prediction
  4. Crop Systems Suitability
  5. Soils, Geology, and Aquifer Characterization
  6. Land Use Planning and Management
  7. Water Quality
  9. Environment
  10. People and Water
- 

### Implementation Factors:

8. Feasibility Analysis
- 

**Description of Gaps and Connection to Flood-MAR:** There are gaps related to tools and methods for quantifying environmental benefits related to Flood-MAR, such as benefits related to sustain groundwater dependent ecosystems, increase groundwater storage and reduce pressure to meet instream flow requirements from surface water sources, improve water temperature during summer because of higher groundwater levels and groundwater contributions to rivers, reconnecting floodplains now occupied by other land use (e.g., agriculture) with river water.

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### Strategy for Gaps Implementation:

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Cost:

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**Action Item 5 Clarify Uncertainty for each Flood-MAR Component or Model**

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Category: Research, Data, Tool

Scale: State, Regional

Availability: Gap

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Other Themes That Will Benefit:

1. Hydrology Observation and Prediction
  3. Infrastructure Conveyance and Hydraulics
  4. Crop Systems Suitability
  5. Soils, Geology, and Aquifer Characterization
  6. Land Use Planning and Management
  7. Water Quality
  8. Recharge and Extraction Methods & Measurement
  9. Environment
  11. Economic Analysis
- 

Implementation Factors:

1. Governance and Coordination
  2. Funding and Incentives
  3. Source Water
  4. Conveyance
  5. Site Suitability
  6. Recharge Method
  7. Groundwater Use
  8. Feasibility Analysis
- 

Description of Gaps and Connection to Flood-MAR:

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Strategy for Gaps Implementation:

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Cost:

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## **Action Item 6 Identify Stakeholder Preferences that Affect Flood-MAR Adoption**

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Category: Research, Data

Scale: State, Regional

Availability: Gap

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### Other Themes That Will Benefit:

10. People and Water

11. Economic Analysis

12. Local, State, and Federal Policies and Legal Considerations

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### Implementation Factors:

1. Governance and Coordination

2. Funding and Incentives

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**Description of Gaps and Connection to Flood-MAR:** Implementing Flood-MAR projects requires understanding of which strategies are acceptable or preferred by local stakeholders. For example, whether on-farm recharge is acceptable for any specific farmer is likely a result of crop type, soil, underlying geology, and other weather-related conditions. Today, there is a gap in knowing and cataloging which strategies can be implemented in any specific region for any specific stakeholder, which hampers exploration of the full potential for Flood-MAR. Filling this gap would ideally create a system where local stakeholders can voluntarily input their own preferences on Flood-MAR strategies so other local authorities can further explore these opportunities as needed.

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### Strategy for Gaps Implementation:

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Cost:

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## Action Item 7 Identify Critical Water Quality Processes and Impacts

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Category: Research, Data, Tool

Scale: State, Regional

Availability: Gap

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Other Themes That Will Benefit:

1. Hydrology Observation and Prediction
  7. Water Quality
  8. Recharge and Extraction Methods & Measurement
  9. Environment – Terrestrial and Riparian/Aquatic
  10. People and Water
- 

Implementation Factors:

5. Site Suitability
- 

**Description of Gaps and Connection to Flood-MAR:** Water quality is an important factor in assessing the feasibility of Flood-MAR projects. Surface water quality, mobile constituents in soils, quality of urban or agricultural runoff, and groundwater quality must all be considered. There is often limited information available on site-specific water quality conditions. There is a need to include water quality considerations in the analytical tools used for Flood-MAR analysis. This may include the fate and transport of chemical constituents in urban or agricultural runoff and the leaching potential and transport of chemical constituents from flooded agricultural fields into the underlying soils and aquifers. Analytical tools are available to perform some of these analyses but are seldom developed for specific Flood-MAR locations under consideration.

