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TECHNICAL MEMORANDUM

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SUBJECT: Proposed Updated Methodology to Calculate the Safe Yield of the Chino Basin

This Technical Memorandum (TM) documents West Yost's findings related to the development of an updated Safe Yield Reset methodology. This TM is prepared pursuant to the scope of work[1] to comply with the April 28, 2017, Court Order regarding the Safe Yield of the Chino Basin (2017 Court Order).[2]

1.0 BACKGROUND AND OBJECTIVES

The Chino Basin Judgment defines the Safe Yield as the "long-term average annual quantity of ground water (excluding replenishment or stored water but including return flow to the Basin from use of replenishment or stored water) which can be produced from the Basin under cultural conditions of a particular year without causing an undesirable result."[3] The Judgment set the initial Safe Yield at 140,000 acre-feet per year (afy).

The Judgment also provides for a Physical Solution to provide maximum flexibility and adaptability in order that Watermaster and the Court may be free to use existing and future technological, social, institutional, and economic options in order to maximize the beneficial use of the Chino Basin.[4]

Watermaster's Optimum Basin Management Program (OBMP) Implementation Plan called for an initial redetermination of the Safe Yield in 2011 using monitoring data collected during the period of 2001 through

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[1] The scope of work is described in Exhibit B of West Yost's October 29, 2021 letter http://www.cbwm.org/docs/othermeetings/2021%2010%2026%20-%20Safe%20Yield%20Reset%20Methodology%20Peer%20Review/downloads/20211029_SYCourtOrder_Supp_Scope_Budget.pdf

[2] *Orders for Watermaster's Motion Regarding the 2015 Safe Yield Reset Agreement, Amendment of Restated Judgment*, Paragraph 6, Superior Court for the County of San Bernardino (2017), http://www.cbwm.org/docs/WatermasterCourtFilings/2017/20170418%20Further%20Revised%20Proposed%20Order%20re%20SYRA%20and%20Final%20Rulings%20and%20Order%20for%20Oral%20Argument.pdf

[3] Section I.4.x of the *2012 Chino Basin Restated Judgment*, http://www.cbwm.org/docs/WatermasterCourtFilings/2012/2012%20Watermaster%20Restated%20Judgment.pdf

[4] See paragraph 40 of the *2012 Chino Basin Restated Judgment*

2010.[5] This was incorporated as a requirement in Watermaster's Rules and Regulations.[6] In 2012, Watermaster began an investigation to recalculate the Safe Yield of the Chino Basin, which was completed in 2015. The investigation developed and implemented a methodology to calculate Safe Yield and concluded that the Safe Yield for the period of fiscal year (FY) 2010/11 through 2019/20 was 135,000 afy (WEI, 2015).[7] The methodology used to calculate the Safe Yield was approved in the 2017 Court Order and is described below:

> *"The methodology to redetermine the Safe Yield for 2010/11 and the recommended methodology for future Safe Yield evaluations is listed below. This methodology is consistent with professional custom, standard and practice, and the definition of Safe Yield in the Judgment and the Physical Solution.*
>
> 1. *Use the data collected during 2000/01 to 2009/10 (and in the case of subsequent resets newly collected data) in the re-calibration process for the Watermaster's groundwater-flow model.*
> 2. *Use a long-term historical record of precipitation falling on current and projected future land uses to estimate the long-term average net recharge to the Basin.*
> 3. *Describe the current and projected future cultural conditions, including, but not limited to the plans for pumping, stormwater recharge and supplemental-water recharge.*
> 4. *With the information generated in [1] through [3] above, use the groundwater-flow model to redetermine the net recharge to the Chino Basin taking into account the then existing current and projected future cultural conditions.*
> 5. *Qualitatively evaluate whether the groundwater production at the net recharge rate estimated in [4] above will cause or threaten to cause "undesirable results" or "Material Physical Injury". If groundwater production at net recharge rate estimated in [4] above will cause or threaten to cause "undesirable results" or "Material Physical Injury" then Watermaster will identify and implement prudent measures necessary to mitigate "undesirable results" or "Material Physical Injury", set the value of Safe Yield to ensure there is no "undesirable results" or "Material Physical Injury", or implement a combination of mitigation measures and a changed Safe Yield."*

