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Update of the Safe Yield Reset Methodology

Peer Review Meeting

May 19, 2022

Agenda

- Welcome and Introductions
- Background and Objectives
- Overview of Uncertainty in Modeling and the CVM
- Q&A
- Break
- Evaluation of Methods for Characterizing and Addressing Uncertainty
- Recommended Process to Calculate the Safe Yield
- Discussion
- Next Steps and Schedule

Background – April 28, 2017 Court Order

- April 28, 2017 Court Order
  - Approved current Safe Yield reset methodology
  - Included a provision to update the Safe Yield reset methodology
  - Required a peer review process

“4.4 Safe Yield Reset Methodology. […] In furtherance of the goal of maximizing the beneficial use of the waters of the Chino Basin, Watermaster, with the recommendation and advice of the Pools and Advisory Committee, may supplement the Reset Technical Memorandum’s methodology to incorporate future advances in best management practices and hydrologic science as they evolve over the term of this order.”

Background – 2020 Safe Yield Recalculation

- Applied Court-approved methodology to reset the Safe Yield for fiscal year 2021 through 2030
- Several peer review comments recommended that the SY reset methodology account for:
    - Parameter uncertainty
    - Predictive uncertainty (hydrology and water demands/supply plans)

Background – Scope to Implement Court Order

- Spring 2021 – Watermaster proposed a scope of work to update the SY Reset methodology to address uncertainty
- Appropriative Pool requested modified scope to solicit feedback early in the process
- Peer review meeting in October 2021 to define sources of uncertainty to be addressed in update of SY Reset methodology

Background – October 2021 Peer Review Meeting

- Emphasis on cost-effective process
- Suggestions for methods to consider in updated Safe Yield Reset methodology
- Feedback and responses can be found in the October 29, 2021 letter supporting the supplemental scope and budget to implement the 2017 Court Order

Meeting Goals

- Peer reviewers understand the proposed updated Safe Yield Reset methodology
- Gather feedback from peer review committee on the proposed updated Safe Yield Reset methodology

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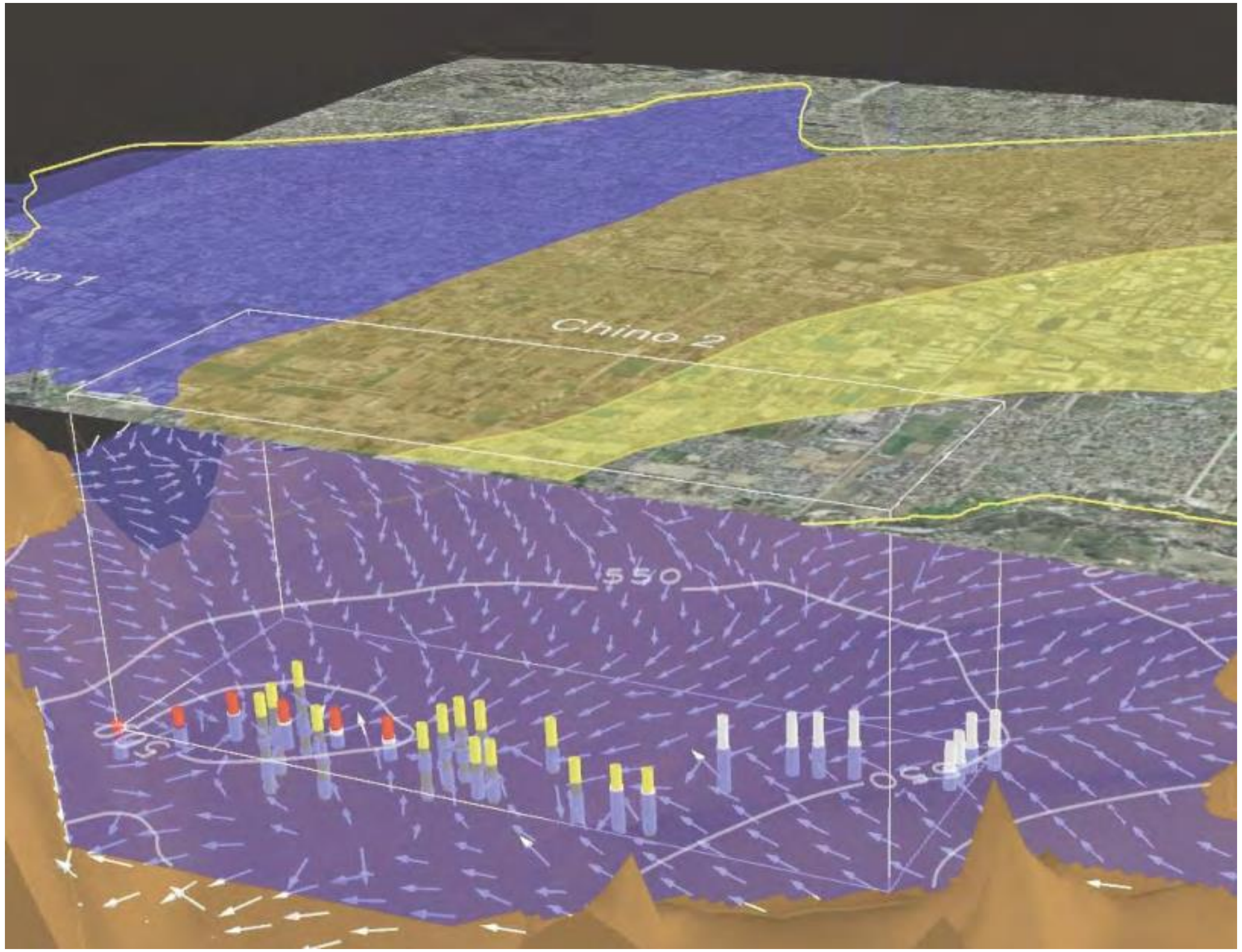
What is Uncertainty?

- Difference between the model and the physical system that it represents
- Inherent and unavoidable in <u>all</u> models



Overview of Uncertainty in Surface Water and Groundwater Modeling

- Sources of uncertainty in surface water and groundwater modeling
- SGMA Modeling BMP to address uncertainty (DWR, 2016)

Sources of Uncertainty in Surface Water and Groundwater Modeling

- Historical data
- Surface water and groundwater model parameters
- Demand and supply plans
- Climate/hydrology

Source of Uncertainty: Historical Data

- Types of historical data
  - **Directly observed**: geologic, precipitation, temperature, stream discharge, metered pumping, managed artificial recharge, wastewater discharge, and groundwater levels
  - **Not observed/not measured directly**: ET, unmanaged recharge, septic tank discharge, unmetered pumping, and unmeasured applied water.
- Model uncertainties related to historical data
  - Measurement error
  - Lack of records
  - Inconsistent spatial resolution
  - Inconsistent temporal resolution

Source of Uncertainty: Surface Water and Groundwater Model Parameters

- Hydrologic processes that are not measured directly – ET, DIPAW, stream percolation
- Hydraulic parameters – HK, VK, Ss, Sy, etc.
- Hydrogeologic features that are not well characterized – stratigraphy, fault barriers, aquifer geometry
- Non-unique solutions of the calibrated model parameters

Source of Uncertainty: Demand and Supply Plan Projections

- Forecasting water supply and demand is uncertain and influenced by
    - Macro-socioeconomic factors
    - Climatic factors
    - Behavior of water purveyors
    - Behavior of water users
    - Regulatory environment
    - Wastewater re-use and disposal plans

Source of Uncertainty: Projected Climate/Hydrology

- Climate change
  - The climate impacts the groundwater system through recharge and changes in demand.
  - Currently, many studies on climate impacts rely on the downscaled results of Global Climate Models (GCMs) - CMIP5 and CMIP6.
  - GCM projections are inherently uncertain.