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Strategy for Gaps Implementation:

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Cost:

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## Action Item 8 Expand Temporal Coverage of Data/Tools

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Category: Data, Tool

Scale: State, Regional

Availability: Gap

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### Other Themes That Will Benefit:

1. Hydrology Observation and Prediction
  2. Reservoir Operations
  3. Infrastructure Conveyance and Hydraulics
  4. Crop Systems Suitability
  5. Soils, Geology, and Aquifer Characterization
  6. Land Use Planning and Management
  7. Water Quality
  8. Recharge and Extraction Methods & Measurement
  9. Environment
  10. People and Water
- 

### Implementation Factors:

1. Governance and Coordination
  2. Funding and Incentives
  3. source Water
  4. Conveyance
  5. Site Suitability
  6. Recharge Method
  7. Groundwater Use
  8. Feasibility Analysis
- 

**Description of Gaps and Connection to Flood-MAR:** To effectively evaluate the timing and volume of water for Flood-MAR projects, there is a need to more effectively integrate between analytical tools that capture daily, or sub-daily peak-flow water movement and tools used for longer-term planning by aggregating flows at weekly or greater time scales. There are different tools suited to these different time scales, but there is no easy way to effectively link these two for an integrated analysis of Flood-MAR constraints and opportunities.

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### Strategy for Gaps Implementation:

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Cost:

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## Action Item 9 Quantify Hydrologic / Hydrogeologic Processes

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Category: Research, Data, Tool

Scale: State, Regional

Availability: Gap

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### Other Themes That Will Benefit:

1. Hydrology Observation and Prediction
  2. Reservoir Operations
  3. Infrastructure Conveyance and Hydraulics
  4. Crop Systems Suitability
  5. Soils, Geology, and Aquifer Characterization
  7. Water Quality
  8. Recharge and Extraction Methods & Measurement
- 

### Implementation Factors:

3. Source Water
  4. Conveyance
  5. Site Suitability
  6. Recharge Method
  7. Groundwater Use
- 

**Description of Gaps and Connection to Flood-MAR:** Some gaps have been identified for precise representation of some hydrological processes that are driven by Flood-MAR practices. These identified gaps are those which cannot simulate for example the effects of specific processes such as maximizing the use of runoff from atmospheric rivers or determining how much flood flow is safe to divert for MAR from a water rights point of view. There is a need to estimate how inundated areas for a Flood-MAR project relate to flood impact analysis, ecosystem restoration, agricultural production, and water quality. Those specific processes are particular to Flood-MAR practices that have not been studied before since the Flood-MAR concept did not exist.

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### Strategy for Gaps Implementation:

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Cost:

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## **Action Item 10 Analyze Agricultural Processes that Affect Flood-MAR Adoption**

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Category: Research, Data

Scale: State, Regional

Availability: Gap

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### Other Themes That Will Benefit:

4. Crop Systems Suitability
  5. Soils, Geology, and Aquifer Characterization
  6. Land Use Planning and Management
  7. Water Quality
  8. Recharge and Extraction Methods & Measurement
  9. Environment
- 

### Implementation Factors:

5. Site Suitability
- 

**Description of Gaps and Connection to Flood-MAR:** Research is needed to understand agricultural processes that determine the site and crop suitability. For example, there is a need to understand how different crops and their root systems respond to high groundwater levels and flooded winter conditions and the subsequent impacts (if any) on yields and crop quality. This implies to determine the tolerance to flooded conditions such as flooding time and duration to ensure agricultural systems continue to be economically viable and sustainable. Until these processes are well understood, a correct simulation of them can be developed.