In addition to approving the current Safe Yield Reset methodology, the 2017 Court Order included provisions regarding potential future updates to the Safe Yield Reset methodology:

> *"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*

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[5] OBMP Implementation Plan, p. 44-45, Program Element 8 – Develop and Implement Groundwater Storage Management Program, Program Element 9 – Develop and Implement Storage and Recovery Program, http://www.cbwm.org/docs/legaldocs/Implementation_Plan.pdf

[6] See Section 6.5 of the June 2001 Chino Basin Watermaster Rules and Regulations, http://www.cbwm.org/docs/rulesregs/CBWM%20Rules%20and%20Regulations.pdf

[7] The report 2013 Groundwater Model Update and Recalculation of the Safe Yield Pursuant to the Peace Agreement, http://www.cbwm.org/docs/engdocs/WEI%202013%20CBWM%20Recalculation%20Model%20Update/20151005_WEI_2013_CBWM_Recal_Model_Final_low.pdf

> *incorporate future advances in best management practices and hydrologic science as they evolve over the term of this order."*

Page 17 of the 2017 Court Order requires that "[t]he Pools be provided with reasonable opportunity, no less frequently than annually, for peer review of the collection of data and the application of the data collected in regard to" the update of the Safe Yield Reset methodology and the other requirements set forth in the 2017 Court Order.

The Safe Yield of the Chino Basin was recalculated in May 2020 using the 2020 Chino Valley Model (2020 CVM) and documented in the *2020 Safe Yield Recalculation Report* (2020 SYR Report) (WEI, 2020).[8] The Court adopted a Safe Yield of 131,000 acre-feet per year for the period of FY 2020/21 through 2029/30.[9] To aid the development of the 2020 CVM and its application to recalculate the Safe Yield, Watermaster conducted several peer review/stakeholder workshops for the Parties and their invited technical consultants. The questions and comments that arose during the review process were recorded and responded to in writing in Appendix F of the 2020 SYR Report. Several of these comments and questions are related to the Safe Yield Reset methodology and can be grouped into the following two categories:

- Recommendations to characterize and address uncertainty in the 2020 CVM and SYR methodology.
  - Uncertainty in groundwater model parameters (Appendix F-6, page 2-3; Appendix F-6, page 25)
  - Uncertainty in historical data (Appendix F-6, page 14)
  - Uncertainty in supply and demand projections (Appendix F-2, page 4; Appendix F-2, page 8; Appendix F-4, page 4; Appendix F-6, page 2-3; Appendix F-6, page 20)
  - Uncertainty in projected hydrology and human behavior (Numerous)
- Recommendations to reconsider the 10-year prospective calculation of the Safe Yield (Appendix F-5, page 1; Appendix F-5, page 3; Appendix F-6, page 22; Appendix F-7, page 1-2).

1.1 Scope of Work to Update the Safe Yield Reset Methodology

In FY 2020/21 and early FY 2021/22, Watermaster and the Parties collaborated to develop and refine a scope of work to update the Safe Yield Reset methodology pursuant to the 2017 Court Order and the above recommendations of the Parties. The initial scope of work comprised the following steps:

1. Watermaster's Engineer will develop a TM defining the various sources of modeling uncertainty that should be considered and addressed in an updated Safe Yield Reset methodology, including related questions necessary to answer when updating the Safe Yield Reset methodology. This TM will be submitted to the Parties for review and comment.
2. Watermaster's Engineer will conduct a peer review meeting to discuss the content of the TM described in Step 1. Feedback gathered from the peer review committee will inform the development of a process to define the proposed approaches to address the sources of model uncertainty in the proposed Safe Yield Reset methodology update.

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[8] The 2020 Safe Yield Recalculation Report, http://www.cbwm.org/docs/engdocs/Ground%20Water%20Modeling/20200515_Final_2020SYR_Report.pdf

9 Orders for Watermaster's Motion Regarding the 2020 Safe Yield Reset Agreement, Amendment of Restated Judgment, Paragraph 6, Superior Court for the County of San Bernardino (2020), http://www.cbwm.org/docs/WatermasterCourtFilings/2020/20200806%20Notice%20of%20Orders.pdf

3. Watermaster's Engineer will prepare responses to the comments received from the peer review committee and prepare a supplemental scope and budget for the process to define and document the proposed approaches to address model uncertainty. Watermaster will introduce this supplemental scope and budget as a budget amendment to be approved through the Watermaster process.

