# Hydrologic Modeling Scientific Studies for Forecast Informed Reservoir Operation (FIRO)


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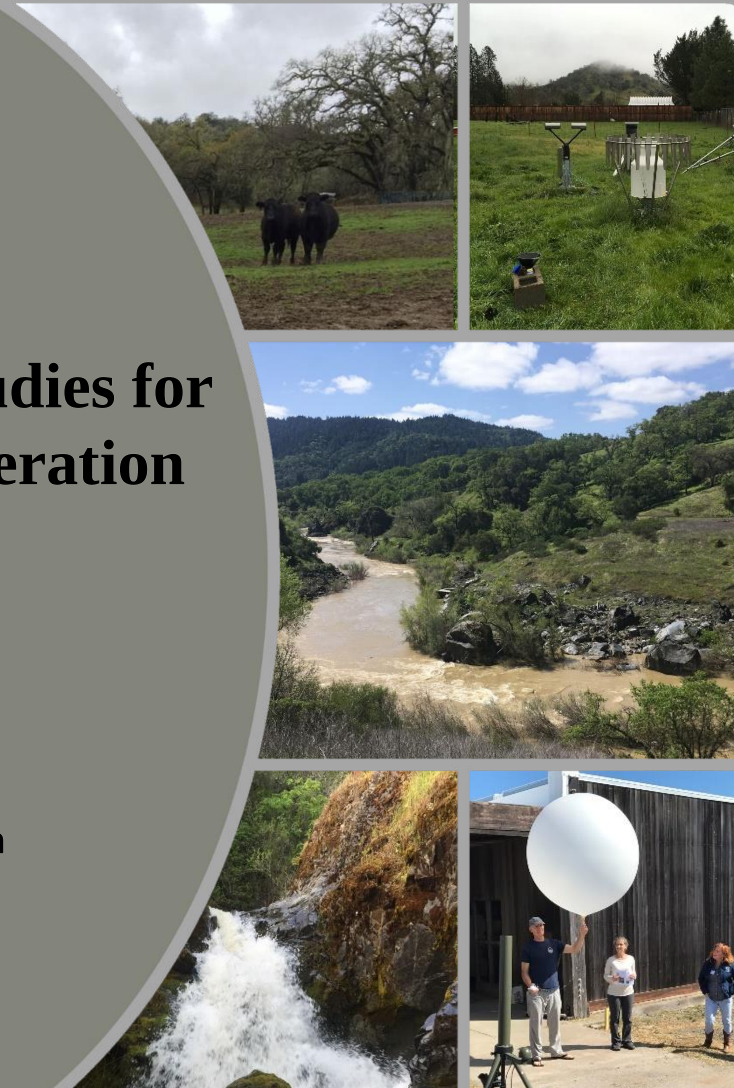

CW3E

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# Final Viability Question

- Can research into advanced forecasting tools produce improvements to rainfall, runoff, and reservoir forecast over existing methods currently in use?

# What We Are Doing

- Develop integrated physics based models in the upper Russian River.
- Couple the hydrologic models to West-WRF, and other rainfall forecast products.
- Simulate the runoff and reservoir response using observed and forecast precipitation.
- Field effort to collect additional model forcing and output calibration/verification data.
- Assess model outputs: flows, lake levels, soil moistures, in relation to observations and other model results.
- Incorporate the hydrologic model into the NCAR data assimilation framework.

# Desired Product

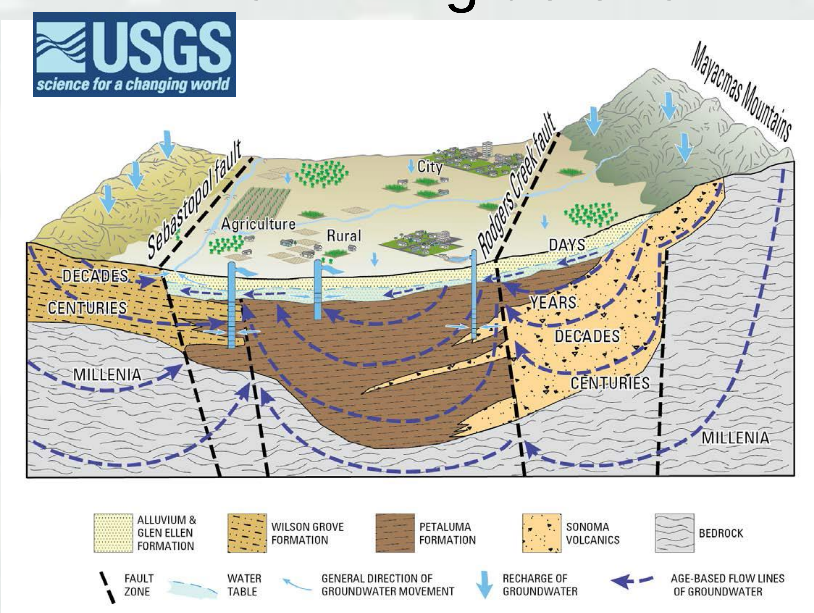
- Meteorological, hydrologic, and data assimilation system, developed and tuned to local conditions, that can provide short term hydrologic forecast that represent state-of-art capability in hydrologic forecasting for use in the FVA.

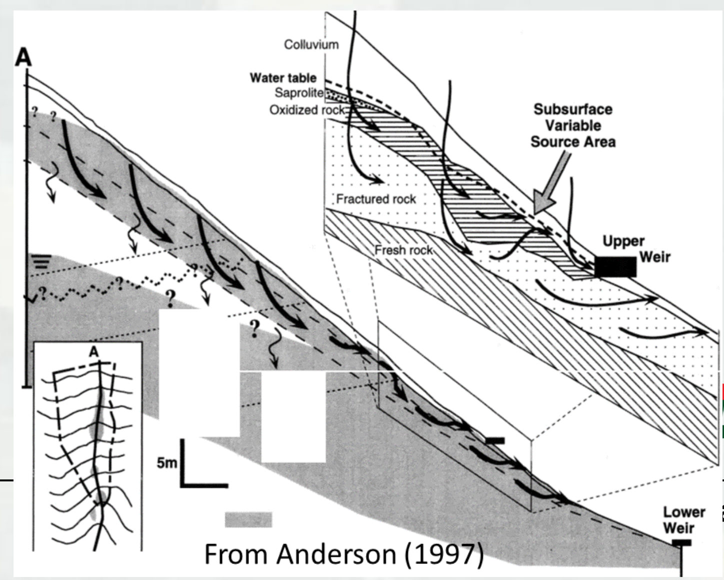
# Important Hydrologic Considerations

- Physical processes
- Model resolution
- Meteorological inputs
  - Observed verses forecast
  - Temporal/spatial resolution
- Calibration
- Data assimilation

