Appendix 1

Hydrology Observation and Prediction

Contents

Hydrology Observation and Prediction

Theme Subcommittee Members

The Flood-MAR Hydrology Observation and Prediction Subcommittee consists of two co-chairs, eight subcommittee members, and a theme coordinator; subcommittee individuals are listed by name below.

Position	Name and Title	Affiliation	Email
State Co-Chair	Michael Anderson, State Climatologist	California Department of Water Resources	Michael.L.Anderson@water.ca.gov
Non-State Co-Chair	Lorraine Flint, Research Hydrologist	USGS	lflint@usgs.gov
Sub-Committee Member	Michael Dettinger	USGS	mddettin@usgs.gov
Sub-Committee Member	Ben Hatchett, Postdoctoral Fellow Meteorology, Research Hydrologist	Western Regional Climate Center	Benjamin.Hatchett@dri.edu
Sub-Committee Member	Stephanie Granger, Research Scientist	NASA/Caltech JPL	Stephanie.L.Granger@jpl.nasa.gov
Sub-Committee Member	Scott Steinschneider, Assistant Professor	Cornell University	ss3378@cornell.edu
Sub-Committee Member	Ate Visser, Research Scientist - Noble Gas and Isotope Hydrology	Lawrence Livermore National Laboratory	visser3@llnl.gov
Sub-Committee	Laura Foglia, Assistant Adjuct	UC Davis	lfoglia@ucdavis.edu

Position	Name and Title	Affiliation	Email
Member	Professor		
Sub-Committee Member	David Curtis, Vice President	West Consultants	dcurtis@westconsultants.com
Theme Coordinator	Wyatt Arnold, Water Resources Engineer	California Department of Water Resources	wyatt.arnold@water.ca.gov

Engagement Process

The State and non-State co-chairs were proposed by the California Department of Water Resources (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 organizations. In collaboration with the DWR Flood-MAR team, the co-chairs identified a list of potential members to integrate the subcommittee. The identified candidates are experts, practitioners, and researchers with experience and expertise in climate, weather prediction and observation, and groundwater. The final list of members who accepted to participate in the theme as subcommittee members are listed above. The State and non-State co-chairs engaged subcommittee members via two email surveys to (1) collect a list of all tools, research, and data (including a list of potential gaps, which, if filled, could speed and enhance implementation of flood-event focused managed aquifer recharge projects), and (2) illicit a recommended prioritization of which gaps should be filled first. Follow-up discussion was carried out via written communication.

Available Research, Data, and Tools

Name: Sub-Seasonal to Seasonal Prediction Project Database

Website: https://www.ecmwf.int/en/research/projects/s2s

Description: The subseasonal-to-seasonal (S2S) prediction project database provides a state-of-the-art, multi-model ensemble of reforecasts that provides forecast data in six-hour increments (covering the last two to three decades) and was recently made available through a new World Weather Research Programme/World Climate Research Programme initiative on S2S prediction. An archive of S2S reforecasts is available from 11 operational ensemble prediction systems. This archive is modeled on The Observing System Research and Predictability Experiment (THORPEX) Interactive Grand Global Ensemble (TIGGE) database for extended-range forecasts. Although the TIGGE reforecasts begin in 2006, models in the S2S database have a range of earlier reforecast start dates, with the earliest beginning in 1981, the latest in 1999, and the majority before 1995. The models in the archive with earlier start dates tend to have less-frequent reforecasts, ranging from daily to bimonthly, and different spatial resolutions. Recently, this database has been used to assess short-to-medium range forecasts of atmospheric rivers across the West coast and globally (https://link.springer.com/article/10.1007/s00382-018-4309-x).

This database can be used to retrospectively test forecast-informed reservoir operations used to support managed aquifer recharge (MAR), while also reducing flood risk, improving drought preparedness, and generally improving all services provided by major multi-purpose reservoirs in California.

Name: The National Water Model

Website: http://water.noaa.gov/about/nwm

Description: The national water model (NWM) is a hydrologic model that simulates observed and forecast streamflow over the entire continental U.S. (conus). The NWM complements current hydrologic modeling in a simplified manner for approximately 4,000 locations across the conus by providing information at a very fine spatial and temporal scale at those locations, as well as for locations that do not have a traditional river forecast. The core of this system is the national center for atmospheric research-supported community weather research and forecasting hydrologic model (WRF-hydro). It ingests forcing from a variety of sources including multi-radar/multi-sensor system radar-gauge observed precipitation data, and high-resolution rapid refresh, rapid refresh, global forecasting system (GFS) and climate forecast system numerical weather prediction forecast data. WRF-hydro is configured to use the NOAH-Multiparameterization (NOAH-MP) land surface model (LSM) to simulate land surface processes.

The model runs an hourly uncoupled analysis (simulation of current conditions). Short-range forecasts are executed hourly while medium-range forecasts out to 10 days are produced four times per day. A daily ensemble long range forecast to 30 days is also produced. All model configurations provide streamflow for 2.7 million river reaches and other hydrologic information on 1-kilometer (km) and 250-meter (m) grids. This tool can provide highresolution forecasts of streamflow that could be used by reservoir operators in new release policies that support managed aquifer recharge, while also reducing flood risk, improving drought preparedness, and generally improving all services provided by major multi-purpose reservoirs in California.