The TM described in Step 1 was distributed to the Parties on October 21, 2021. The peer review meeting described in Step 2 was held on October 26, 2021. The supplemental scope and budget described in Step 3 was introduced to the Watermaster Pool Committees, Advisory Committee, and Board in November 2021 and was approved by the Watermaster Board on November 18, 2021. The remaining steps in the scope of work include:

4. Watermaster's Engineer will complete a survey of the state-of-the-art approaches to address the sources of uncertainty identified in the TM described in Step 1 (i.e., model parameters, water supply/demand projections, and climate projections). This will include the alternative approaches and datasets suggested in the October 26, 2021, peer review meeting. Watermaster's Engineer will choose up to three approaches for each source of uncertainty to define in the next step.
5. Watermaster's Engineer will define a method to implement each of the approaches selected in Step 4. Each method will consist of detailed steps for implementation in the calculation of the Safe Yield.
6. Watermaster's Engineer will quantify the feasibility of the methods defined in Step 5. This will involve (i) testing the chosen methods and amending them as needed; (ii) determining the necessary computational capabilities necessary to implement the methods (e.g., parallel computing); and (iii) developing a general analysis of costs (e.g., staff time, computational resources) and benefits for each of the proposed methods. Sub-steps (i) and (ii) pertain to parameter uncertainty only. These estimates will aid in a comparison and selection of a preferred updated Safe Yield Reset methodology.
7. Watermaster's Engineer will prepare a TM documenting the findings from Steps 4 through 6 and a recommended Safe Yield Reset methodology update. This TM will be reviewed with Watermaster staff before distributing to the Parties for review.
8. Watermaster will conduct multiple peer review workshops to solicit feedback on the TM and the recommended Safe Yield Reset methodology update. This step may include multiple iterations of the draft TM.
9. Following the completion of the peer review process, Watermaster's Engineer will finalize the TM prepared in Steps 7 and 8 and prepare a summary TM with the proposed Safe Yield Reset methodology for submittal to the Court.
10. Watermaster's Engineer will work with Watermaster staff and legal counsel to assist with the Court-approval process.

Two drafts of this TM (prepared as Step 7) were distributed to the Parties and the peer review committee in May and July 2022 for review and comment. Watermaster held workshops on May 19, 2022 and July 20, 2022, to review the contents of the draft TMs and solicit feedback from the Parties and the peer review committee (Step 8). Following these workshops, several peer reviewers provided written comment on the draft TMs. These comments and West Yost's responses to the comments are included as Attachment B. A summary TM has also been prepared and is included as Attachment C (Step 9).

1.1 Outline of This Technical Memorandum

This TM includes the following sections.

- **Section 1: Background and Objectives**
- **Section 2: Overview of Uncertainty in Surface-Water and Groundwater Modeling**
  Provides an overview of the sources of uncertainty in surface-water and groundwater modeling as well as a description of best management practices published by the California Department of Water Resources (DWR) on how to address uncertainty in sustainable groundwater management.
- **Section 3: Uncertainty in the CVM and its Use in the Safe Yield Reset**
  Discusses the sources of uncertainty specific to the CVM and the Safe Yield Reset methodology.
- **Section 4: Potential Approaches for Characterizing and Addressing Uncertainty**
  Describes potential approaches and recommended methods to characterize and address uncertainty for updating the Safe Yield Reset methodology.
- **Section 5: Recommended Process to Calculate the Safe Yield**
  Describes the recommended Safe Yield Reset methodology update.
- **Section 6: Cost Estimate and Schedule**
  Summarizes the cost estimate and schedule developed for the implementation of the updated Safe Yield Reset methodology into the 2025 Safe Yield Reevaluation.
- **Section 7: References**

2.0 OVERVIEW OF UNCERTAINTY IN SURFACE-WATER AND GROUNDWATER MODELING

This section provides an overview of uncertainties in surface-water and groundwater modeling as well as a description of best management practices published by the DWR on how to address uncertainty in sustainable groundwater management.