Source of Uncertainty: Projected Climate/Hydrology

- Effects of climate on behavior, such as legislation to promote water conservation in response to drought
    - Model Water Efficient Landscape Ordinance (MWELO) enacted in 1993 and updated in 2015
    - New water efficiency standards for purveyors in response to the California drought – The Water Conservation legislation of 2018 (AB1668 and SB 606).

SGMA Modeling BMP to Address Uncertainty (DWR, 2016)

Develop and run predictive scenarios to:

- Include (1) expected future conditions under varying climate conditions, and (2) various projects and management actions.
- Assess the anticipated conditions at five-year milestones.
- Demonstrate that the sustainability goal will be maintained over the 50-year horizon.

SGMA Modeling BMP to Address Uncertainty (DWR, 2016)

Conduct an uncertainty analysis of the scenarios to:

- Identify the impact of parameter uncertainty on the model's ability to support decision making.
- Identify high-value data gaps.
- Assist in a formal optimization simulation of management options.

Uncertainty in the CVM and its Use in the Safe Yield Reset

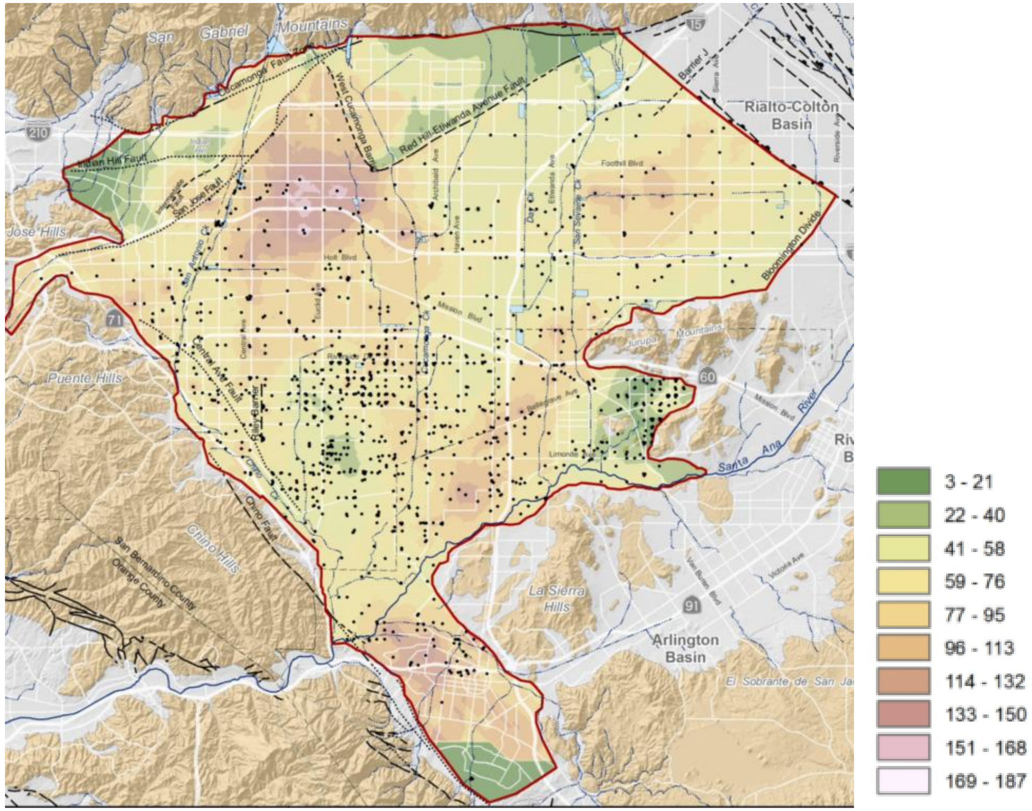
- Historical data
- Surface water and groundwater model parameters
- Demand and supply plans
- Climate/hydrology

Source of Uncertainty: Historical Data

- Pumping
- Groundwater levels
- Stream discharge
- Managed artificial recharge
- Wastewater discharge
- Precipitation
- Potential ET
- Evaporation
- Applied water
- Land use
- Septic tank discharge
- Subsurface inflow from adjacent groundwater basins
- Mountain-front inflow

Source of Uncertainty: Surface Water and Groundwater Model Parameters

- Surface hydrologic parameters
- Hydraulic conductivity, specific storage and specific yield
- Hydraulic characteristics of faults
- Stream properties
- Groundwater evapotranspiration
- Vadose zone travel (lag) time



Layer 1 Initial and Pre-calibrated Horizontal Hydraulic Conductivity (ft/day) Based on Borehole Lithology

Source of Uncertainty: Demand and Supply Plan Projections

- Groundwater pumping
- Managed artificial recharge
- Wastewater discharge
- Land use
- Future extent of septic tanks
- Subsurface inflow from adjacent groundwater basins
- Replenishment obligations
- Management programs (e.g., OBMP PEs)

Source of Uncertainty: Projected Climate/Hydrology

- The DWR (2018) climate change datasets in the form of change factors of precipitation, ET_0, and surface runoff for 2030 and 2070 were used to model climate change in the 2020 Safe Yield Recalculation.
- The change factors represented the central tendency of future climate. Effects due to individual climate projections could not be characterized.
- The impact of new conservation legislation was not included in the 2020 Safe Yield Recalculation.