Name: Other Surface Hydrology Models for the Sierra Nevada and Central Valley

Website: http://uncglobalhydrology.org/research/

https://blogs.umass.edu/hydrosystems/

Description: Besides the National Water Model described above, a suite of other hydrologic models exist that are capable of ingesting short-, medium-, and long-range forecasts of climate to produce forecasts of streamflow for key reservoir inflow points across the California water system. Calibrated models that are readily available include a distribution version of the Sacramento Soil Moisture Accounting (SAC-SMA) model coupled with the snow17 model, a distribution version of the HYMOD rainfall-runoff model, and VIC. These models were all calibrated by researchers at the University of Massachusetts Amherst and are designed to produce daily streamflow estimates into nine major reservoirs across the Sacramento-San Joaquin River Basin. The hydrologic models have been coupled with the Cal-Sim model of reservoirs throughout the state.

In addition, as part of a recent NSF INFEWS project, the WFR model has been coupled with the NOAH LSM for hydrologic simulations in the Sierra

Nevada. The model has been calibrated specifically to produce realistic streamflows into major reservoirs throughout the Sacramento-san Joaquin basin. The output from this model is currently being integrated into a separate systems model of conveyance and storage for the California Water system, also developed under the aforementioned INFEWS project. These Tools can provide forecasts of streamflow that could be used by reservoir operators in new release policies that support managed aquifer recharge, while also reducing flood risk, improving drought preparedness, and generally improving all services provided by major multi-purpose reservoirs in California.

Wrzesien ML, Durand MT, Pavelsky TM, Kapnick SB, Zhang Y, Guo J, and Shum CK. (2018a). A new estimate of North American mountain snow accumulation from regional climate model simulations. Geophysical Research Letters, 45, 1423–1432. https://doi.org/10.1002/2017GL076664

Wrzesien ML, Durand MT, Pavelsky TM, Kapnick SB, Zhang Y, Guo J, and Shum CK. (2018b). Comparison of Methods to Estimate Snow Water Equivalent at the Mountain Range Scale: A Case Study of the California Sierra Nevada. https://journals.ametsoc.org/doi/pdf/10.1175/JHM-D-16-0246.1

Schwarz, Andrew, Patrick Ray, Sungwook Wi, Casey Brown, Minxue He, Matthew Correa. (California Department of Water Resources). 2018. Climate Change Risks Faced by the California Central Valley Water Resource System. California's Fourth Climate Change Assessment. Publication number: CCCA4-EXT-2018-001. https://www.energy.ca.gov/sites/default/files/2019-12/Water_CCCA4-EXT-2018-001_ada.pdf

Name: Central Valley Hydrologic Model (CVHM)

Website: https://ca.water.usgs.gov/projects/central-valley/central-valley-hydrologic-model.html

Description: The U.S. Geological Survey (USGS) has developed a hydrologic modeling tool — the Central Valley Hydrologic Model (CVHM), an extensive, detailed three-dimensional (3D) computer model of the hydrologic system of the Central Valley. The CVHM simultaneously accounts for changing water supply and demand across the landscape and simulates surface water and groundwater flow across the entire Central Valley. The complex hydrologic system of the Central Valley is simulated using the USGS hydrologic modeling software, MODFLOW. MODFLOW simulates natural and human-induced water movement and consumption over the landscape and accounts for supply-constrained and demand-driven conjunctive use of surface and groundwater in agricultural, urban, and natural settings. It is combined with the MODFLOW farm process (FMP), which models the processes of evaporation, transpiration, runoff, and deep percolation to groundwater. The FMP allocates water, simulates or approximates processes, and computes mass balances for defined subregions of the model domain; in the CVHM, these subregions, or "farms," are defined as the water balance subregions.

The CVHM helps to address water competition issues such as conjunctive water use (interdependent use of surface water and groundwater), conservation of agricultural land, land-use change (including environmental concerns and urbanization), its effects on water resources, and the effects of climate change. It could be of direct utility for Flood-MAR, to better determine how proposed strategies of MAR in different locations across the state would impact aquifer recovery and groundwater availability.

Name: Parameter-elevation Regressions on Independent Slopes Model (PRISM)

Website: http://prism.nacse.org/

Description: The Parameter-elevation Regressions on Independent Slopes Model (PRISM) Climate Group gathers climate observations from a wide range of monitoring networks, applies sophisticated quality-control measures, and develops spatial climate datasets to reveal short- and long-term climate patterns. The resulting datasets incorporate a variety of modeling techniques and are available at multiple spatial/temporal resolutions, covering the period from 1895 to the present. Whenever possible, the Northwest Alliance for Computational Science & Engineering offers these datasets to the public, either free of charge or for a fee (depending on dataset size/complexity and funding available for the activity).

Accurate nowcasting or hindcasting of precipitation is crucial for planning.

Name: California Open Data Portal

Website: https://data.cnra.ca.gov/

Description: Portal for water data in California, combines sources of data. Groundwater-level data are important to evaluate to determine which areas can receive Flood-MAR water.