# Technical Challenges in the Russian River Watershed

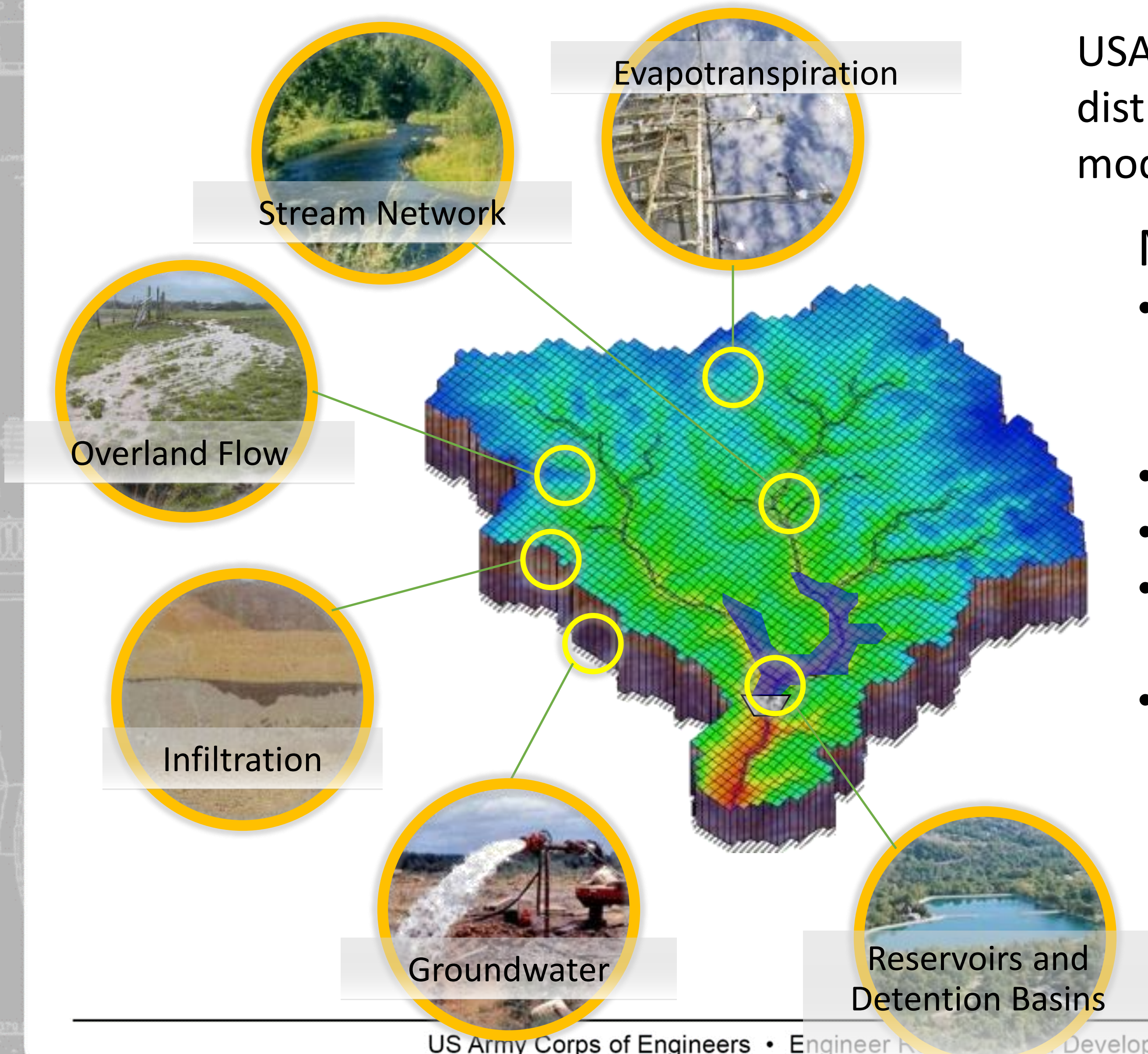
- Groundwater discharge to streams varies greatly within each event, with calculations showing:
  - first 4 hours 10% runoff,
  - 4 to 8 hours 10 to 30% runoff,
  - 8 to 12 hours 30 to 55% runoff,
  - beyond 12 hours of the storm with 55 to 75% runoff
- The flow component on these hillslopes is a combination of overland flow and groundwater flow intermixing as shown in the following figures:



From Anderson (1997)

# GSSHA Watershed Modeling in the Russian



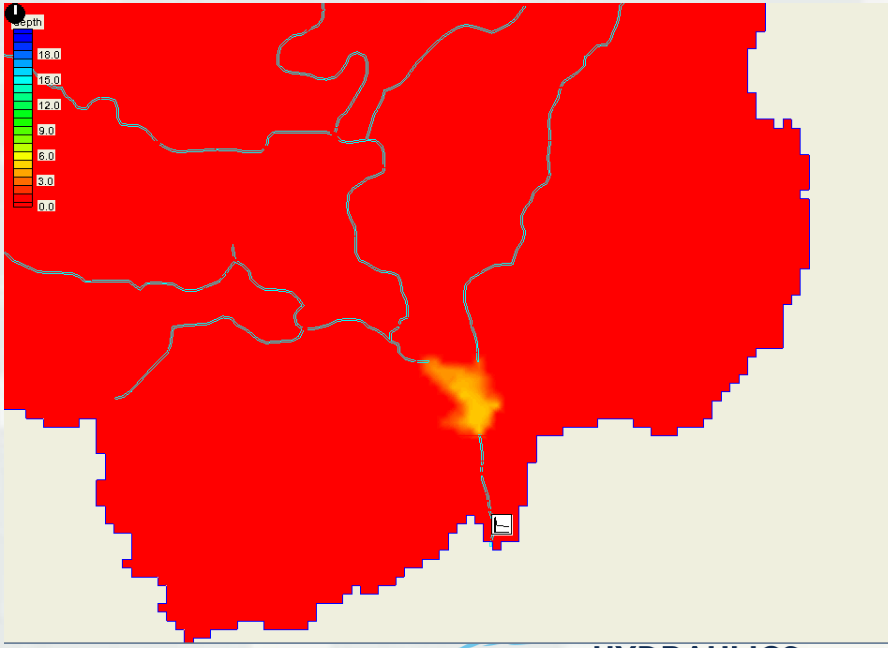

USACE physics based distributed watershed model

## Model Formulation:

- Multi layer infiltration, ET, and soil moisture accounting
- 2D overland flow
- 1D stream network
- Lake Mendocino Reservoir
- 2D groundwater with exchange between streams and reservoir.