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Approaches for Addressing Uncertainty

- Deterministic
  - One “calibrated realization” + one scenario
- Robust Decision Making (RDM)
  - Multiple calibrated realizations + multiple scenarios
- Dynamic Planning Framework
  - Dynamic behaviors triggered by management thresholds

Approaches for Addressing Uncertainty

- Deterministic
  - One “calibrated realization” + one scenario
- **Robust Decision Making (RDM)**
  - **Multiple calibrated realizations + multiple scenarios**
- Dynamic Planning Framework
  - Dynamic behaviors triggered by management thresholds

Recommended Approach:
Robust Decision Making

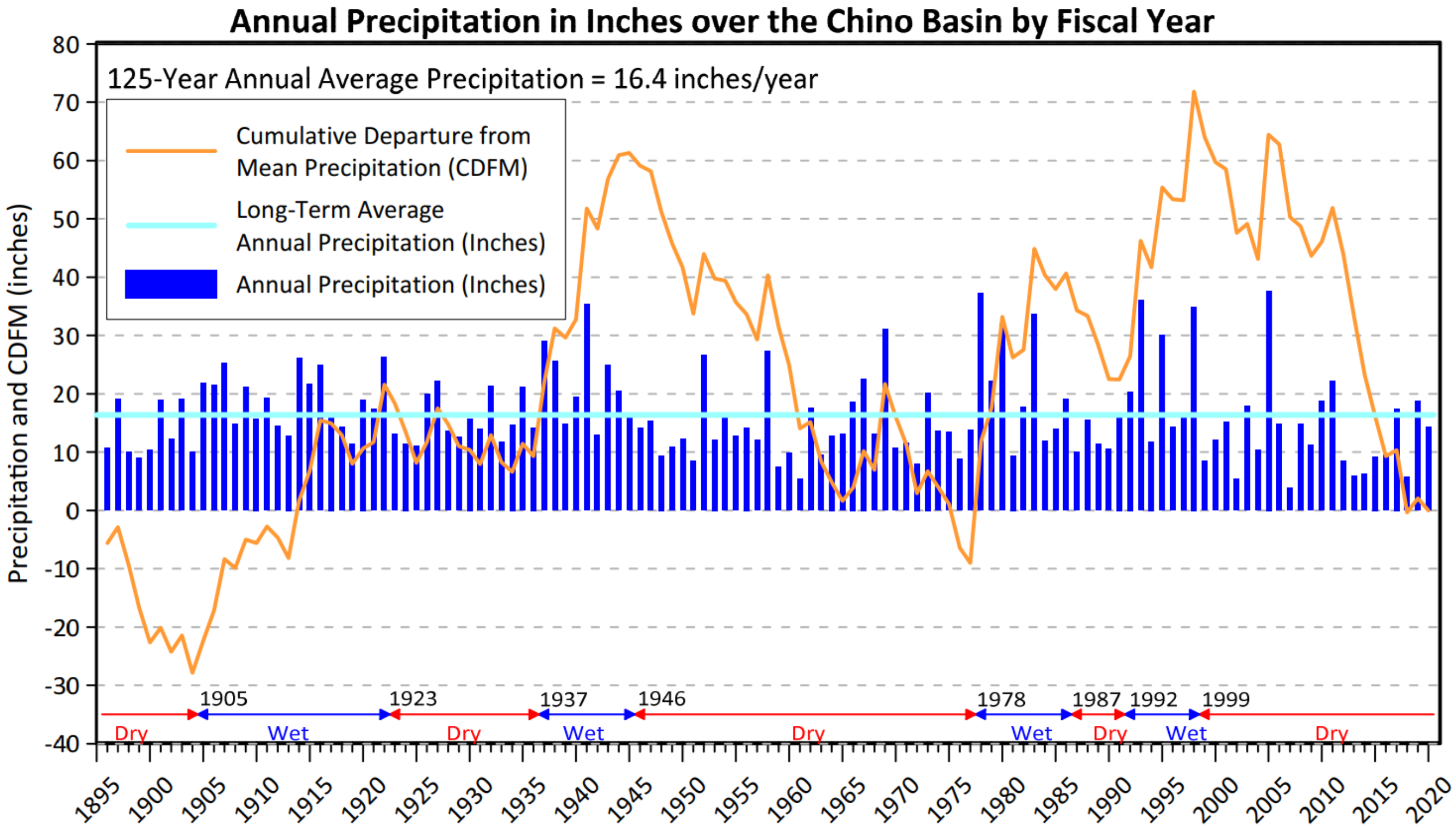
- *"The RDM approach identifies a range of plausible future scenarios, assesses an agency's risk to each modeled scenario and, ultimately, identifies a robust strategy that is likely to perform well across all plausible outcomes."* (Moran, 2016)
- Recommended approach to address uncertainty in SGMA groundwater models
- Allows for exploration of possible futures without complexity of dynamic planning

Methods for Addressing Uncertainty

- Historical data
- Surface water and groundwater model parameters
- Demand and supply plans
- Climate/hydrology

Addressing Uncertainty in Historical Data

- Includes directly observed data and estimated data calculated from observations
- Availability of a lot of data from varying sources
- Will honor historical data



Addressing Uncertainty in Model Parameters

Methods to address Non-uniqueness Problem in Model Parameterization:

1. Generalized Likelihood Uncertainty Estimation (GLUE)
2. Null-Space Monte Carlo (NSMC)
3. Iterative Ensemble Smoother (IES)

Addressing Uncertainty in Model Parameters

- Generalized Likelihood Uncertainty Estimation (GLUE)

  1. Select a group of model parameters with the highest relative sensitivity and define their bounds.
  2. Generate calibrated realizations: Randomly sample model parameters within their bounds. Run model with the sampled parameters and check for calibration criteria. Repeat until a desired number of realization is reached.
  3. Generate projection realizations (calibration realization + climate scenario + demand/supply scenario).
  4. Conduct simulation runs of the projection realizations.

Addressing Uncertainty in Model Parameters

- Null-Space Monte Carlo (NSMC)
  1. Calibrate the model.
  2. Generate calibrated realizations: Conduct a NSMC sampling analysis with the help of multiple programs included in the PEST Groundwater Data Utility. Repeat until a desired number of realization is reached.
  3. Generate projection realizations (calibrated realization + climate scenario + demand/supply scenario).
  4. Conduct simulation runs of the projection realizations.

Addressing Uncertainty in Model Parameters

- Iterative Ensemble Smoother (IES)

  1. Construct the model and prepare it for automatic calibration with PESTPP-IES, including pilot points, variograms, covariance matrices of adjustable model parameters. (see Attachment A of TM).
  2. Generate calibrated realizations: Run PESTPP-IES to generate the desired number of calibrated parameter realizations.
  3. Generate projection realizations (calibrated realization + climate scenario + demand/supply scenario).
  4. Conduct simulation runs of the projection realizations.

Addressing Uncertainty in Model Parameters

Comparison of Methods

Criteria	GLUE	NSMC	IES
Simplicity of the Method	Simple	Complex	Moderate
Computing Cost (in terms of the number of required model runs)	High (due to low acceptance rate)	Moderate (due to the requirement of recalibration of each parameter set)	Low
Does the computing cost grow with the number of adjustable parameters?	Yes	Yes	No
Ability to incorporate heterogeneity in calibrated realizations	Yes (at a very high computing cost)	Yes (at a very high computing cost)	Yes

Addressing Uncertainty in Model Parameters

- Method and Characteristics of the 2020 CVM:
  - A set of model parameters was estimated through model calibration.
  - The uncertainty in the projected Safe Yield due to non-uniqueness problem in model parameters could not be characterized.