Uncertainty analysis in calibration and projection is an important part of surface-water and groundwater modeling. Prior practice in environmental impact assessments typically involves developing a single numerical groundwater model with limited uncertainty analysis. Considered in a risk management context, this approach is often insufficient to predict the range of potential impacts and their likelihood. A quantitative uncertainty analysis, however, delivers a range of model predictions (simulating historical or future conditions) with associated likelihoods, each plausible in that they are consistent with all available information and data. Uncertainty analysis also identifies the main sources of uncertainty and the extent to which the uncertainty in outcomes can be reduced by incorporating additional data into the model (Middlemis and Peeters, 2018). An uncertainty analysis of model parameters has the benefit of identifying gaps in data or understanding that may inform future monitoring (DWR, 2016). An uncertainty analysis of model projections improves the understanding of the sensitivity of modeled responses to future assumptions.

2.1 Sources of Uncertainty in Surface-Water and Groundwater Modeling

Groundwater management faces uncertainty on many fronts: in understanding the behavior of the groundwater system; in anticipating possible future climatic, economic, or geopolitical conditions; and in prioritizing management objectives, all of which combine to add ambiguity in the evaluation of management options (Guillaume et al., 2016). For example, the subsurface environment is complex, heterogeneous, and difficult to directly observe, measure and characterize; and, groundwater systems are influenced by multiple factors, including geology, topography, vegetation, climate, hydrology, and human activities. Uncertainty in these factors affects our ability to accurately describe the existing groundwater system or predict its future state (Middlemis and Peeters, 2018).

Uncertainty in a model can be defined as the difference between the model and the complex physical system that the model represents. Since a mathematical model is a simplification of the complex system and processes, there will always be some difference between the model and reality (Johnson, 2010) and there will always be alternative models or model parameters that are plausible representations of the physical system. Uncertainty can be expressed in terms of the parameters used to describe the system or the accuracy in model predictions.

The remainder of this section summarizes the main sources of uncertainty in surface-water and groundwater modeling.

2.1.1 Historical Data

Historical data can be divided into two groups: (1) data that may be observed directly, such as precipitation, temperature, stream discharge, metered pumping, managed artificial recharge, wastewater discharge, and groundwater levels, and (2) data that cannot be or is not observed/measured directly, such as evapotranspiration, unmanaged recharge, septic tank discharge, unmetered pumping, and unmeasured applied water. Some data of the second group can be estimated based on other measurable data; for example, evapotranspiration can be estimated based on temperature, relative humidity, wind speed, net radiation, and crop type.

Historical data are used in groundwater models for various purposes, primarily for direct model inputs and model calibration. Some historical data are indirectly used to estimate parameters or boundary conditions in the model (e.g., using historical groundwater levels and borehole lithology to infer the hydraulic properties of a fault barrier). The quality of data used to build a model directly affects the quality of the model projection. Some of the types of historical data and their uses are listed in Table 1 below.

Model uncertainties related to historical data may exist due to: measurement error (e.g., inaccurate measurements of groundwater levels which hampers model calibration); lack of records (e.g., inadequate borehole data to describe the aquifer geometry and composition); inconsistent spatial resolution (e.g., paucity of groundwater-level data in areas or depths of the basin which hampers model calibration); and inconsistent temporal resolution (e.g., paucity of historical groundwater-level data which hampers model calibration).

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		

2.1.2 Surface Water and Groundwater Model Parameters

Uncertainty exists in the ways that the physical environment is represented in a model. This includes: (1) hydraulic parameters (e.g., hydraulic conductivity, specific storage, specific yield) that govern the simulated behavior of the groundwater-flow system; (2) hydrogeologic features (e.g., aquifer geometry, hydrostratigraphy, barriers to groundwater flow) that are underground and are often not well understood; and (3) hydrologic processes (e.g., evapotranspiration, streambed recharge, and deep infiltration of precipitation and applied water) that are typically not measured directly. Initial estimated values of hydraulic parameters and parameters representing hydrogeologic features are usually assigned to a groundwater model during model construction. Parameters governing hydrologic processes are assigned to the surface-water and groundwater models. Hydraulic parameters, parameters representing hydrogeologic features, and parameters governing hydrologic processes are then adjusted during the calibration process that attempts to minimize the differences between observed historical data and the model-simulated data.