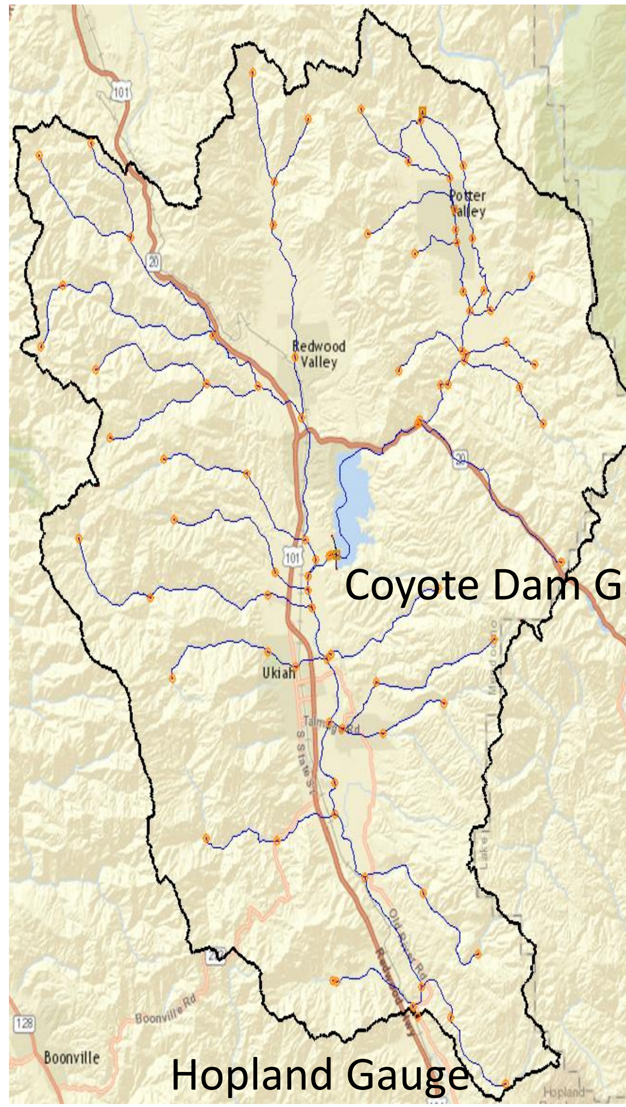
# Reservoir Simulations

- Reservoirs exist in both the 1D stream network and 2D overland.
- Reservoirs are dynamic (expand/contact in both domains)
- Exchange with overland, stream, groundwater, and atmosphere
- Stage, area, volume relationship from USACE SPN.
- USACE surveys, LIDAR measurements, and 10 DEM combined to define elevations within the lake.



# Effects of Model Resolution

Four models of varying resolution to study effects of model resolution on simulations.