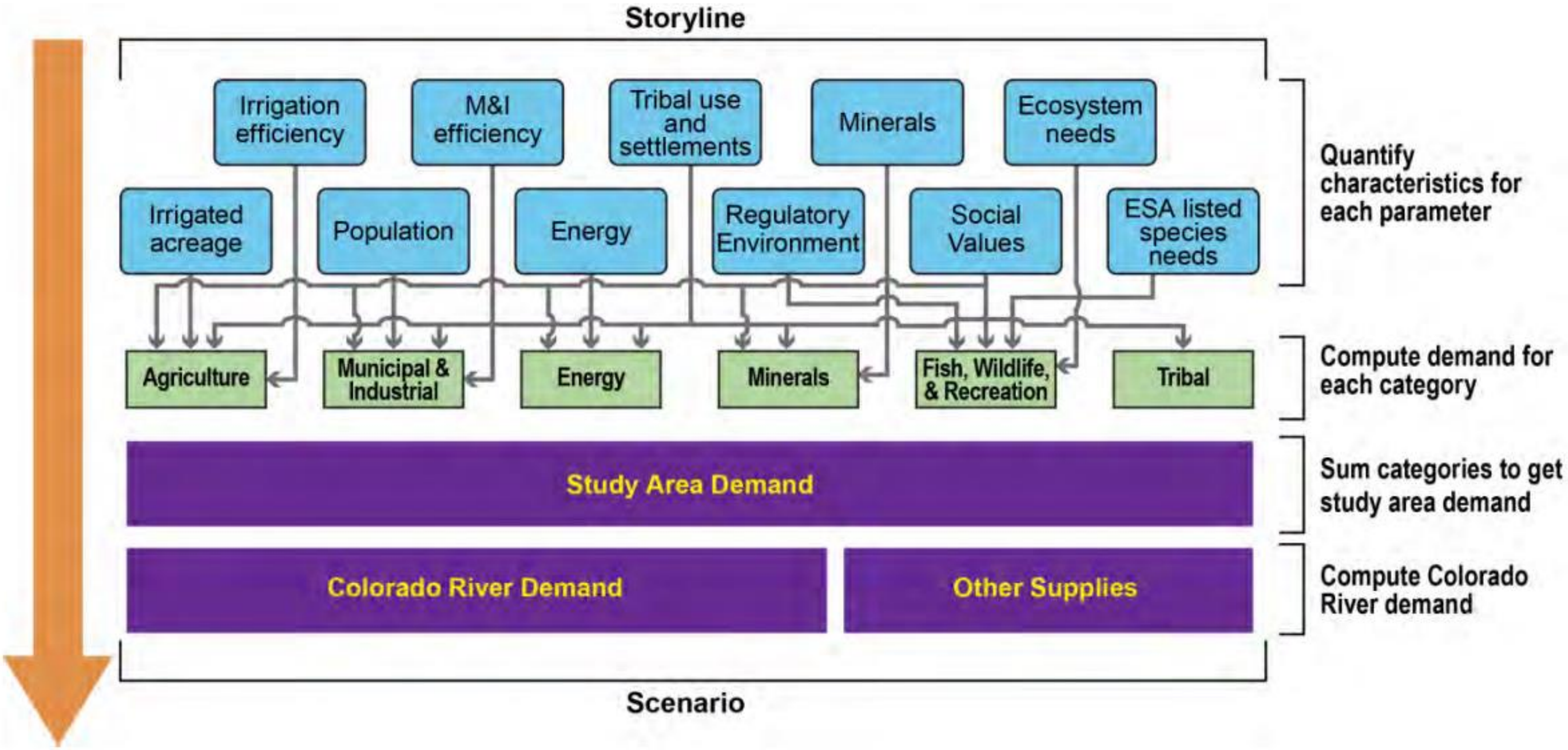
Addressing Uncertainty in Model Parameters

- Recommended Method: Iterative Ensemble Smoother (IES) with PESTPP-IES
    - Relatively low computing cost to address non-uniqueness problems in model parameters.
    - Computing cost does not grow with the number of parameters.
    - Straightforward implementation (Attachment A of TM).

Addressing Uncertainty in Demand and Supply Plan Projections

- Planning studies that employ RDM generally have a goal of informing management decisions
- Level of detail is not prescribed, depends on available data, management schema, and planning objectives

Addressing Uncertainty in Demand and Supply Plan Projections



https://www.usbr.gov/lc/region/programs/crbstudy/finalreport/Technical%20Report%20C%20-%20Water%20Demand%20Assessment/TR-C-Water_Demand_Assessmemt_FINAL.pdf

Addressing Uncertainty in Demand and Supply Plan Projections

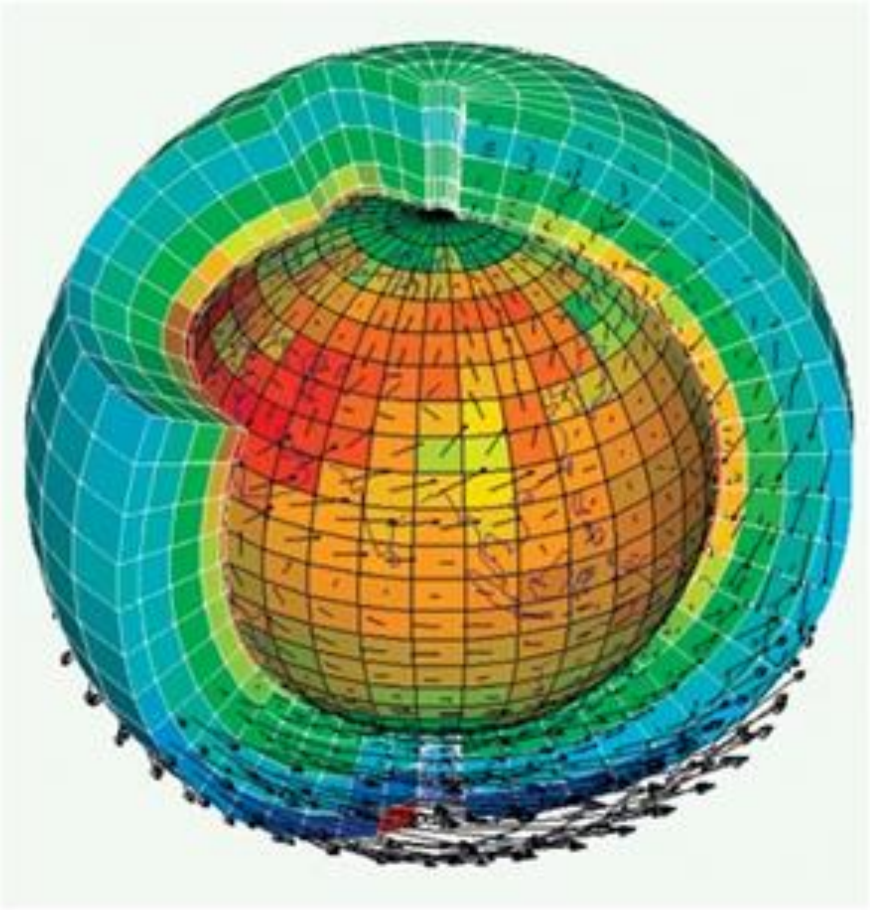
- Method and Characteristics of the 2020 CVM:
  - A single set of planning scenario and groundwater pumping projection was used in the projection model.
  - The uncertainty in the projected Safe Yield due to possible variability of planning scenario and groundwater pumping projection could not be characterized.