Name: NASA Airborne Snow Observatory

Website: https://aso.jpl.nasa.gov/

Description: Detailed snow coverage data from airborne remote sensing Provides input for most accurate snow pack estimates.

Name: Nation Weather Service California Nevada RFC Forecast Points

Website: https://www.cnrfc.noaa.gov/

Description: The National Weather Service (NWS) California Nevada River Forecast Center Forecasts can inform decision-making for water management operations. Forecasts are prepared by experienced staff with knowledge of the area and historical forecast model performance/reliability. Their forecasts are best suited to inform forecast in the window of 0-5 days. Any increase in the accuracy and reliability of this product would greatly benefit Flood-MAR by reducing uncertainty and encouraging water managers to utilize forecast informed operations. Accuracy in runoff predictions would be greatly improved with increased precipitation accuracy, in particular, for atmospheric river events. Forecast currently have accuracy in the total volume of an event but lack the accuracy in the spatial/temporal distribution of the rainfall. Improved instrumentation/monitoring for precipitation and snowpack in the upper Sierra Nevada would help improve forecast model performance.

Name: Water Supply Forecasts

Website: https://www.cnrfc.noaa.gov/
http://cdec.water.ca.gov/

Description: The DWR California Cooperative Snow Surveys water supply index (WSI) forecasts can be used to inform longer-term reservoir operations (i.e., monthly reservoir levels). Experienced staff with knowledge of the area and historical reliability would be to develop these forecasts. Weekly updates to this product could be of use; this could be implemented by incorporating additional remote sensors (SNOTEL sites) or satellite data. Utilizing the efforts of field crews after snowfall events would also help.

A more promising product is the NWS ensemble river forecasts, which provide a spectrum of forecasts out to 300 days or more. In the short-term, (i.e., 0-14 days), the ensemble forecasts are forced by a combination of observations and weather model outputs. Longer-term forecasts are forced by observed hydrometeorological records covering the past 60 years or so.

Name: National Water Model

Website: http://water.noaa.gov/about/nwm

Description: The National Water Model (NWM) is new and unproven but shows some promise as a developing tool. The main advantage is that all rivers and streams will be forecasted. This may be suitable for rivers without a current NWS river forecast point. One major drawback of NWM is the lack of representation for reservoir operations.

Still, the NWM is worth investigating to determine what NWM product components do have value. For example, modeled soil moisture may help inform some water management decisions.

Name: Atmospheric River Forecast Products

Website: http://cw3e.ucsd.edu/iwv-and-ivt-forecasts/

Description: Atmospheric river forecast products available from the Center for Western Weather and Water Extremes (CW3E) at the Scripps Institution of Oceanography University of California, San Diego provide excellent forecast information. The products leverage data from the National Centers for Environmental Prediction GFS, North American Mesoscale Forecast System, and Global Ensemble Forecast System (GEFS) models. The GEFS products are produced by Dr. Jason Cordeira at Plymouth State University as a cooperative effort with the CW3E.

Name: Moderate Resolution Infrared Spectrometer (MODIS) Global Evapotranspiration Project

Website: http://www.ntsg.umt.edu/project/modis/mod16.php

Description: This effort involves estimating global terrestrial evapotranspiration from earth land surface by using satellite remote sensing data.Areas of high evaporation and low permeability may not be suitable.

Name: Gravity Recovery and Climate Experiment (GRACE)

Website: https://www.nasa.gov/mission_pages/Grace/index.html

Description: The Gravity Recovery and Climate Experiment (GRACE) measures gravity anomalies to determine groundwater levels on a large scale. GRACE is able to identify areas suitable for recharge.

Name: North American Land Data Assimilation System (NLDAS) and Remote Sensing Soil Moisture Data

Website: https://ldas.gsfc.nasa.gov/nldas/NLDAS2forcing.php

Description: This system determines soil moisture content by continental scale modeling and remote sensing via satellite.

Name: Airborne Snow Observatory

Website: https://aso.jpl.nasa.gov

Description: According to the San Joaquin River Restoration Program, more than two-thirds of the San Joaquin River runoff originates from snowpack. As such, accurately estimating how much runoff will result from the watershed's snowpack is critical to understanding runoff supply into reservoirs. The existing snow course and snow station network is limited by high-elevation topography, accessibility, maintenance challenges, and a changing climate.

The Airborne Snow Observatory (ASO) provides watershed-wide, high-resolution information within two to three days of survey.

ASO consists of two sensors — a light imaging detecting and ranging instrument that measures the surface elevation of snow and a hyperspectral instrument that measures snow reflectance. Using snowpack modeling, the airborne sensor data are fused with simulated snow density data provided by the U.S. Department of Agriculture and guided by ground-based observations to derive snow water equivalent (SWE). The ASO can survey an entire watershed in a single day and produce high-resolution maps of snow extent, depth, and SWE within one to three days following the flights for near real-time assessments and decision-making. In addition, estimates of snow albedo (reflectance) tracked by the hyperspectral sensor can be used to help predict snow melt and runoff timing. These data can be further subdivided by elevation band or subbasin for managing smaller reservoirs throughout the basin.