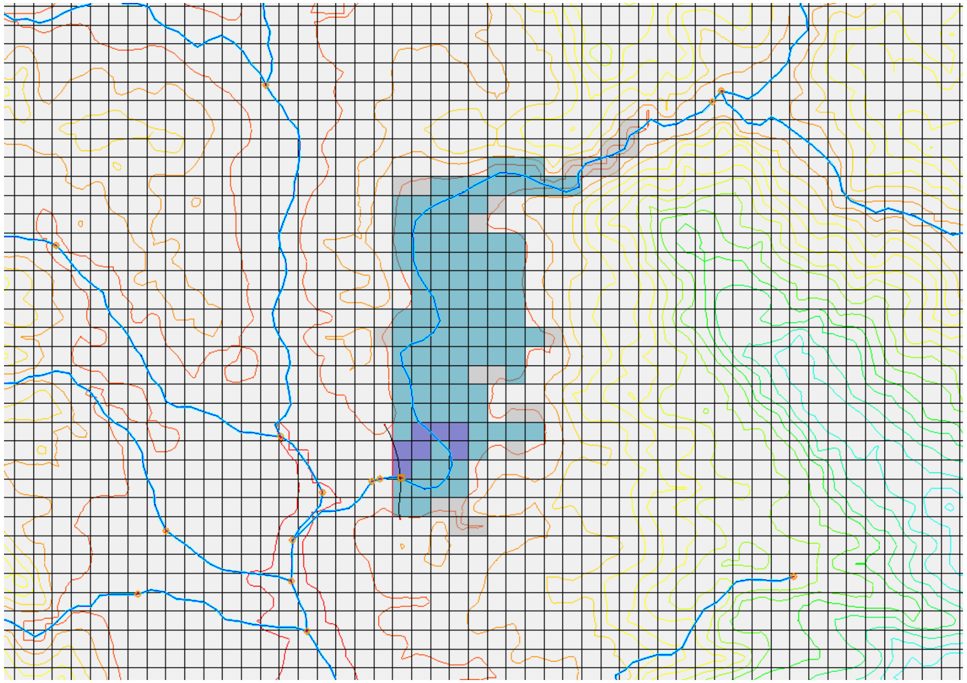

30m grid resolution for watershed above Coyote Dam

270m, 100m, 50m grid resolution in watershed down to Hopland, CA

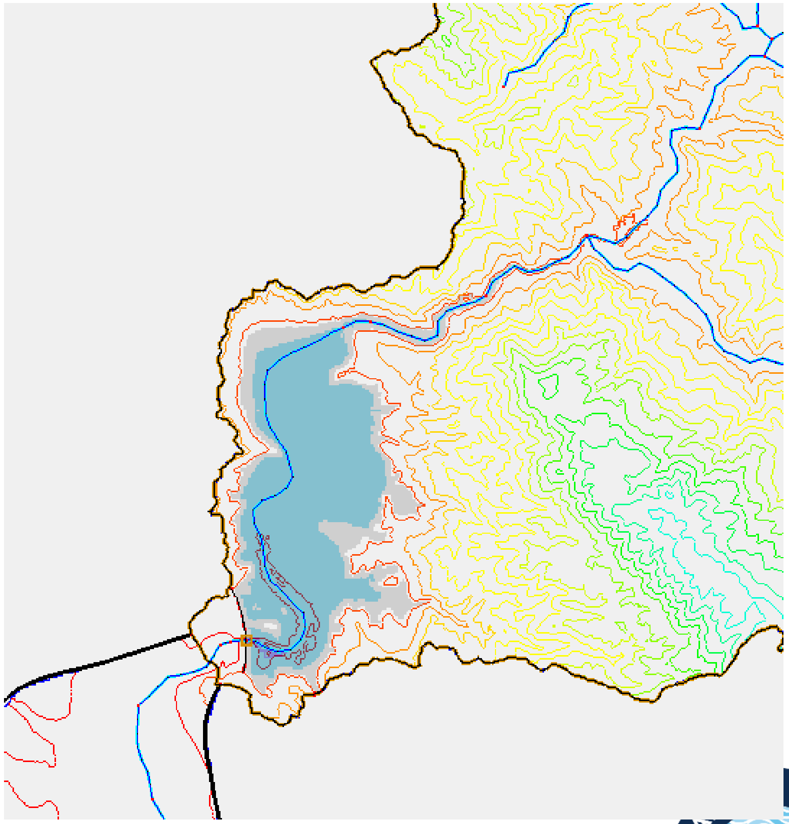
# Effect of Model Resolution

## Resolving Lake Footprint

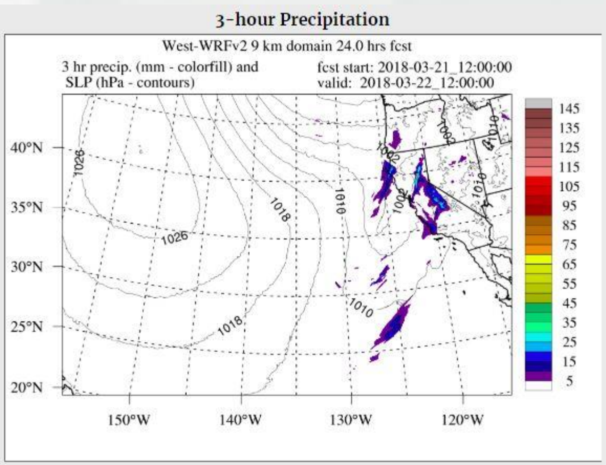
Lake Mendocino Resolved at 270m

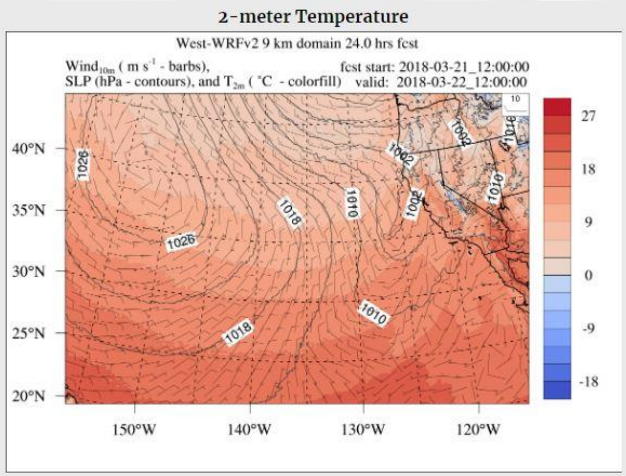


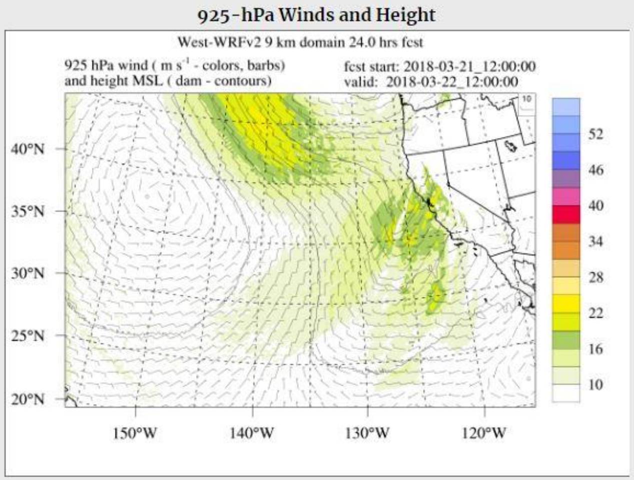
Lake Mendocino Resolved at 30m



# Coupling to Meteorological Forecast



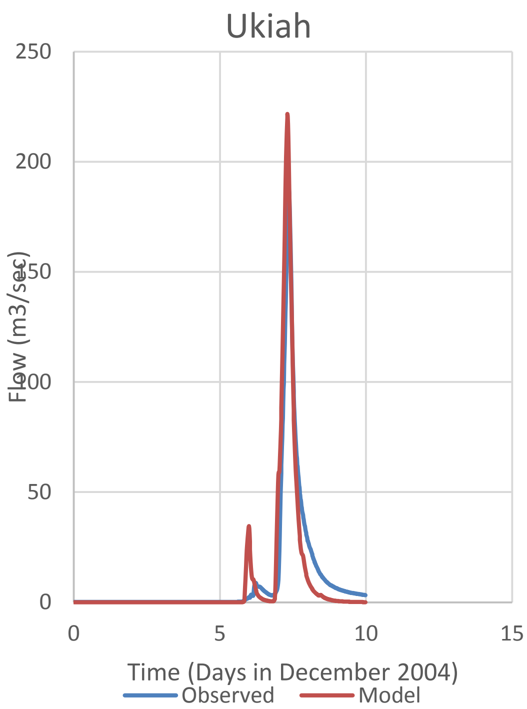



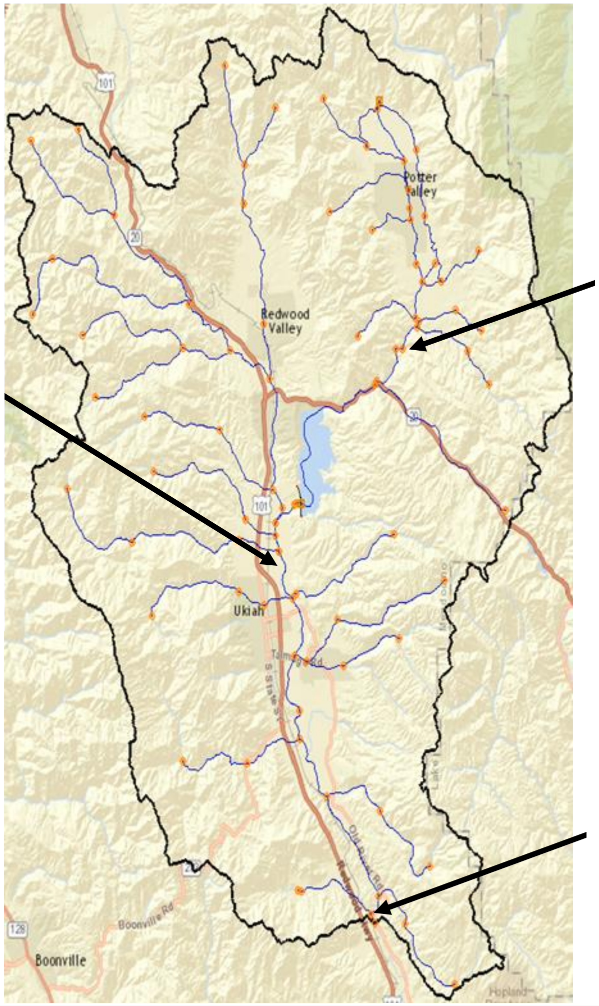

**GSSHAPY Python code inputs NetCDF files, outputs GSSHA input files.**

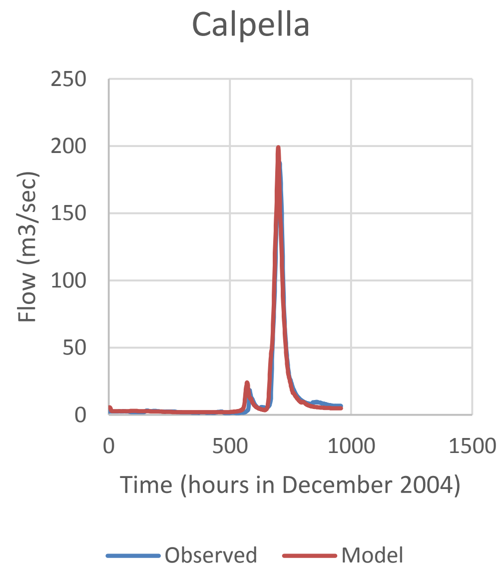