Another related problem regarding uncertainty in model parameters is the existence of non-unique solutions as demonstrated by Freyberg (1988) and Hunt et al. (2020). Non-unique solutions of parameter combinations occur when there is more than one option for an unknown parameter that is being solved during the calibration process. The problem of non-uniqueness can result a model that meets calibration criteria but fails to adequately represent the real system.

2.1.3 Demand and Supply Plan Projections

The ability of a model to forecast the response of a groundwater system is not only dependent on the quality of the model calibration but is also dependent on future surface water and groundwater management projections. Long-term forecasts of water demand and available water supplies are critical inputs to water utility planning efforts and decision making (Kiefer, 2016). Forecasting water demands and supply plans is uncertain and influenced by macro-socioeconomic and climatic factors, as well as local behavior of consumers (Bruce, Brown, and Dufour, 2019).

In groundwater modeling, the projected water demand is coupled with a water-supply plan that assumes the use of various quantities of the available water sources, including groundwater pumping, local surface water, imported water, and recycled water. Wastewater disposal plans that describe the fate of the water supplied are also required to simulate the feedback between wastewater disposal and groundwater recharge. Translating the water supply and wastewater plans into groundwater model inputs also translates the uncertainty in these plans.

2.1.4 Projected Climate Impacts on Land Surface Processes

The climate directly and indirectly impacts the groundwater system through recharge and changes in water use in response to climate.

Currently, many studies on climate impacts rely on the projections of Global Circulation Models or Global Climate Models (GCMs) involved in the fifth phase of the Coupled Model Intercomparison Project (CMIP5) (Taylor and others, 2012). CMIP5 assumes four Representative Concentration Pathways (RCPs) that describe different climate futures, all of which are considered possible. The projections of updated GCMs of the sixth phase of the Coupled Model Intercomparison Project (CMIP6) (PCMDI, 2021) will soon replace those of CMIP5.

For use in SGMA-related water budget development and groundwater modeling, DWR provides climate change datasets in the form of change factors of precipitation, reference evapotranspiration (ET_0), and surface runoff based on 20 projections composed of 10 GCMs, each with two RCPs. According to the Guidance for Climate Data Change Use During Groundwater Sustainability Plan Development (DWR, 2018), change factor ratios were calculated as the future scenario (2030 or 2070) divided by the 1995 historical temperature detrended (1995 HTD) scenario. The 1995 HTD scenario represents historical climate conditions where the observed increasing temperature trend is removed. Review of the change factors for the Chino Valley indicated that average precipitation is projected to decrease and average ET_0 is projected to increase (WEI, 2020). As with all model projections, the GCM projections are inherently uncertain.

Groundwater demands can change in response to climate, and the feedbacks between groundwater demands and climate must be considered in groundwater management. For example, California has taken multiple actions to address the recent drought. On April 1, 2015, Governor Jerry Brown released Executive Order B-29-15, which mandated a statewide reduction in urban potable water usage of 25 percent through February 2016. This resulted in several Chino Basin Parties reducing their groundwater pumping, even though groundwater rights and storage accounts were unaffected by the order.

In 2018, the California legislature passed, and the Governor signed, two pieces of legislation (AB 1668 & SB 606) collectively known as "Making Conservation a California Way of Life" to establish new water efficiency standards for purveyors in response to the California drought. The legislation requires water suppliers to meet their supplier-specific urban water use objective starting in 2027, which is defined as a combination of objectives set for indoor residential water use, outdoor residential water use (ORWU), as well as other uses. The ORWU objective, which takes direction from previous legislation establishing California's Model Water Efficient Landscape Ordinance (MWELO), has not yet been approved by the State Water Board. However, DWR has proposed the following provisional method to calculate a supplier's ORWU (gallons) objective[10]:

$$ORWU = (ET_0 - P_{eff}) * ETF * LAs * 0.62$$

where, ET_0 is reference evapotranspiration (inches), P_{eff} is effective precipitation (inches), ETF is the supplier level evapotranspiration (ET) factor, LAs is landscape area (square ft) for a water supplier, and 0.62 is the unit conversion factor. If a supplier does not meet their ORWU objective by 2027, they may be required to reduce outdoor water use or be subject to penalties. A reduction in outdoor water use will reduce return flows from irrigation and precipitation (i.e., deep infiltration of precipitation and applied water [DIPAW]). In 2021, the DWR proposed a value of 0.7 for ETF. Additionally, the DWR is considering recommending that the value of ETF be reduced to 0.55 for any new development.