Name: Open Evapotranspiration (OpenET)

Website: https://etdata.org

Description: The Open evapotranspiration (OpenET) project is a trans-disciplinary partnership that includes national and international experts in remote sensing of evapotranspiration (ET) information technology, water policy, and water markets, and partners from agriculture and water resource management communities in the western U.S.

The project aims to provide open and easily accessible ET data at user-defined scales and timeframes for improved water management including several areas relevant to Flood-MAR, notably water trading programs, irrigation management, and sustainable groundwater management. Data from multiple satellites are used with an ensemble of trusted methods to calculate ET development of the OpenET platform is supported by the S.D. Bechtel, Jr. Foundation, the Gordon and Betty Moore Foundation, the Walton Family Foundation, the Windward Fund, and the NASA Applied Science Program. Google Earth Engine, the Water Funder Initiative and partners in the agricultural and water management communities provide in-kind support.

Estimates of evaporation and ET are derived from MODIS, VIIRS (Visible Infrared Radiometer Suite), Ecostress, and Landsat.

Name: Runoff and Water Elevation: Surface Water Ocean Topography (SWOT) Mission

Website: https://www.jpl.nasa.gov/missions/gravity-recovery-and-climate-experiment-grace/

Description: The Surface Water and Ocean Topography (SWOT) mission, expected to launch in 2021, will be NASA's first global survey of Earth's surface water. The SWOT mission will measure the width, height, and slope of water in major lakes, rivers, and wetlands, as well as river discharge at higher spatial resolution than currently possible from a space-based mission. The suite of sensors will measure water height to 1 centimeter (cm) with a spatial resolution of 10–100 m every 20 days. Because of spatiotemporal gaps of direct observations from SWOT (submonthly), the ability of SWOT land measurements to directly contribute to our understanding of terrestrial hydrology and of the climate system will likely be demonstrated through its integration within models. There are discussions underway for near real-time (estimated two to three days) data access for flood mapping and forecasting applications as well as lake and reservoir water height.

Name: Snow: Moderate Resolution Infrared Spectrometer (MODIS)

Website: https://snow.jpl.nasa.gov/portal/data/help_modscag

Description: MODIS provide national daily coverage of snow extent and albedo at no cost to users. The MODIS-derived MODIS snow-covered area and grain size (MODSCAGS) product is currently used by the Colorado Basin River Forecast Center for tuning some forecasts. MODIS products cannot detect snow water equivalent (though algorithms exist to derive SWE), and data availability may be limited by cloud cover. Available at 500-meter spatial resolution in GeoTIFF format.

Name: Soil Moisture Active Passive (SMAP) Mission

Website: https://smap.jpl.nasa.gov

Description: Soil moisture information could contribute significantly to elements in the water cycle, including runoff projections, and is a critical variable for estimating potential for flooding, both of which are directly relevant to Flood-MAR. Remotely sensed soil moisture from NASA's Soil Moisture Active Passive (SMAP) mission can provide homogenous quality of observations of surface soil moisture (approximately 2 inches depth) over large regions. These data can complement existing ground-based measurements that may be sparse and lack consistent measurement standards between the newer and older sensors. The SMAP mission launched January 31, 2015. It has an eight-day repeat cycle (with three days or less revisit interval, if ascending and descending are merged then the revisit interval becomes 1.5 days or less depending upon the latitude) and provides estimates of high-accuracy soil moisture at approximately 5 cm depth and approximately 33 km spatial resolution (gridded at 9 km). SMAP mission also make available a very high-resolution (1 km and 3 km) soil moisture with a revisit interval of 6–12 days. All SMAP data are archived at the NASA DAAC National Snow and Ice Data Center (NSIDC) and are freely available.

Name: Terrestrial Water Storage Change: Gravity Recovery And Climate Experiment (GRACE) And Grace Follow-On (GRACE-FO)

Website: https://www.jpl.nasa.gov/missions/gravity-recovery-and-climate-experiment-grace/

Description: The Gravity Recovery and Climate Experiment (GRACE) mission produces a Terrestrial Water Storage Anomaly (TWSA) data set, that monitors changes in the integrated water stored in snow, surface, and below-ground variables at an approximately 1 arc degree/monthly resolution. These data are the only means to directly measure changes in groundwater volume from space. By comparing time-variable data to a long-term average, anomaly maps can be generated to see where groundwater storage has been depleted or increased. Additionally, water storage data from GRACE can be used to complement in situ observations to identify and monitor regional trends in groundwater movement, to measure the severity of drought events, and to close regional water budgets.

GRACE ended its science mission in October 2017 after 15 years, and the GRACE-FO mission launched in 2018 to extend the GRACE measurements into the next decade.

The National Academies identified mass change (similar to GRACE) as a high-priority observable for NASA in its 2017 Decadal Survey Report, thus ensuring long-term measurements into the future.