Addressing Uncertainty in Demand and Supply Plan Projections

- Recommended method:
  1. Identify drivers of changes in future demands and supplies (e.g., population growth, water conservation mandates, climate change)
     a. Conduct workshops with Parties and wholesale agencies
  2. Develop scenarios based on combinations of drivers
  3. Select a subset of scenarios in (2) to incorporate into projection realizations
  4. Quantify water supply plans for selected scenarios
     a. Conduct workshops with Parties and wholesale agencies
  5. Translate water supply plans into model inputs

Addressing Uncertainty in Climate/Hydrology Projections

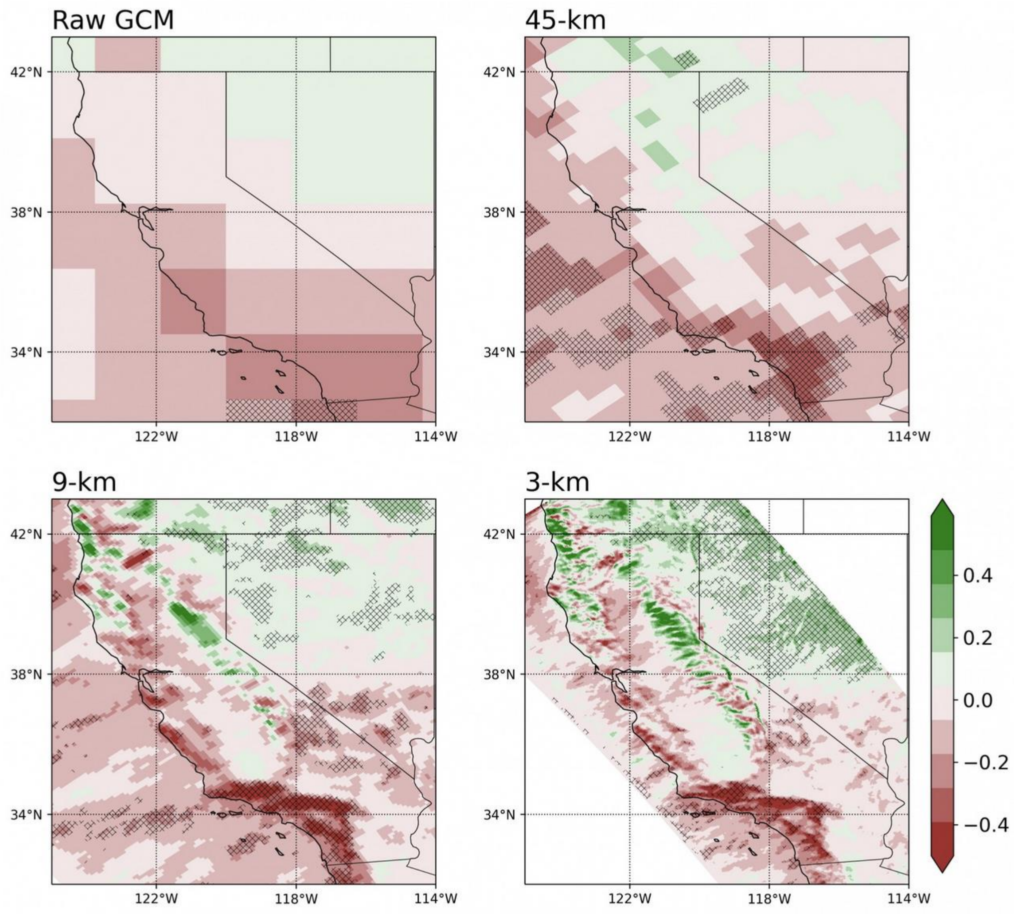
- Results of Global Climate Models (GCMs) are used in many studies on climate impacts.
- Several Phases of Coupled Model Intercomparison Projects (CMIP) coordinated the research efforts.
- The most recent CMIP phase is CMIP6 (2021) that consists of 134 GCMs.



https://orchidas.lsce.ipsl.fr/overview/lmdz.php

Addressing Uncertainty in Climate/Hydrology Projections

- Raw GCM output is not always adequate to be used directly in groundwater and surface-water models due to the limitations:
  - Coarse spatial scales (grid cells are 150 to 400 miles width).
  - Biases relative to observational data.

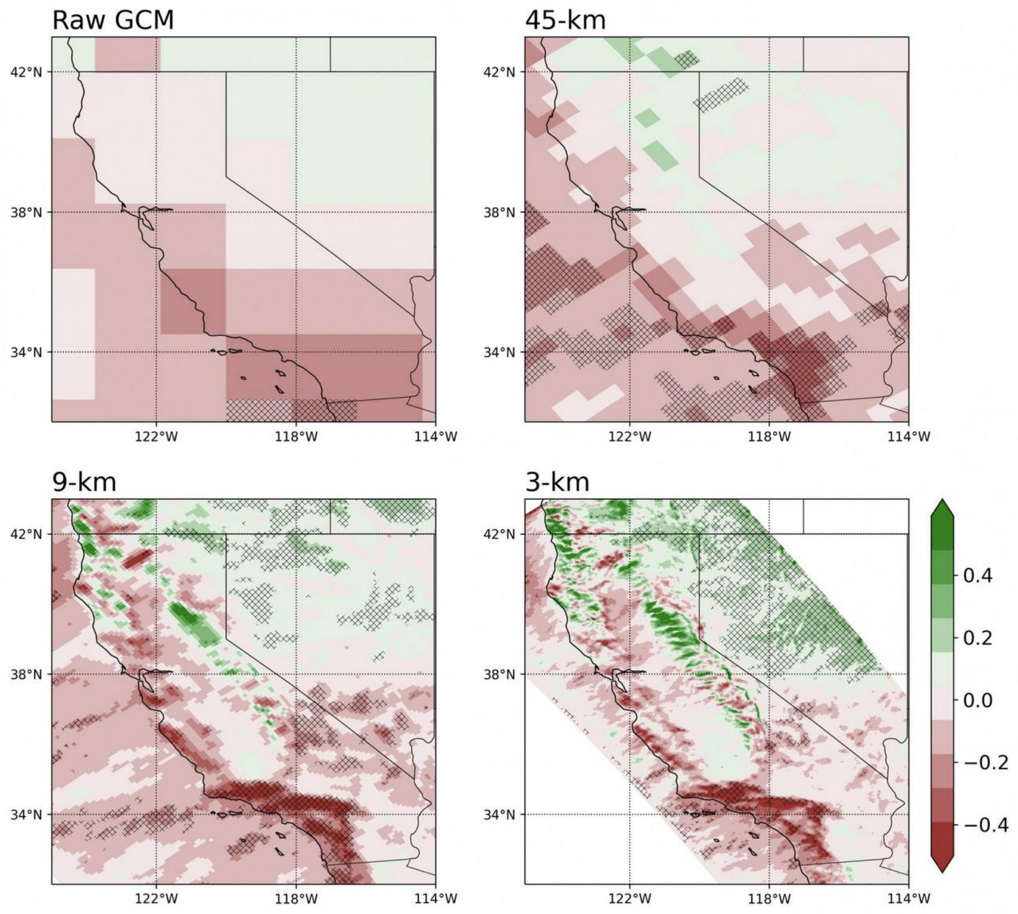


Future (2080-2100 average) minus historical (1980-2015 average) simulated precipitation anomalies [mm/d] from a raw GCM and from WRF downscaling grids. Hatching denotes statistical significance greater than 0.9, and cross hatching denotes significance greater than 0.99.