# Modeling/Calibration Strategy

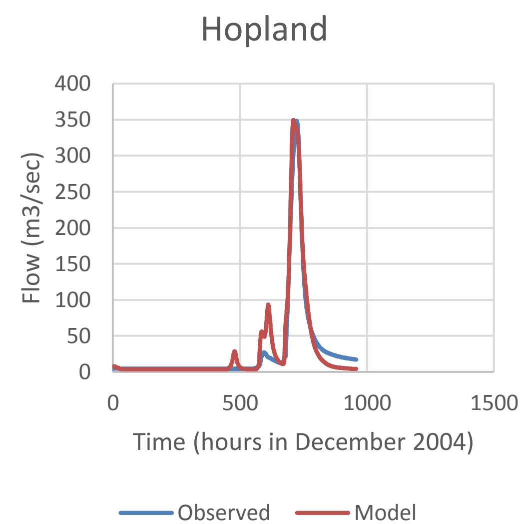
- Single event surface water parameter adjustments, observed data 2004.
- Seasonal surface/subsurface water parameter adjustment
  - “historic” rainfall data, 2004/2005.
  - expanded CW3E observed network, 2018.
- Seasonal calibration to WestWRF 3 day forecast, 2018.
- BeoPEST on the DoD Supercomputing Resource Centers (DSRCs) for the 270, 100, and 50m models.

# Surface Water Calibration



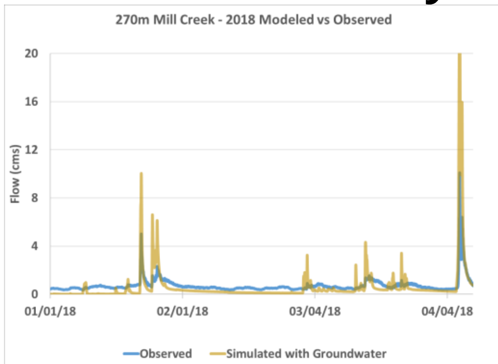



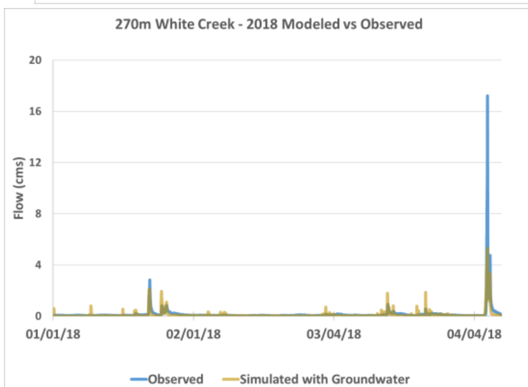



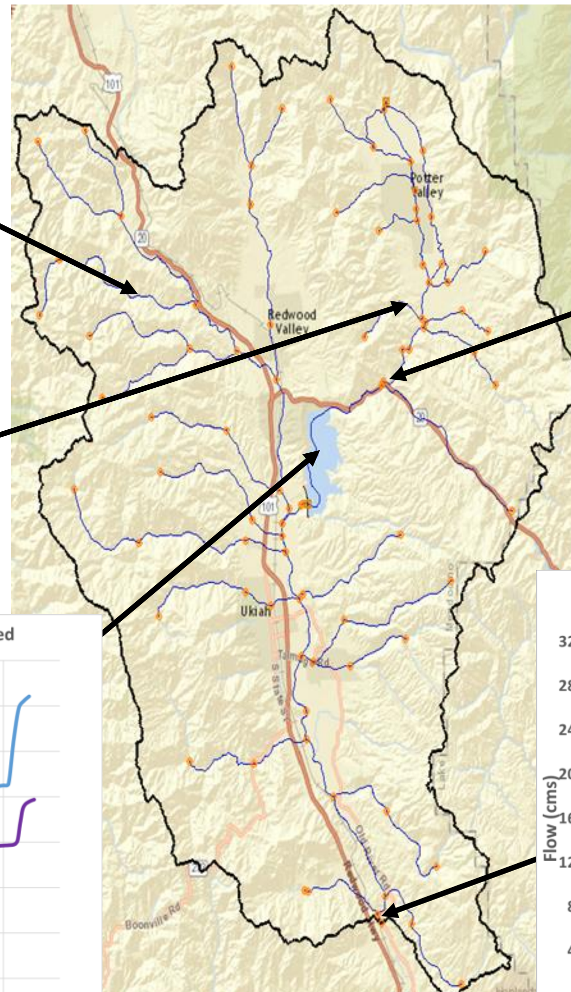



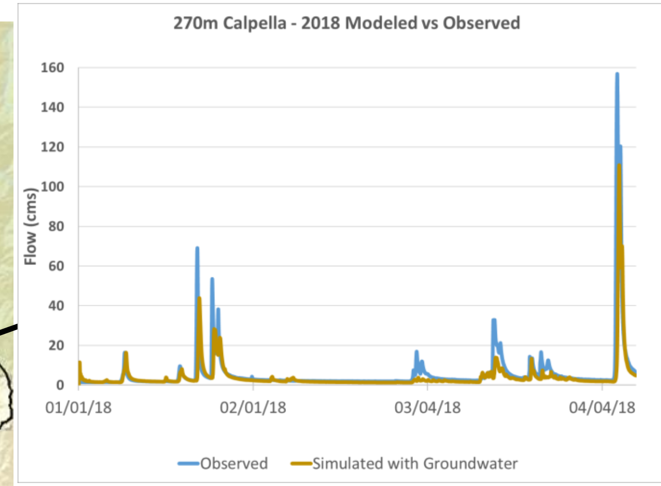
# Preliminary Verification with Surface Water/Groundwater