2.2 Modeling Best Management Practices for the Sustainable Groundwater Management Act

The Sustainable Groundwater Management Act (SGMA) was passed by the California legislature in 2014 "to support the long-term sustainability of California's groundwater basins". Pursuant to SGMA, the DWR published a series of Best Management Practices (BMPs) to aid Groundwater Sustainability Agencies (GSAs) and other stakeholders in efforts to meet the Groundwater Sustainability Plan (GSP) Regulations (DWR, 2016). The DWR's Modeling BMP (Modeling BMP) is meant to "assist with the use and development of groundwater and surface water models."

The Modeling BMP includes the following two recommendations for characterizing and addressing uncertainty:

1. ***Develop and run predictive scenarios that establish expected future conditions under varying climatic conditions, and implementing various projects and management actions.*** *Predictive scenarios should be designed to assess whether the GSP's projects and management actions will achieve the sustainability goal, and the anticipated conditions at five-year interim milestones. Predictive scenarios for the GSP should demonstrate that the sustainability goal will be maintained over the 50-year planning and implementation horizon.*
2. ***Conduct an uncertainty analysis of the scenarios.*** *This is to identify the impact of parameter uncertainty on the use of the model's ability to effectively support management decisions and use the results of these analyses to identify high priority locations for expansion of monitoring networks. Predictive uncertainty analysis provides a measure of the likelihood that a reasonably constructed and calibrated model can still yield uncertain results that drive critical decisions. It is important that decision makers understand the implications of these uncertainties when developing long-term basin management strategies. As discussed in other sections of this BMP, this type of analysis can also identify high-value data gaps that should be prioritized to improve confidence in model outputs and yield a tool that has an increased probability of providing useful information to support effective basin management decisions. A formal optimization simulation of management options may be employed, taking advantage of the predictive uncertainty*

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[10] DWR's proposed method is provisional because DWR is still finalizing the landscape area measurement data and considering stakeholder input.

> *analysis to minimize economic costs of future actions, while meeting regulatory requirements at an acceptable risk level.*

The Chino Basin is adjudicated and therefore exempt from many of the requirements of SGMA including the need to develop a GSP. The groundwater and surface-water models used in the Chino Basin have been approved for use by the Court. Furthermore, the groundwater models developed for GSPs are designed and interpreted to meet specific requirements of SGMA that are not entirely applicable to the Chino Basin. However, it is instructive to consider the above two recommendations when updating the Safe Yield Reset methodology, as they represent "best management practices" which are referenced in the 2017 Court Order.

3.0 UNCERTAINTY IN THE CVM AND ITS USE IN THE SAFE YIELD RESET

The previous section summarized the general sources of uncertainty in surface-water and groundwater modeling. This section identifies the sources of uncertainty specific to the CVM. Each source of uncertainty includes a brief description of how the model values were estimated for use in the 2020 SYR. Refer to the 2020 SYR Report for a more detailed description of each model input.

3.1 Historical Data

The following subsections describe the historical data sets that were collected or developed for use in the CVM, not including any historical data used to develop model parameters.

3.1.1 Precipitation

Precipitation is the primary source of water for the Chino Basin watershed. Estimates of precipitation over the 2020 CVM model domain were developed from precipitation stations operated and/or reported by the Los Angeles, San Bernardino, and Riverside County Flood Control Districts, NOAA, and others, and gridded precipitation data products produced by the PRISM Climate Group and NOAA. The monthly gridded precipitation estimates from the PRISM Climate Group were used to inform the spatial distribution of daily precipitation developed from precipitation stations for the period prior to the availability of gridded daily precipitation estimates from NEXRAD. NEXRAD estimates of daily precipitation were used starting in 2002.

3.1.2 Stream Discharge

Daily discharge estimates were obtained from the USGS through the USGS National Water Information System for the streams and channels tributary to and including the Santa Ana River. These discharge data were used in calibration of multiple parts of the 2020 CVM, including mountain-front runoff from the San Gabriel Mountains (the HSPF model) and the rest of the Chino Basin watershed tributary to Prado Dam (the R4 model).