Name: Western Land Data Assimilation System

Website: https://ldas.gsfc.nasa.gov/index.php

Description: The Western Land Data Assimilation System (WLDAS) is a NASA-developed integrated modeling framework that includes several land surface models (NOAH-MP, CSM, VIC) and multivariate data assimilation capability that allows for the assimilation of a number of remotely sensed and other datasets. The framework is optimized for the western U.S. and provides near real-time simulations that address a number of Flood-MAR relevant hydrologic variables including snow water equivalent, soil moisture, groundwater anomalies, soil temperature, at 1km resolution. The primary purpose of the system for Flood-MAR implementation would be to support daily observations of hydrologic conditions based on satellite observations at regional scales. In addition, the a 38-year reanalysis at 1km, daily resolution is available to support retrospective analyses.

Name: WaterTrek/Western States Water Mission (WSWM)

Website: N/A

Description: WaterTrek is a system of interactive hydrologic web-based data tools to support the needs of research, data applications, and informed decision-making for water resources in the western U.S. Innovative architecture, the leveraging of existing software, and the new development of computationally intensive science data visualization and analytics tools has resulted in quick-query (subsecond) data access capabilities. These breakthroughs have provided the means to serve trusted data — including estimates and uncertainties — for high-resolution hydrologic quantities of interest such as snow-water equivalent, stream flow, and groundwater. Scientists at the Jet Propulsion Laboratory are now using the working prototype for research, and currently loaded data sets include instances of high-resolution VIC model outputs, ASO snow data, GRACE observations, river streamflow simulations, and in situ soil moisture, and snow and stream gage data sets.

Name: Experimental Short-Term Forecasting of Atmospheric Rivers

Website: N/A

Description: Atmospheric rivers (ARs) are a global occurrence that can have a profound impact on local climate and water extremes including floods. In the western U.S., atmospheric rivers account for nearly 50 percent of precipitation With funding from DWR, a team of researchers at NASA-JPL, UCSD-Scripps, UCLA, and European Centre for Medium-Range Weather Forecasts (ECMWF) are working to improve the forecasts of ARs three or more weeks into the future with the goal of improving water resource management in Califonia. Thus far, in a global analysis, the team has demonstrated skill in AR prediction out three to four weeks.

The work is conducted using NASA remote sensing observations and a number of forecast models.

Name: Forecasting Ridging Events Relevant for Western US Water

Website: N/A

Description: Atmospheric ridging is a condition in which a high-pressure ridge can occur (and persist) in winter off the west coast of the United States. These ridge events divert rain-bearing systems away from California as was seen in 2013-2014 during the "Ridiculously Resilient Ridge" event that drove systems north and east of California, coinciding with a drought event in the state. With funding from the CADWR, a team of researchers at NASA-JPL, UCSD-Scripps, UCLA, and ECMWF are working to explore and quantify the skill of sub-seasonal to seasonal forecast skill of west coast ridging. Because ridging has longer space and time scales than storms, this suggests that they will be predictable further out in time. When they occur, they play a strong role in determining AR conditions, so predicting strong ridge occurrence or absence further out time, it may allow extending the predictability of ARs.

Gaps in Research, Data, and Tools Related to Flood-MAR

Table 1 Comprehensive Snowpack Monitoring (ASO + In Situ)

Category: Data, Tool

Scale: Regional

Availability: Gap

Other Themes That Will Benefit:

Source Water Availability; Reservoir Operations

Public Benefits Informed By:

Flood risk reduction, drought preparedness, aquifer replenishment, subsidence mitigation, climate change adaptation.

Description, including Connection to Flood-MAR:

The current snow-instrumentation network in the Sierra Nevada is designed mostly in support of warm-season water-supply forecasting. Even so, it is notable for its paucity of spatial coverage (mostly on meadows or flat spots, focused at accessible middle elevations, open cover). The ASO program is moving forward to fill in these spatial gaps, but remains focused almost entirely on the late-season support of warm-season water-supply forecasting. Given the important role that unseasonable or too-rapid snowmelt episodes play in flood generation and thus Flood-MAR prospects, extension of this modern capacity to include spatially comprehensive monitoring of snow water contents and snowpack losses prior to and after key storms during the winter season is needed in support of Flood-MAR hydrologic prediction. Additionally, the extension of the ongoing snowpack modeling effort by JPL that incorporates real-time MODIS observations should be extended to include the entire runoff domain above the Shasta Reservoir.

The State coordinates networks of snow instrumentation and measurements, and increasingly the ASO program, which provide valuable information regarding (mostly) springtime snowpacks and for warm-season water supply forecasts. One important gap between these two networks is monitoring that targets conditions associated with snowmelt-augmented flood risks. Filling this gap in the on-ground networks would require adjustments to address heat and water budgets of/within snowpacks that are most likely to support major flooding, especially in winter. An initial research phase will be needed to develop the measurement/monitoring strategies (including locations) best suited to provide forecast-supportive data for anticipating and characterizing rain-on-snow, rainfall-runoff-from snow, and other snow-centered flood generation processes and conditions. This research and the needed monitoring capacities should focus on characterization of energy budgets (cold balances) and liquid-water conditions/budgets within snowpacks, rather on the more traditional snowpack-total-water content focus.