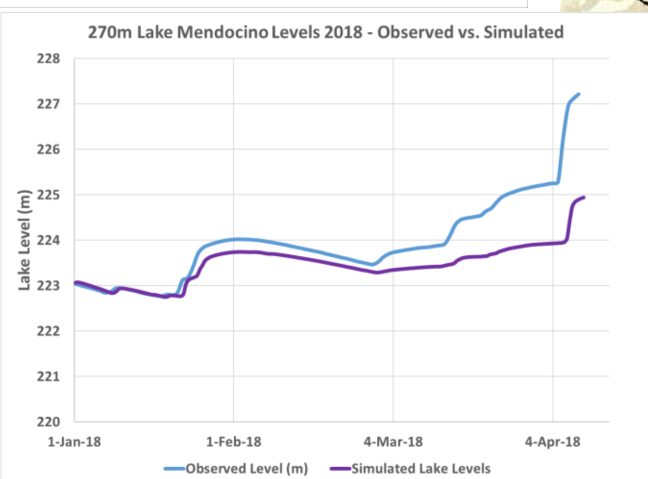
## 2017-2018 Period

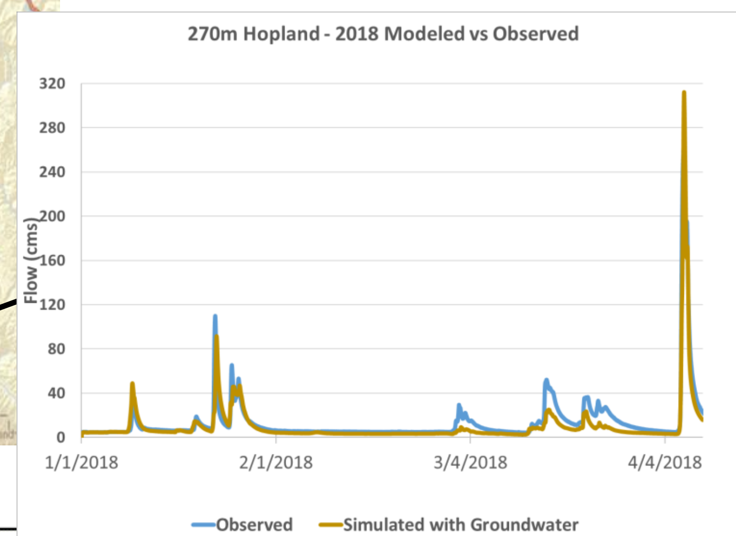


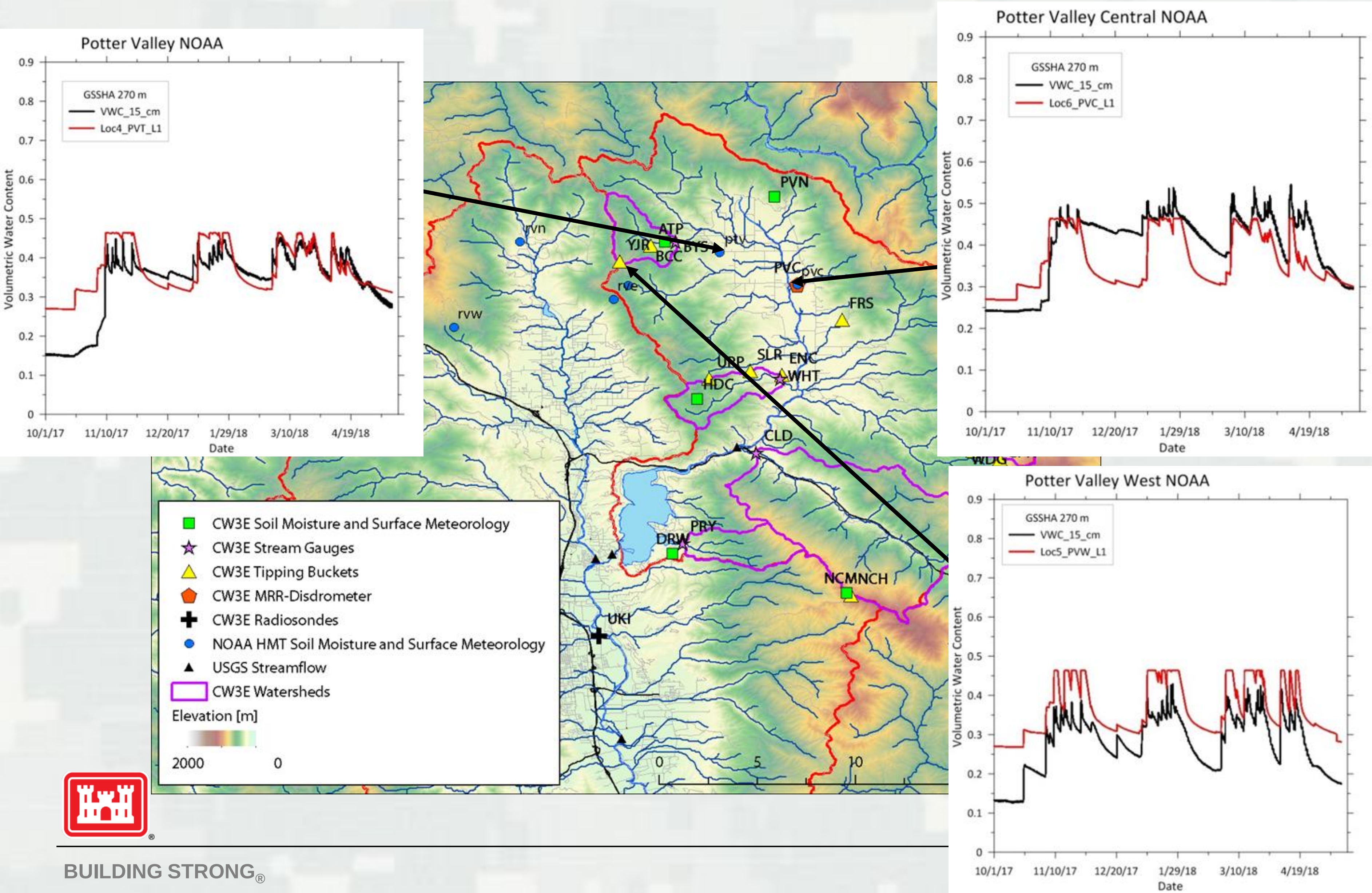



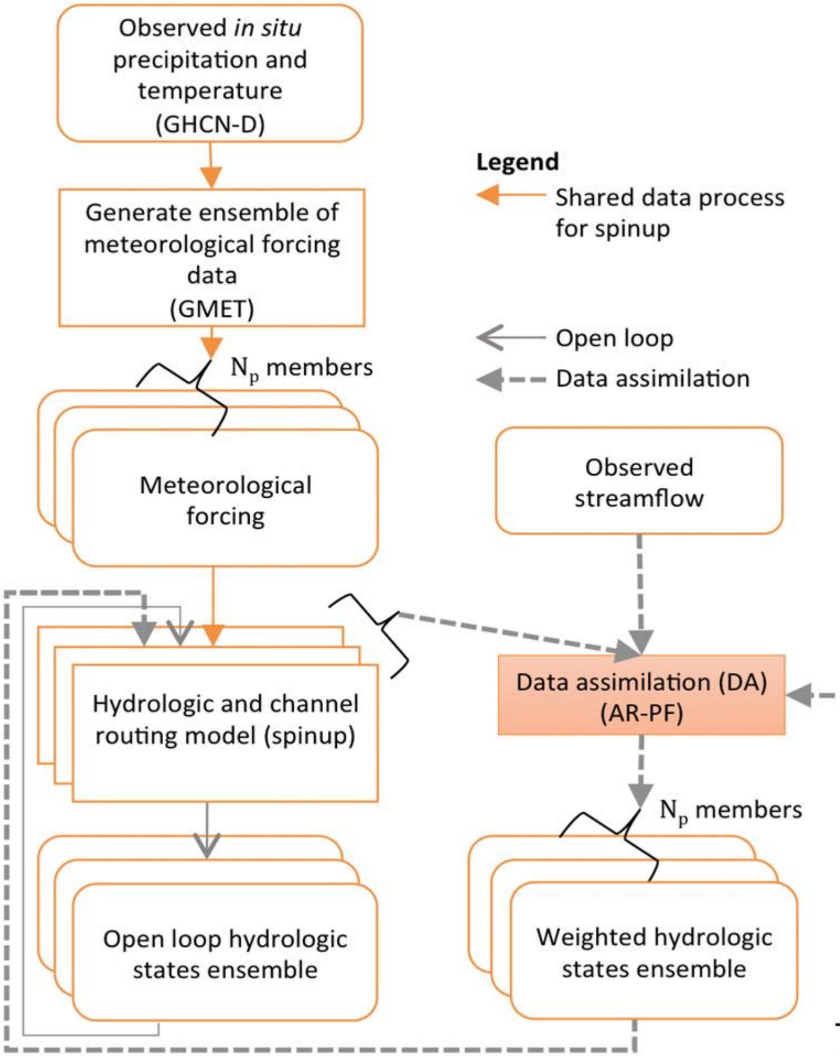



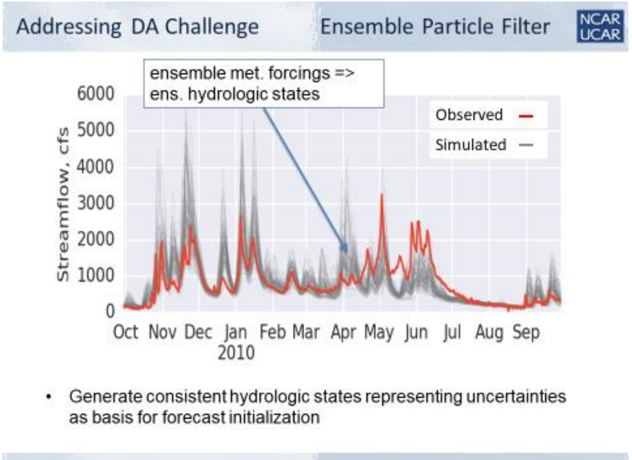
# Soil Moisture Assessment



# Data Assimilation



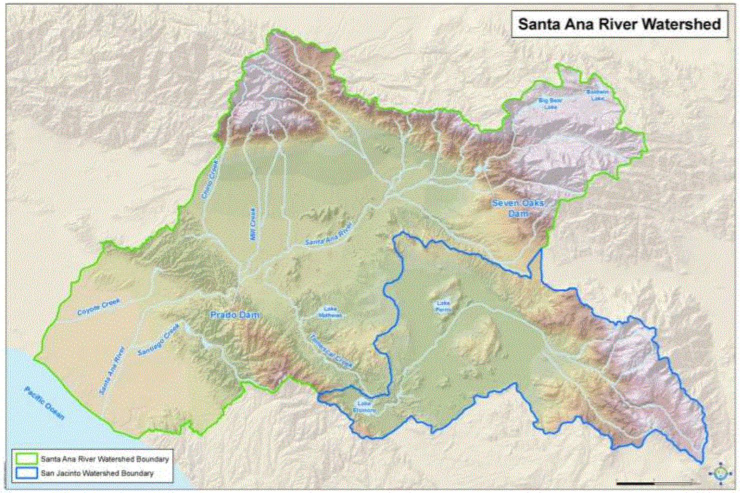

- Integrate observations into hydrologic forecast
- Andy Wood (NCAR)
- Adapt ensemble inputs for GSSHA inputs
- Apply DA techniques for both streamflow and soil moisture.
- Create GSSHA ensemble forecast
- Hand off to ERDC



# Santa Ana River Watershed

- Field and modeling efforts just beginning
- Coordinating with OCWD, USACE SPL, CW3E, and…

You?




# Use of a Distributed Hydrologic Watershed Model for Forecasting Stream Flows and Reservoir Storage in the Russian River Test Watershed of Northern California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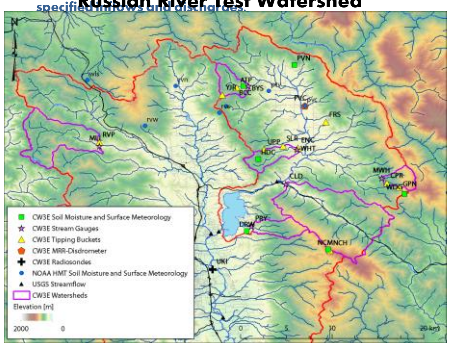
ERDC Engineer Research and Development Center · Coastal & Hydraulics Laboratory · CW3E · Scripps Institution of Oceanography · UC San Diego