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### Strategy for Gaps Implementation:

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Cost:

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## Action Item 11 Expand Spatial Coverage of Data/Tools

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Category: Data, Tool

Scale: State, Regional

Availability: Gap

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### Other Themes That Will Benefit:

1. Hydrology Observation and Prediction
  2. Reservoir Operations
  3. Infrastructure Conveyance and Hydraulics
  4. Crop Systems Suitability
  5. Soils, Geology, and Aquifer Characterization
  6. Land Use Planning and Management
  7. Water Quality
  8. Recharge and Extraction Methods & Measurement
  9. Environment – Terrestrial and Riparian/Aquatic
  10. People and Water
- 

### Implementation Factors:

1. Governance and Coordination
  2. Funding and Incentives
  3. Source Water
  4. Conveyance
  5. Site Suitability
  6. Recharge Method
  7. Groundwater Use
  8. Feasibility Analysis
- 

**Description of Gaps and Connection to Flood-MAR:** There is a wide disparity in the spatial coverage within California of analytical tools that could be used to support Flood-MAR analysis at the needed resolution. Gaps below are described for inside and outside of the Central Valley.

*Inside the Central Valley:* There is good spatial coverage of analytical tools for some aspects needed for Flood-MAR analysis. For example, the C2VSIM model developed and maintained by DWR and CVHM model developed and maintained by the United States Geological Survey (USGS) each can describe important watershed-scale surface water and groundwater conditions for the entire Central Valley. However, these two integrated hydrologic models are not of sufficient resolution to assess small-scale Flood-MAR projects within a water district. And these two models do not capture all the

## Flood-MAR Research and Data Development Plan

important Flood-MAR factors including flood routing, environmental benefits, detailed agricultural processes, economic and other factors that may be necessary for assessment of Flood-MAR potential. Some water districts and regional water management groups have created local or regional models that may be better suited to Flood-MAR analysis, but there is not a publicly available catalog of these tools.

There is a general need to create and catalog available information that can be used to develop and calibrate existing and new analytical tools. This includes information on land use, surface and groundwater use, soil properties, hydrogeological parameters, stream flow, stream aquifer connections, and many other factors. There is a need to access improved technologies like remote sensing to capture and update these factors on a wide scale. Along with this data, there is a need for improved geospatial analysis tools that can effectively make use of remote sensing and other spatial information.

*Outside the Central Valley:* Some water districts and regional water management groups have created localized models, but there is not a publicly available catalog of these tools. In some cases, the USGS has created local-scale integrated hydrologic models in partnership with local and regional water management agencies. As with the Central Valley, there is a need to create and catalog available information that can be used to develop and calibrate existing and new analytical tools.

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Strategy for Gaps Implementation:

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Cost:

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## Top Three Research, Data, and Tools Actions

As part of the recommendations provided to the co-chairs during the Research Advisory Committee (RAC) meetings; the RAC coordinators suggested to present consistent levels of information for all research themes to support a coherent message throughout the R&DD plan. Another recommendation was to define the top three actions items, corresponding description, connection to Flood-MAR, and the strategy for implementation that each theme wanted to move forward in the R&DD plan.

Based on these recommendations, the lead theme consulted and had to make some adjustments to the information provided by all subcommittee members. The final top three contributions and the format of how it was submitted to the RAC committee is shown below.

### Action 1: Conduct Cost/Benefit Analysis, Including Multi-Benefit

**Description and Connection to Flood-MAR:** There are gaps related to quantifying the cost and benefits of implementing Flood-MAR strategies. On the cost side, there is a need for more spatially explicit estimates on costs to implement (capital expenditures, plus ongoing operating costs) across all Flood-MAR strategies. Likewise, there lacks a way to estimate the benefit of actions along financial/economic terms, including economic impacts of flooding (avoidance). This would require sophisticated models that include time value of money, discount rate, and other cash flow implications of understanding when and how Flood-MAR strategies are implemented. Importantly, this kind of financial analysis would help identify Flood-MAR funding gaps (e.g., capital investments needed) and, likewise, possible incentives for implementing Flood-MAR by local stakeholders. Ideally, this quantification of cost and benefits would be inherently multi-benefit, including non-monetary considerations such as impacts on local communities, environmental/ecological benefit, and other hydrological/geological benefits consistent with avoiding the undesirable results stated in SGMA.