3.1.3 Pumping

With one exception, groundwater pumping estimates were obtained from all pumpers through the Chino Basin and Six Basins Watermasters, the City of Corona, and the Cucamonga Valley Water District. The exception is overlying agricultural pumping in the Chino Basin which was estimated with the R4 model for the period 1978 through 2004.

3.1.4 Managed Aquifer Recharge

With one exception, estimates of Managed Aquifer Recharge (MAR) in the 2020 CVM domain were obtained from the entities that conduct recharge operations. The exception is estimates of stormwater captured at the major stormwater detention and recharge facilities in the Chino Basin which was estimated with the R4 model for the period 1978 through 2004. Starting in 2005, IEUA prepared estimates of stormwater captured at these facilities.

3.1.5 Wastewater Discharges

Wastewater discharges to stream channels in the 2020 CVM watershed. Data was obtained from the California Integrated Water Quality System, annual reports of the Santa Ana River Watermaster, the Cities of Corona, Riverside, and San Bernardino, and IEUA.

3.1.6 Groundwater Levels

Groundwater level measurements were obtained from the Chino Basin and Six Basins Watermasters, the Cities of Corona and Riverside, Cucamonga Valley Water District, the USGS, and the West Valley Water District.

3.1.7 Land Use

Historical land use datasets were acquired from the Southern California Association of Governments (SCAG), the DWR, and San Bernardino County. These land use datasets were available for specific years, and historical data before 1990 have gaps of six years or more between datasets. The R4 surface water model was run to simulate Deep Infiltration of Precipitation and Applied Water (DIPAW) and stormwater recharge (when data were unavailable) for each of these land use years, and the R4 model outputs were linearly interpolated between land use years.

3.1.8 Potential ET

ET_0 estimates for the 2020 CVM watershed were obtained from the California Irrigation Management Information System (CIMIS) stations located in Pomona and Riverside. The spatial distribution of daily ET_0 across the 2020 CVM watershed was estimated from the Pomona and Riverside CIMIS station ET_0 estimates using a spatial-temperature interpolation algorithm. For the period prior to these CIMIS stations becoming active, ET_0 was estimated by regression relationships developed at these stations with evaporation at Puddingstone reservoir.

3.1.9 Evaporation

Pan evaporation data from an evaporation pan at Puddingstone reservoir, operated by Los Angeles County Department of Public Works, was used to estimate evaporation losses from free water surfaces from surface water impounded in flood control and conservation basins and streamflow in channels.

3.1.10 Subsurface Inflow from Adjacent Groundwater Basins

Subsurface inflow from the Riverside Basin to the Chino Basin through the so-called Bloomington Divide area was set as a time-variant specified head boundary for the calibration period. The hydraulic conductivity of Layers 1, 3, and 5 adjacent to this boundary and the subsurface inflow from the Riverside Basin were estimated in calibration using the observed groundwater levels located in the Riverside Basin near the boundary.

Subsurface inflow from the Rialto Basin that occurs across the Rialto-Colton Fault was assumed to be the same value estimated in the calibration of the 2013 Chino Basin Model (WEI, 2015). The flux across the Rialto Fault is assumed to be either a constant inflow rate to the Chino Basin or a no-flow boundary depending on the geology along the fault. The range of subsurface inflow from the Arlington Basin to the Temescal Basin was estimated based on the Arlington Basin Model (WEI, 2009).

3.1.11 Unmanaged and Unintentional Recharge

Maliva (2019) defines unmanaged and unintentional recharge as “recharge incidental to other human activities. Unmanaged and unintentional urban recharge includes leakage from water and wastewater mains, discharges from on-site sewage systems, recharge from stormwater management infrastructure, and return flows from the irrigation of parks, lawns, and other vegetated areas.” The recharge estimates from on-site sewage systems and irrigation return flows are described below. The leakage from water and wastewater mains are not explicitly accounted for in the groundwater model for multiple reasons: 1) the inability to quantify the magnitude and geographic distribution of these losses and the proportion of losses that result in recharge, and 2) the likely small magnitude of these losses compared to the other recharge components in the Chino Basin. Recharge from stormwater management infrastructure (i.e., Municipal Separate Storm Sewer Systems) beyond the MAR facilities is minor (WEI, 2018a) and not explicitly accounted for in the 2020 CVM.