## Abstract


- US Army Corps of Engineers (USACE) reservoirs are operated according to a rule curve that specifies target water levels and discharges based on the time of year.
- Rule curves are developed to maximize flood protection by specifying releases of water before the dominant rainfall period for a region.
- While this operational approach provides for the required flood control purpose, it may not result in optimal reservoir operations in terms of water supply storage
- In the Russian River Valley of California a multi-agency research effort called Forecast-Informed Reservoir Operations (FIRO) is assessing the application of forecast weather and streamflow predictions to potentially enhance the operation of reservoirs in the watershed.
- The focus of the study has been on Lake Mendocino, a USACE project important for flood control, water supply, power generation and ecological flows.
- As part of this effort, the Engineer Research and Development Center (ERDC) is assessing the ability of utilizing the physics based, distributed watershed model Gridded Surface Subsurface Hydrologic Analysis (GSSHA) (Downer and Ogden 2004a) to simulate stream flows, reservoir stages, and discharges while being driven by weather forecast products.
- A key question in this application is the effect of watershed model resolution on forecasted stream flows, so multiple GSSHA grid resolutions, 30, 50, 100, and 270m, were developed.
- The models were derived from common inputs: DEM, soils, land use, stream network, reservoir characteristics and specified inflows and discharges.


## Russian River Test Watershed



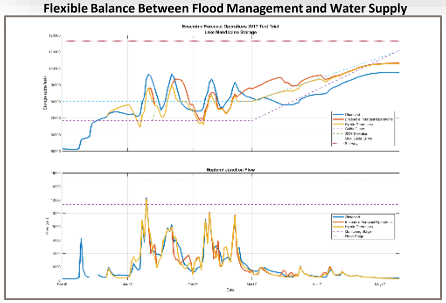

- 6 meteorological stations
- 6 soil moisture stations
- 6 tributary streams gages
- 10 additional rain gages
- Augments 29 USGS gaging, 14 NOAA meteorology /soil moisture stations

## Current Approach

- **Create 270m, 100m, 50m, and 30 models with common input dataset model.**
- **Calibrate with historic streamflow and lake levels, then compare simulated versed measures values.**
- **Calibration is performed with both measured rainfall as well as WestWRF precipitation and meteorological data.**

### Lake Mendocino Rule Curve – Lake Level Mandated for Each Day of the Year

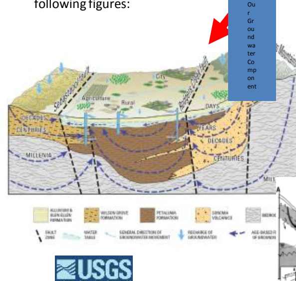

### Flexible Balance Between Flood Management and Water Supply

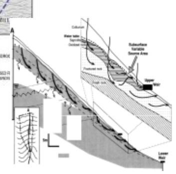


### Technical Challenges

- Groundwater discharge to streams is thought to be an important component of streamflow for the watershed, but the hillslope flow processes in the Coast Range of California are extremely complicated.
- The flow component on these hillslopes is a combination of overland flow and groundwater flow intermixing as shown in the following figures:

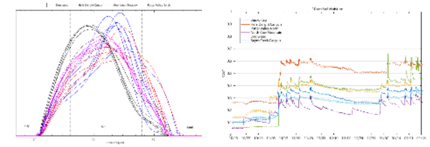
Our Groundwater Component





From Anderson (1997)

### Soils and Meteorology Data in Russian River Valley

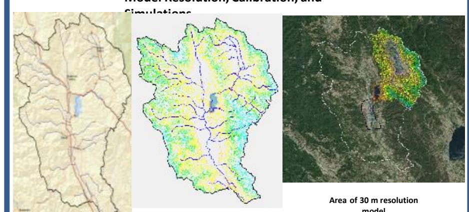


The current set of models include groundwater. Groundwater is being included in the models in conjunction with a new set of calibration data the CW3E has created. These soil data will be used to verify the soil moisture simulations in GSSHA.

## Incorporating Groundwater Component

- GSSHA simulates 2D lateral free surface groundwater. In this application GSSHA will be used to simulate the surficial aquifer likely to interact with the streams and reservoir. This water has residence time of days in the watershed. Water in deeper systems may have residence times of years and may not contribute to the surface waters.
- GSSHA can simulate exchange with groundwater between the streams and reservoirs. Including groundwater gains/losses for the streams and the reservoir is expected to improve simulations of both stream flow and reservoir levels.

### Model Resolution, Calibration, and Simulations



Area of 270 and 50 m resolution models

Area of 30 m resolution model

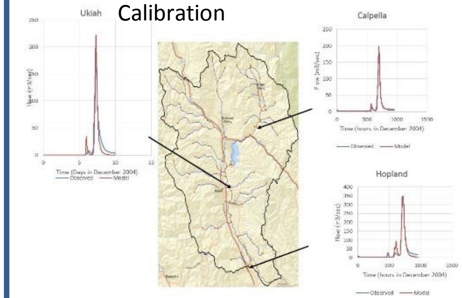
Model Calibration Methods

- Calibration methods of 270, 50, and 30 m models
  - SCE (Shuffled Complex Evolution)
  - Efficient Local Search (PEST)

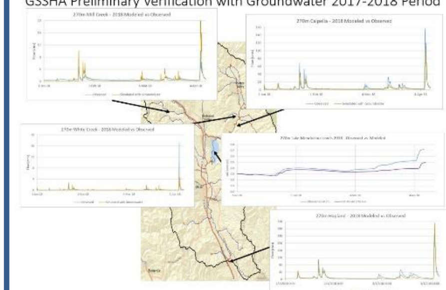
31 model parameters are varies in the Distributed Watershed model including:

- 6 overland flow roughness values
- 2 stream channel roughness values
- 4 overland retention depth values
- 4 canopy resistance values
- 2 bedrock porosity values
- 13 infiltration hydraulic conductivity values

## Single Event Calibration




### GSSHA Preliminary Verification with Groundwater 2017-2018 Period



### Conclusions

- The physics based model was able to accurately simulate runoff for dry conditions.
- The model appeared to be less accurate for wet conditions, possibly due to the lack of groundwater contribution. Currently upgrading groundwater model to incorporate groundwater.
- The model is helping the team to understand the system response of the Russian River watershed to ARs.
- The plan is to incorporate revised reservoir operation algorithm into GSSHA watershed model.

## References


*Downer, C. W., and Ogden, F. L. (2003). "Prediction of runoff and soil moistures at the watershed scale: Effects of model complexity and parameter assignment." Water Resources Research, 39(3)*

*Anderson, S.P, and W.E. Dietrich, D.R. Montgomery, R. Torres, M.E. Conrad, K. Loague (1997) "Subsurface Flow Paths in a Steep, Unchannel Catchment" Water Resources Research, 33(12)*