**Draft Strategy for Implementation:** What: The resulting product of this TAD priority is the definition and quantification a cost benefit analysis that can be a module added to the Flood-MAR tool that can be used to identify associated cost and benefits (direct and indirect) for specific Flood-MAR projects. This likely would exist as a spreadsheet (Google or Microsoft Excel), with the possibility to analyze different physical setting of Flood-MAR (different tabs can be used for different

settings). Depending on the exact Flood-MAR strategies evaluated, it would presumably require different inputs and outputs across cost (e.g., capital investment, operational and maintenance cost, etc.) and benefits (e.g., reduction in electricity for pumping, increased in baseflow during summer). This modular tool will help to identify funding gaps and possible incentives for implementing Flood-MAR by local stakeholders.

**Who:** A group of economist, engineers, practitioners and Flood-MAR decision-makers will provide the design for the cost-benefit Flood-MAR modular tool to ensure the resulting tool significantly increases current ability to evaluate the economic viability of Flood-MAR projects at the appropriate spatial and temporal scales. Subcommittee members, plus others who may be interested, would need to coordinate with other Flood-MAR subcommittees to identify the variable and build the modular tool.

**When:** The actual tool design process can begin immediately, once appropriate Flood-MAR strategies (e.g., on-farm, floodplain, watershed Flood-MAR) are prioritized and a local pilot area is selected. It is believed the first prototype tool can be completed in 12–18 months, with the bulk of this initial time dedicated to defining user requirements with end-users, coordinating with other Flood-MAR subcommittees, and gathering needed datasets at appropriate spatial/temporal scale. Given that other research, development, and technologies (RD&Ts) from other subcommittees may take longer than this 18-month period, there is a need to coordinate on simplifying assumptions that will enable the first prototype tool to be built in an agile fashion (ensuring new data and research can be added later, as available).

**Draft Cost Estimate (Breakdown):** How: An approximate estimate for the overall integrated pilot tool creation likely would be in the range of \$600,000 – \$850,000 (one project coordinator, one economist, one professional expert, one web developer, plus traveling and workshops meetings) for three essential tasks: design, development, and coordination. The estimated budget split among these three essential tasks:

1. Tool design to work with potential users, including decision-makers to create a user specification (approximately 35 percent of time).
2. Identifying cost and potential database for the development of the tool, and quality assurance/quality control (QA/QC) (40 percent of time).

3. Time required to coordinate the integration of cost and benefit inputs/outputs and data aggregation across other Flood-MAR subcommittees (25 percent of time).

**Cost Estimate:** \$850,000

## Action 2: Identify Policy Linkages and Governance Structure

**Description and Connection to Flood-MAR:** There are gaps related to defining the legal (e.g., California Water Code) and regulatory framework (e.g., water right permits) of Flood-MAR, its linkages with other regulations and policies (e.g., SGMA), and the ability to simulate different policy (e.g., state incentives) and regulatory scenarios to define Flood-MAR governance structures for funding, implementation, operation and coordination among individuals landowners, irrigation districts, and multiple agencies (e.g., individual landowners vs. group of landowners).

**Draft Strategy for Implementation:** What: The resulting product of this TAD priority is the definition of organizational structures, roles, responsibilities, and regulatory framework for each component of the organizational structure. The product of this action item will be a set of organizational diagrams, the definition of each component, and flowcharts of the different steps for the identification of Flood-MAR strategies.

Who: A group of practitioners, lawyers, and Flood-MAR decision-makers will brainstorm different organizational structures and decision-making process to identify the organizational viability of Flood-MAR projects at the appropriate spatial and temporal scales. Subcommittee members, plus others who may be interested, would need to coordinate with other Flood-MAR subcommittees to identify the components and define the organizational structures.

When: The actual tool design process can begin immediately, once appropriate Flood-MAR strategies (e.g., on-farm, floodplain, watershed Flood-MAR) are prioritized and a local pilot area is selected. It is believed the first organizational structures can be completed in 12–18 months.

**Draft Cost Estimate (Breakdown):** How: An approximate estimate for the overall integrated pilot tool creation likely would be in the range of \$400,000–\$600,000 (one project coordinator, one water resources manager consultant, one

land use manager consultant, one web developer, plus traveling and workshops meetings).