Website:

Contact:

Email:

Table 2 Inter-model Comparison of Surface Hydrologic Models with Available Historical Precipitation Products

Category: Research, Data

Scale: State

Availability: Gap

Other Themes That Will Benefit:

Source Water Availability; Reservoir Operations

Public Benefits Informed By:

Flood risk reduction, drought preparedness, aquifer replenishment, subsidence mitigation, climate change adaptation.

Description:

Many of the surface hydrologic models have not been systematically compared to determine their relative strengths and weaknesses, including the ability to reproduce streamflow, snowpack, soil moisture, and other relevant hydrologic variables in the Sierra Nevada and across the Central Valley. Computational runtimes and ease of model use should also be assessed. Finally, there could be an exploration of whether model output could be combined to improve the quantification of uncertainty in hydrologic forecasts. Such an inter-model comparison would help determine which model(s) would best support other analyses linked to Flood-MAR, such as the testing of alternative reservoir operation strategies to improve MAR without increasing flood risk or degrading other reservoir services.

Driving hydrologic models with the suite of available historical precipitation reconstructions/reanalyses and examining the differences in results would help constrain model sensitivity to varying input data. How do models calibrated with one precipitation product perform if driven by another product? This would help create an envelope of potential outcomes for Flood-MAR projects. For example, how would the actual feasibility of a project change if this project was deemed unfeasible if driven by the driest precipitation estimate but feasible by the wettest estimate? A complete compilation of satellite and gauge-based data, products like PRISM or Livneh that use observations to produce spatially distributed output, and pure numerical model output (such as from weather model simulations) could be developed and used to examine hydrologic model sensitivity. A similar investigation could be performed for other input variables to the models if more than one dataset exists.

Website:

Contact:

Email:

Table 3 Spatially Distributed Soil Moisture Network for the Upper Watershed

Category: Data
Scale: Regional
Availability: Gap

Other Themes That Will Benefit:

Aquifer Characterization, Reservoir Operations

Public Benefits Informed By:

Improved flood forecasting, knowledge of potential for shallow landslides or other mass movements.

Description:

The development of a high-resolution spatially distributed soil moisture network would provide important information regarding antecedent conditions contributing runoff generation, drought monitoring, infiltration rates, and recharge potential. Real-time observations could be used to constrain watershed forecast modeling for springtime snowmelt. Initially, the network could be preferentially installed in regions that have been identified as highly suitable for Flood-MAR projects and used to develop and calibrate integrated groundwater models and to better understand processes driving gaining rivers under a variety of soil moisture conditions. A soil moisture network would also provide substantial improvements in the observation and understanding of natural hazards such as wildfire and mass movements, both of which subsequently impact runoff generation and potentially the feasibility of successfully implementing Flood-MAR projects.

Website:

Contact:
Email:

Table 4 Extensions of EFRP/HMT Storm Monitoring

Category: Research, Data
Scale: Regional
Availability: Gap

Other Themes That Will Benefit:

Source Water Availability; Reservoir Operations

Public Benefits Informed By:

Flood risk reduction, climate change adaptation.

Description:

The State (in cooperation with the National Oceanic and Atmospheric Administration [NOAA]) has installed a broad, modern-tech Enhanced Flood Response Preparedness (EFRP) and Hydrometeorology Testbed (HMT) monitoring network for determining atmospheric snow levels, atmospheric vapor transports, and atmospheric profiles (and, less so, soil moisture changes) during major storms. This network has the potential for supporting nowcasting (and limited-lead forecasting) of storm and flood conditions and is providing the basis for a more complete understanding of recent storms and their flood impacts that will ultimately support improved long-term storm and flood forecasts.

Website:

Contact:
Email:

Table 5 End-to-End Uncertainty Analysis of Short-to-Medium Range Hydrologic Forecasts

Category: Research

Scale: State

Availability: Gap

Other Themes That Will Benefit:

Source Water Availability; Reservoir Operations

Public Benefits Informed By:

Flood risk reduction, drought preparedness, aquifer replenishment, subsidence mitigation, climate change adaptation.

Description:

There is a gap in understanding of the true range of uncertainty in hydrologic forecasts at different lead times and under different hydrologic conditions. Uncertainty arises as a result of errors in the climate forecasts, the hydrologic model structure, its parameterization, and uncertainty in observations used to initialize the model. This uncertainty may differ depending on antecedent conditions or forecasted weather conditions (e.g., larger variance in predictions under wetter conditions). Forecast-informed reservoir operations that are designed to improve MAR need to be robust to total forecast uncertainty, so that new policies do not threaten current flood risk reduction services while trying to support new MAR objectives. Accordingly, there would be significant benefit in quantifying the end-to-end uncertainty in hydrologic forecasts at different lead times, so that the uncertainty could be taken into consideration when designing reservoir reoperation strategies to support MAR.

Website:

Contact:

Email:

Table 6 Augment CVFED Model for Flood-MAR Operational Modelling

Category: Data, Tool
Scale: Local
Availability: Gap

Other Themes That Will Benefit:

Public Benefits Informed By:

Flood risk reduction.