https://dept.atmos.ucla.edu/alexhall/downscaling-cmip6

Addressing Uncertainty in Climate/Hydrology Projections

- Downscaling methods can be used to address the limitations:
  - Statistical downscaling: use statistics-based techniques to determine relationships between GCMs and observed local climate responses.
  - Dynamical downscaling: use high-resolution regional simulations to dynamically interpolate the effects of GCMs to regional scales of interest.



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Addressing Uncertainty in Climate/Hydrology Projections

- Available Statistical Downscaled Datasets
  - NASA Earth Exchange (NEX) Downscaled Climate Projections (NEX-DCP30): Monthly results of CMIP5 models from 1950 to 2099 at 800-meter grid resolution.
  - NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP-CMIP6): Daily results of CMIP6 models from 1950 to 2100 at 17.5-mile grid resolution.
- Available Dynamical Downscaled Datasets
  - UCLA CMIP6 Downscaling Using the Weather Research and Forecasting model (WRF-CMIP6): Daily results of CMIP6 models from 1980 to 2100 at 2-mile grid resolution.

Addressing Uncertainty in Climate/Hydrology Projections

- Method and Characteristics of the 2020 CVM:
  - Future climate in the model was obtained by adjusting the historical records by the DWR’s Change Factors
  - The DWR's Change Factors are based on statistical downscaled datasets of 20 CMIP5 scenarios
  - The 2020 CVM represents a projected central tendency of future climate
  - The uncertainty in the projected Safe Yield due to individual climate projections could not be characterized

Addressing Uncertainty in Climate/Hydrology Projections

- Recommended Method:

  1. Review and select a subset of the available dynamically downscaled datasets.
  2. Review and select representative future cultural conditions consistent with the water demand and supply plan scenarios. This includes a combination of future land use and applied water patterns.
  3. Incorporate the chosen combinations of climate datasets and cultural conditions into the CVM:
     - Execute the HSPF and R4 models with the land use data, precipitation, and ET_0 datasets from the climate projection.
     - Develop SAR discharges from the upper SAR watershed at Riverside Narrows based on regional model results (e.g., ISARM). The estimated SAR discharges at Riverside Narrows will be used as input data to the MODFLOW model of CVM.

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Combining the Proposed Methods

- “Projection realization” includes:
  1. Calibrated groundwater model
  2. Water demand and supply plan scenario
  3. Climate scenario
- Total number of projection realizations is the product of (1) through (3)
  - *40 calibrated models* X *3 demand/supply plan scenarios* X *5 climate scenarios* = **600 projection realizations**
- All projection realizations = model ensemble

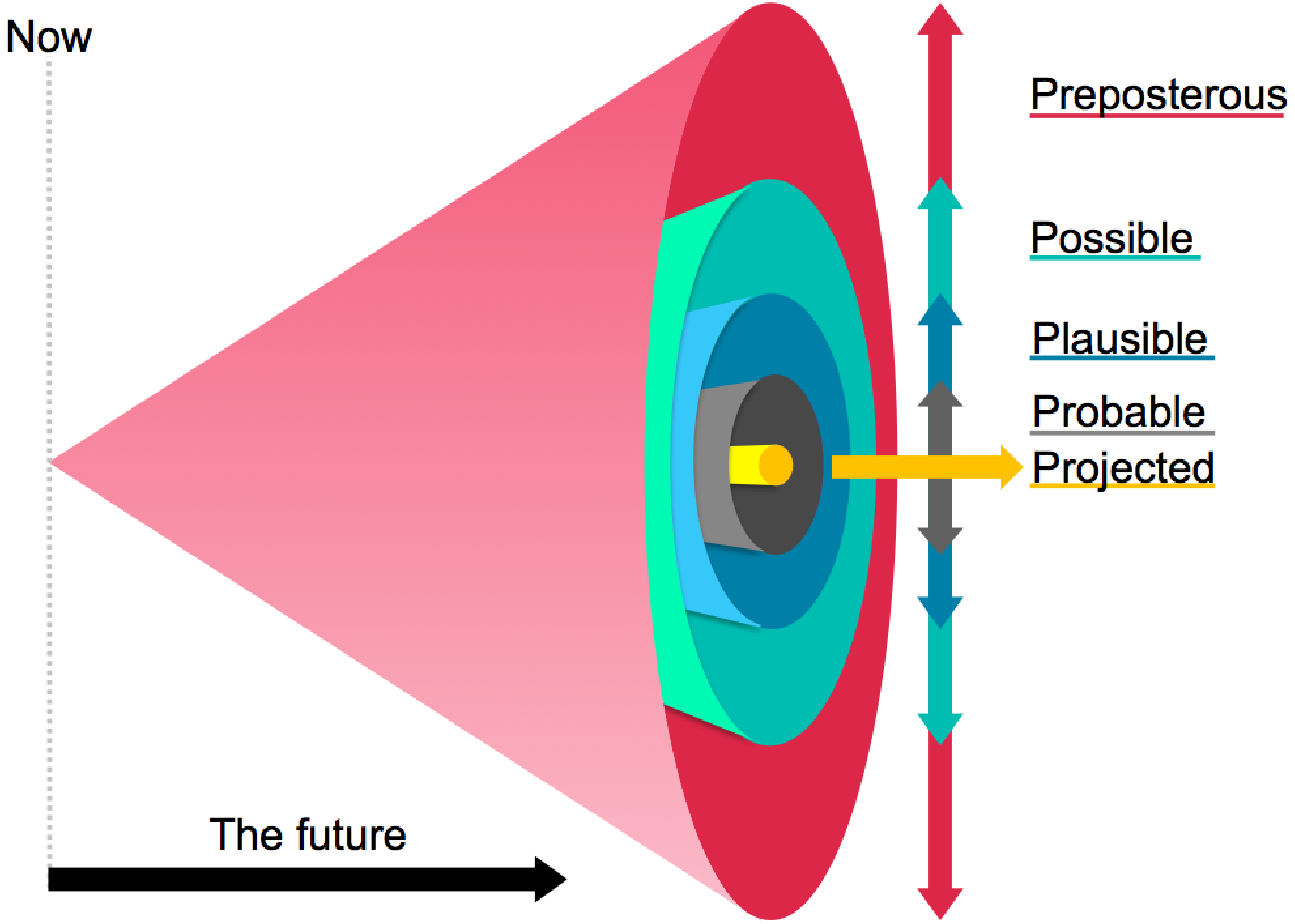
Sounds like a lot of models. Is that feasible?

https://www.gaapdynamics.com/images/user-uploads/9.11_Inline_Image_1_copy.jpg

- Yes, thanks to cloud computing
- Amazon Web Services = $4k/month
- 6 months of use = $24k

How should we interpret the model ensemble?