**Cost Estimate:** \$600,000

### **Action 3: Create Decision Support Tools to Integrate Flood-MAR Disciplines**

**Description and Connection to Flood-MAR:** As stated above, many independent tools and models exist that represent different functional aspects involved in a typical Flood-MAR project. Today, a gap exists to seamlessly integrate these models to fully represent the required system, and to effectively share technical results in a manner that is accessible to decision-makers. There is a need to link data inputs and outputs between tools, at comparable spatial/temporal scale, so that models can be connected as needed. In a similar way, there also lacks the ability to know what are required common assumptions to ensure consistency of what is being modeled. Filling this gap would benefit from a use case-driven approach, ideally with simplified visualization in a cloud-based spatial optimization tool, that will allow decision-makers to implement Flood-MAR projects without having expertise in all coupled models. Addressing these gaps would dramatically expand the effectiveness of the tools for communicating with decision-makers (e.g., local water agencies, GSAs) who may implement a Flood-MAR project. Note: Creation of decision support tools for Flood-MAR would hopefully leverage the ongoing Assembly Bill 1755 process that is helping establish water data infrastructure for California.

**Draft Strategy for Implementation:** Product: The resulting product of this TAD priority is the creation of a Flood-MAR tool that can be used to integrate research, data, and models from many other Flood-MAR subcommittees in the direct evaluation of specific Flood-MAR projects. This likely would exist as a GIS (map-based) spatial and temporal optimization tool, with the possibility that multiple interoperable tools are needed to address all possible use case (e.g., perhaps built in a modular fashion). Depending on the exact Flood-MAR strategies evaluated, it would presumably require interconnected inputs and outputs across hydrology, reservoir, infrastructure, crop, soil/geology/aquifer, land use, and water quality. This would be integrated to understand resulting Flood-MAR hydrological benefits, combined with a detailed multi-benefit analysis that also covers environment, people, and economics. It would also need to consider human system issues,

including policies and legal constraints, which likely would constrain where and when actual Flood-MAR projects could be implemented.

**Lead and Partners:** A group of scientist, practitioners and Flood-MAR decision-makers will build a Flood-MAR tool to ensure it significantly increases current ability to evaluate Flood-MAR projects at the appropriate spatial and temporal scales. Subcommittee members, plus others who may be interested, would need to coordinate with other Flood-MAR subcommittees to integrate the inputs/outputs and build the tool.

**Estimated Timeline:** The actual tool design process can begin immediately, once appropriate Flood-MAR strategies (e.g., on-farm, floodplain, watershed Flood-MAR) are prioritized and a local pilot area is selected. It is believed the first prototype tool can be completed in 12–18 months, with the bulk of this initial time dedicated to defining user requirements with end-users, coordinating with other Flood-MAR subcommittees, and gathering needed datasets at appropriate spatial/temporal scale. Given that other RD&Ts from other subcommittees may take longer than this 18-month period, there is a need to coordinate on simplifying assumptions that will enable the first prototype tool to be built in an agile fashion (ensuring new data and research can be added later, as available).

**Draft Cost Estimate (Breakdown):** Without working on a detailed breakdown of tasks, it is only possible to provide an estimate for a potential integrated Flood-MAR decision support tools. An approximate estimate for the integrated pilot tool creation likely is in the range of \$750,000–\$950,000 (one project coordinator, two senior scientists, one web developer, plus traveling and workshops meetings) for three essential tasks: design, development, and coordination. The estimated budget is roughly split among these three essential tasks:

1. Tool design to work with potential users, including decision-makers to create a user specification (approximately 25 percent of time).
2. Software coding, tool development, and QA/QC (approximately 50 percent of time).
3. Time required to coordinate the integration of cost and benefit inputs/outputs and data aggregation across other Flood-MAR subcommittees (approximately 25 percent of time).

**Cost Estimate: \$950,000**