Description:

The Central Valley Floodplain Evaluation and Delineation Program (CVFED) provides hydrology and hydraulics support for preparation of the Central Valley Flood Protection Plan and feasibility studies associated with the existing State-federal protection system in the Central Valley. CVFED could be augmented with additional and higher quality floodplain delineation maps that would allow the model to be used for Flood-MAR operations and improve conveyance estimates.

Website:
Contact:
Email:

Table 7 Forecasts of Atmospheric Rivers Tailored for Reservoir Operations

Category: Research, Tool

Scale: Regional

Availability: Gap

Other Themes That Will Benefit:

Source Water Availability; Reservoir Operations

Public Benefits Informed By:

Flood risk reduction, drought preparedness, aquifer replenishment, subsidence mitigation, climate change adaptation.

Description:

Currently, the value of the full field of AR-related forecast information produced by model prediction systems for the reoperation of reservoirs at different lead times is unknown. This gap leads to the following suggestion: design studies to identify what AR-related forecast information is needed to support reservoir operations for MAR at different lead times and assess the skill of AR forecasts with respect to those measures in available forecasting products. Most forecast development and assessment frameworks choose performance measures a priori (e.g. the correct prediction of atmospheric river landfalls along different regions of the coast, the total precipitation delivered by these events, its spatial distribution, etc.). Biases in the forecast models may lead to degraded skill in some of these measures, particularly at medium-to-long lead times (4-14 days), which may be a critical timeframe to inform reservoir operations. However, from an operational perspective, it is possible that good decisions can be made even if some hydrologic measures of performance are poor. As an example, at a 7–10 day lead, it might be sufficient to know that a major AR is forecasted somewhere in the pacific basin, even if its landfall location is highly uncertain. The mere presence of a forecasted AR within “x” radius from a location of interest could be used by conservative water managers to trigger initial releases from a full reservoir. While this might lead to some lost water for MAR if the AR doesn’t make landfall, it could help hedge against significant, low-probability but high impact risks associated with major flooding. Given the conservative nature of water managers charged with flood risk reduction, such a strategy may be needed to facilitate reservoir reoperation to support Flood-MAR.

Website:

Contact:

Email:

Table 8 Regionally Compiled Agricultural-Fields Soil-Moisture and Deep-Percolation Monitoring for Reduction of Recharge Rate Uncertainties

Category: Data

Scale: Regional, Local

Availability: Gap

Other Themes That Will Benefit:

Public Benefits Informed By:

Description:

California's CIMIS system provides publicly available monitoring of Micromet and Penman-Monteith estimates of evaporative demands in a large number of agricultural areas but does not provide direct observations of soil moisture. With recent technological advances, soil moisture measurements have become more common in agricultural fields and in key infrastructures like levees and canal berms, but these data are not usually publicly available. Regional compilation (in real time) of observations of soil moisture status (or new observation sites) all along the major Flood-MAR corridors are going to be necessary as a basis for decisions regarding when and where to attempt inundation recharges. Flood-MAR may also want to consider "deep soil monitoring" that combines soil-moisture monitoring to greater than normal depths with deeper unsaturated/saturated zone multi-level monitoring wells/piezometers to allow more direct inferences of partitioning between deep percolation (recharge to water table) vs shallow percolation that ultimately is lost to evapotranspiration or seepage to stream channels and "return flows" that cannot be credited as Flood-MAR successes.

Website:

Contact:

Email:

Table 9 Understanding of Groundwater Surface Water Interactions

Category: Research, Data
Scale: Regional, Local
Availability: Gap

Other Themes That Will Benefit:

Public Benefits Informed By:

Description:

Flood-MAR water will alter the (dis)connection between groundwater and surface water. The efficiency of flood-MAR depends on return flows to surface water. While typically considered a loss when evaluating groundwater recharge, these could have great ecological benefits by sustaining flows in dry seasons. And implications for reservoir operation that could count return flows in lieu of environmental releases. This interaction is highly site specific, and depends on many factors (including geology, geomorphology, soils, vegetation, water levels, pumping).

Website:
Contact:
Email:

Table 10 Groundwater Recharge Rates Measurements to Inform Suitability Maps and Reduce their Uncertainty for Flood-MAR Site Selection

Category: Data
Scale: Regional, Tool
Availability: Gap

Other Themes That Will Benefit:

Public Benefits Informed By:

Description:

Flood-MAR suitability maps are excellent tools. The existing maps are based on a combination of soil, land use and geological maps and data, and combined to estimate potential recharge rates. Measurements of recharge rates are essential to inform where to apply Flood-MAR resources.

Website:
Contact:
Email:

Prioritization Process

The prioritization was completed by polling each subcommittee member's recommended order of priority. Gaps that were considered as fitting more neatly under a different research theme were prioritized lowest (e.g. groundwater recharge suitability mapping). Gaps were cross-referenced with Flood-MAR implementation factors to understand where a bottleneck in project implementation may occur if the gap was left unfilled. Other considerations included how 'project-ready' a gap was, how many available sources of funding could be identified, as well as recent and anticipated legislation that may act in support of a filling a gap (e.g. Airborne Snow Observatory).