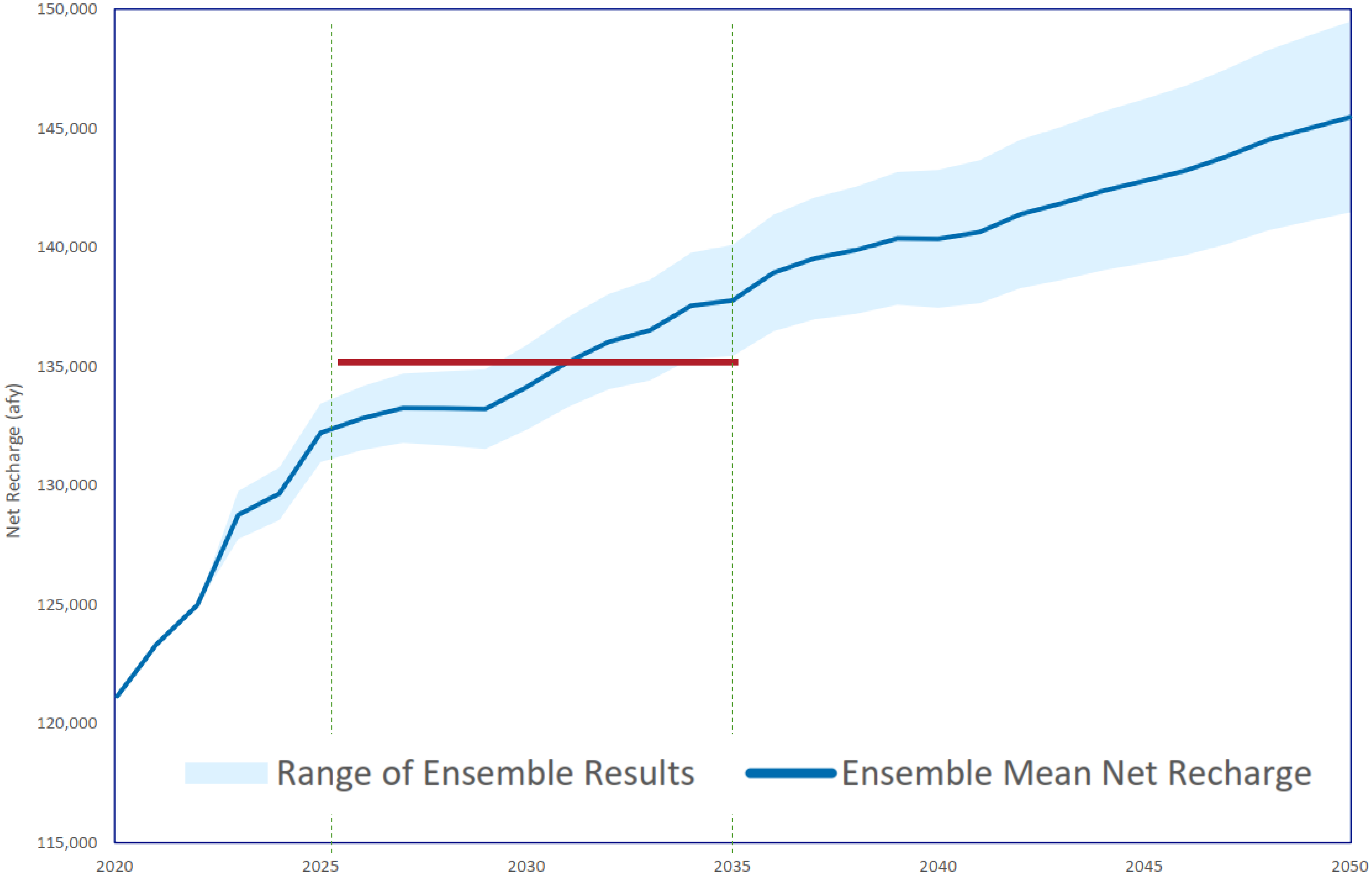
- Automate the generation of key model outputs, including:
  - Water budget
  - Net recharge
  - Extent of potential MPI (land subsidence, pumping sustainability, water quality)
  - Hydraulic Control
- Use the ensemble statistics to calculate Safe Yield and evaluate for MPI and undesirable results



Envisioning the future for strategic planning - Goal Atlas

How should we interpret the model ensemble?