Top Three Research, Data, and Tools Actions

Priority 1

Action: Comprehensive Snowpack Monitoring (ASO + In Situ)

Description and Connection to Flood-MAR: The current snow-instrumentation network in the Sierra Nevada is designed mostly in support of warm-season water-supply forecasting. Even so, it is notable for its paucity of spatial coverage (mostly on meadows or flat spots, focused at accessible middle elevations, open cover). The ASO program is moving forward to fill in these spatial gaps but remains focused almost entirely on the late-season support of warm-season water-supply forecasting. Given the important role that unseasonable or too-rapid snowmelt episodes play in flood generation and thus Flood-MAR prospects, extension of this modern capacity to include spatially comprehensive monitoring of snow water contents and snowpack losses prior to and after key storms during the winter season is needed in support of Flood-MAR hydrologic prediction. Additionally, the extension of the ongoing snowpack modeling effort by JPL that incorporates real time MODIS observations should be extended to include the entire runoff domain above the Shasta Reservoir.

The state coordinates networks of snow instrumentation and measurements, and increasingly the ASO program, which provide valuable information regarding (mostly) springtime snowpack and for warm-season water supply forecasts. One important gap between these two networks is monitoring that targets conditions associated with snowmelt-augmented flood risks. Filling this gap in the on-ground networks would require adjustments to address heat and water budgets of/within snowpack that are most likely to support major flooding, especially in winter. An initial research phase will be needed to develop the measurement/monitoring strategies (including locations) best suited to provide forecast-supportive data for anticipating and characterizing rain-on-snow, rainfall-runoff-from snow, and other snow-centered flood generation processes and conditions. This research and the needed monitoring capacities should focus on characterization of energy budgets (cold balances) and liquid-water conditions/budgets within snowpack, rather on the more traditional snowpack-total-water content focus.

Draft Strategy for Implementation

- Product: Augment ASO data product/services with spatially comprehensive monitoring of snow water contents and snowpack losses prior to and after large storms during the winter season. Project to determine concept of operations.
- Lead: California Co-op Snow Survey, DWR, and Forecast Coordinated Operations (FCO)
- Partners: CA Cooperators Snow Survey; water management agencies; ASO "Inc."
- Estimated Timeline: 3 years
- Note: $15M in funding moving through legislature for 10-year ASO operations authorization (Kern watershed through Upper Sacramento).

Draft Cost Estimate: $1M/year ($3M total)

Priority 2

Action: Inter-model Comparison of Surface Hydrologic Models with Available Historical Precipitation Products

Description and Connection to Flood-MAR: Many of the surface hydrologic models have not been systematically compared to determine their relative strengths and weaknesses, including the ability to reproduce streamflow, snowpack, soil moisture, and other relevant hydrologic variables in the Sierra Nevada and across the Central Valley. Computational runtimes and ease of model use should also be assessed. Finally, there could be an exploration of whether model output could be combined to improve the quantification of uncertainty in hydrologic forecasts. Such an inter-model comparison would help determine which model(s) would best support other analyses linked to Flood-MAR, such as the testing of alternative reservoir operation strategies to improve MAR without increasing flood risk or degrading other reservoir services.

Driving hydrologic models with the suite of available historical precipitation reconstructions/reanalyzes and examining the differences in results would help constrain model sensitivity to varying input data. How do models calibrated with one precipitation product perform if driven by another product? This would help create an envelope of potential outcomes for Flood-MAR projects. For example, how would the actual feasibility of a project change if this project was deemed unfeasible if driven by the driest precipitation estimate but feasible by the wettest estimate? A complete compilation of satellite and gauge-based data, products like prism or Livneh that use observations to produce spatially-distributed output, and pure numerical model output such as from weather model simulations could be developed and used to examine hydrologic model sensitivity. A similar investigation could be performed for other input variables to the models if more than one dataset exists.

Draft Strategy For Implementation

- Product: Monitoring network augmented to provide decision support.
- Lead: USGS and DWR Surface Observing Workgroup, Forecast Coordinated Operation (FCO)
- Partners: Local Cooperators
- Estimated Timeline: 3 year

Draft Cost Estimate: $2M for 3 years; ongoing O&M of $1M

Priority 3

Action: Spatially Distributed Soil Moisture Network for the Upper Watershed

Description and Connection to Flood-MAR: The development of a high-resolution spatially distributed soil moisture network would provide important information regarding antecedent conditions contributing runoff generation, drought monitoring, infiltration rates, and recharge potential. Real-time observations could be used to constrain watershed forecast modeling for spring time snowmelt. Initially, the network could be preferentially installed in regions that have been identified as highly suitable for Flood-MAR projects and used to develop and calibrate integrated groundwater models and to better understand processes driving gaining rivers under a variety of soil moisture conditions. A soil moisture network would also provide substantial improvements in the observation and understanding of natural hazards such as wildfire and mass movements, both of which subsequently impact runoff generation and potentially the feasibility of successfully implementing Flood-MAR projects.

Draft Strategy for Implementation

- Product: Report/research project
- Lead: [insert principle investigator]
- Partners: Federal agencies with operational models (USACE, USGS, NOAA, CNRFS) with associated institutional authors of respective precipitation dataset
- Estimated Timeline: 3 years

Draft Cost Estimate: $1M/yr ($3M total)