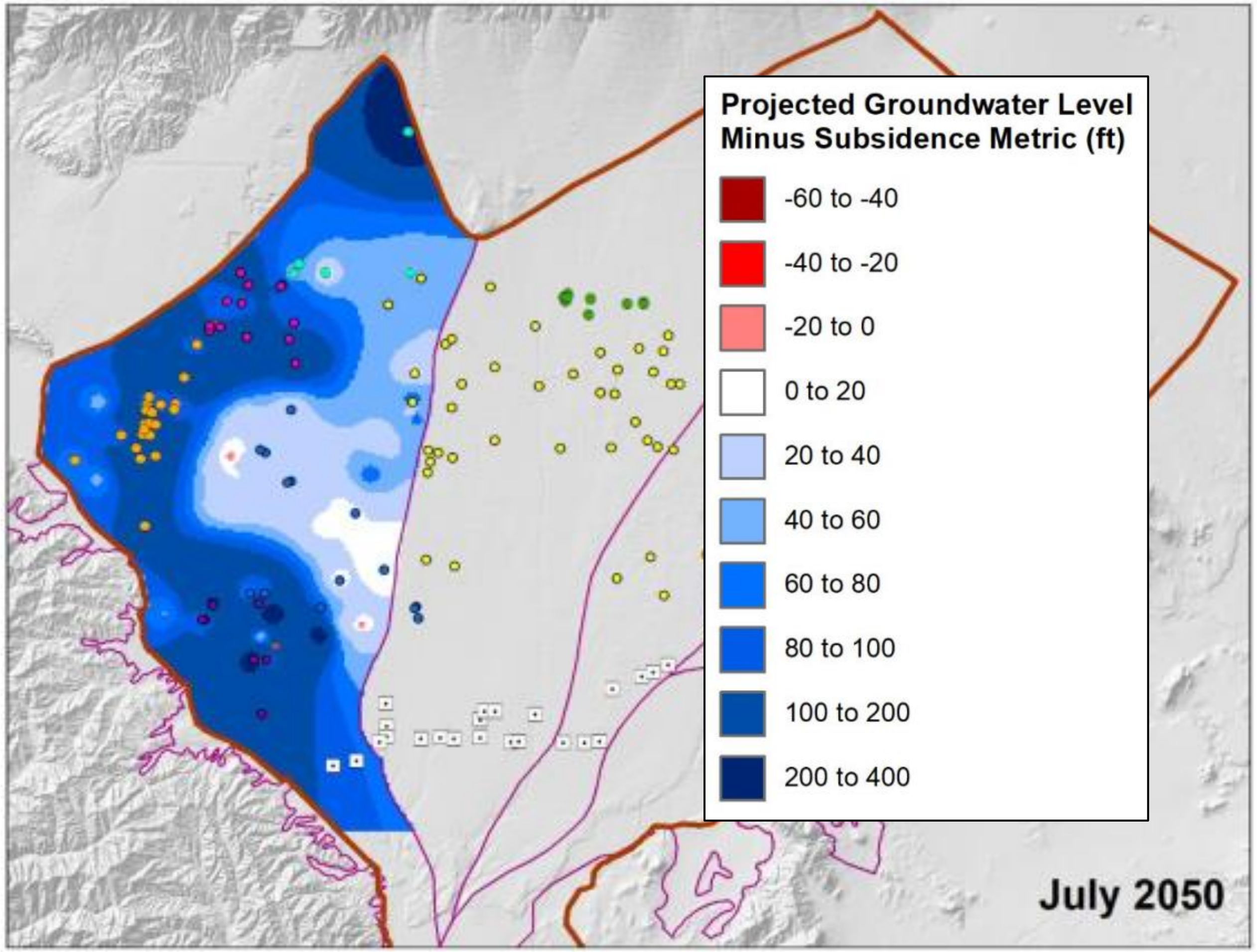
Figure 1. Hypothetical Projected Net Recharge Using Ensemble Approach



How should we interpret the model ensemble?

- Risk of MPI and undesirable results should be evaluated based on thresholds
  - What is the threshold for the potential for MPI in a single projection realization?
  - What constitutes a significant percentage of projection realizations that indicate potential for MPI?
- Examining the ensemble allows us to identify the causes of potential risks
  - What we learn can provide guidance for Basin optimization

Example of interpreting risk for MPI



- Risk for MPI related to new land subsidence can be quantified as the percentage of projection realizations that result in projected groundwater levels that decline below the sustainability metric.

Proposed Updated Methodology to Calculate the Safe Yield (1/3)

1. Update model and generate multiple calibrated groundwater model realizations:
    a. Update and calibrate HSPF/R4 models
    b. Update MODFLOW model for the historical period
    c. Select adjustable parameters and prepare files to include parameters in PESTPP-IES
    d. Prepare observation calibration targets
    e. Use PESTPP-IES to estimate model parameters and generate calibrated realizations

Proposed Updated Methodology to Calculate the Safe Yield (2/3)

2. Develop future scenarios of demands, water-supply plans, and climate/hydrology using the recommended approaches and methods
3. Generate up to 600 projection realizations
4. Simulate the ensemble of projection realizations over the planning period and quantify the water budget, net recharge, Safe Yield, the state of Hydraulic Control, and the potential for MPI or undesirable results for each projection realization.

Proposed Updated Methodology to Calculate the Safe Yield (3/3)

5. Conduct statistical analyses of ensemble results, including
    a. Water budget and net recharge over 50-year planning period
    b. Safe Yield = ensemble mean net recharge over prospective 10-year period
    c. Statistics of projection realizations that result in MPI or loss of hydraulic control
6. Evaluate risk for MPI and loss of hydraulic control based on statistics. *"Identify and implement prudent measures necessary to mitigate [MPI and undesirable results], set the value of Safe Yield to ensure there is no [MPI and undesirable results], or implement a combination of mitigation measures and a changed Safe Yield."*

Comparison of Current and Proposed SY Reset Methodologies

Step	Current SY Reset Methodology	Proposed SY Reset Methodology
Calibration of groundwater model	Calibrate groundwater model with parameter zones and PEST to generate single model realization	Calibrate groundwater model using pilot points and PESTPP-IES to generate multiple calibrated model realizations
Incorporation of demand and supply plans in scenario development	Using the current planning data collected from the Parties and other sources to develop a single projection scenario of future demands and supply plans. Minimal stakeholder engagement beyond clarifying the collected data.	Collecting the same data sets as are collected with the current SY Reset methodology. A stakeholder process will be implemented using RDM principles to understand the drivers and potential responses to stresses to aid in the development of multiple plausible projections for demand and supply plans.
Projection realization development	One projection scenario is developed based on a combination of the best estimates of future demands, supply plans, and long-term expected value hydrology adjusted for climate change.	Multiple projection realizations will be developed as unique combinations of calibrated model realizations, future demands and supply plans, and future hydrology and climate.

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Comparison of Current and Proposed SY Reset Methodologies

Step	Current SY Reset Methodology	Proposed SY Reset Methodology
Evaluation of model results	The projection scenario is evaluated based on whether the projected groundwater pumping *"will cause or threaten to cause 'undesirable results' or 'Material Physical Injury'."*	The method to evaluate model results is similar to the current SY Reset methodology, but the method is automated and applied to the ensemble of projection scenarios. Ensemble statistics are generated to characterize potential MPI and the state of hydraulic control and allow for identification of the causes of MPI or the loss of hydraulic control.
Calculation of Safe Yield based on model results	Safe Yield is calculated as the 10-year average of the net recharge for the single model projection realization.	Safe Yield is calculated as the ensemble mean of the 10-year average net recharge for the ensemble of projection scenarios.

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Next Steps and Schedule

- Summarize feedback from today's meeting
- Collect additional feedback by Friday, June 24th
- Update draft TM and distribute for peer review by Friday, July 8th
- Peer review meeting to be scheduled in late July

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WATERMASTER
Partners in Basin Management

THANK YOU

Table 1. Typical Historical Data used in Groundwater Models

Data Type	Purpose of Data	Use of Data in Model		
		Direct Input	Indirect Input	Model Calibration
Groundwater levels	Groundwater simulation		X	X
Groundwater pumping	Groundwater simulation	X		
Lithology and geologic data	Groundwater simulation	X	X	
Climatic data (precipitation, ET_0, temperature, evaporation, etc.)	Recharge estimation	X		
Ground elevation data	Recharge estimation		X	
Land use	Recharge estimation	X		
Stream discharge	Recharge estimation	X		X
Wastewater treatment plant influent	Recharge estimation			X
Water and wastewater infrastructure (sewersheds, water supply maps)	Recharge estimation		X	
Managed aquifer recharge	Recharge estimation/ groundwater simulation	X		X
Stream geometry	Recharge estimation/ groundwater simulation	X		
Wastewater treatment plant effluent	Recharge estimation/ groundwater simulation	X		