3.1.12 Septic Tank Discharge

Data for parcels with septic tanks were collected for the entire 2020 CVM model domain. The septic tank parcel data were overlaid on the groundwater model, and the numbers of septic tank parcels within each model cell were determined. Various leakage rates from septic tanks were applied to account for the groundwater recharge flux of each model cell with septic tanks. These rates were based on observed in wastewater inflows to nearby wastewater treatment plants.

3.1.13 Applied Water

The initial estimate of applied water for urban areas was estimated from reports prepared by the IEUA. Final estimates of applied water for urban irrigation were developed by calibrating the R4 model and extending the calibration results to non-IEUA areas in the Chino Basin. Estimates of DIPAW for agricultural, native, and undeveloped areas (land in transition from vacant and agricultural uses to urban uses) were made with the R4 model using historical information on vegetation type and associated root zone depth, soil type, permeable area, irrigable area, evapotranspiration, and precipitation.

3.2 Model Parameters

The following subsections describe the data sets and processes used to develop the model parameters for the CVM.

3.2.1 Hydraulic Conductivity, Specific Storage, and Specific Yield

The following procedure was used to estimate horizontal hydraulic conductivity, vertical hydraulic conductivity, specific storage, and specific yield in the groundwater model. First, data collected from multiple well boreholes was used to estimate the aquifer-system properties at the well locations. The Kriging method was used to spatially interpolate the estimates across the model domain. The model domain was then subdivided into several parameter zones based on an estimate of logical depositional environments. Each parameter zone was assigned a scaling factor which was adjusted during the model calibration process. The final calculated parameter value for any model cell (by model layer) was the product of the adjusted scaling factor and the initial hydraulic parameter value.

3.2.2 Hydraulic Characteristics of Faults

The faults that separate the Chino Basin, Cucamonga and Six Basins as well as internal faults and barriers within these basins, were simulated as horizontal flow barriers with the MODFLOW Horizontal-Flow Barrier (HFB) package. The estimated hydraulic conductivity values for these barriers were adjusted through model calibration. The sensitivity analysis conducted during calibration of the 2020 CVM indicated that the hydraulic characteristics of several faults are sensitive parameters in the model.

3.2.3 Stream Properties

For use in the surface water simulations, as-built drawings and field surveys from prior investigations were used to develop sub-watershed boundaries, channel and flood control and conservation basin geometry and facility operating schemes. For the groundwater model, the streambed elevations and geometry along creeks and channels were extracted from the 2015 LiDAR data along Santa Ana River with 1-meter resolution (US Army Corps of Engineers, 2015). Other streambed properties (e.g., conductance) were defined based on the streambed characteristics of the Santa Ana River and its tributaries. The stream properties were determined to be insensitive and were not adjusted through model calibration.

3.2.4 Groundwater Evapotranspiration

Groundwater ET was simulated with the MODFLOW Evapotranspiration Segments Package (ETS). This package requires the user to define the spatial extent of the riparian vegetation, the maximum ET rate for each model cell within the spatial extent, and a relationship between ET rate and depth to groundwater. The spatial extent of the riparian vegetation and the maximum ET rates were estimated based on aerial photos and the evaporation analysis of the Prado Basin prepared by Merkel (2006). The relationship between the ET rate and depth to groundwater was based on other modeling studies with similar climate and riparian vegetation. The groundwater ET parameters were determined to be insensitive and were not adjusted through model calibration.

3.2.5 Vadose Zone Travel (lag) Time

The HYDRUS-2D model was used to estimate lag time at several boreholes with detailed lithologic descriptions. For the boreholes that were investigated, the primary factor contributing to lag time was vadose zone thickness. These lag times were then generalized throughout the Chino Basin model domain based on vadose thickness and individual lag times were estimated for each model cell. Vadose zone travel (lag) time from the root zone to the water table ranges from about one to four years near the Santa Ana River to over 30 years in the City of Upland area, and typically ranges from 5 to 30 years in other areas. Vadose zone travel (lag) time was not adjusted through model calibration.

3.2.6 Land Use Parameters

Land use parameters (hydrologic soil type, crop coefficient, irrigation efficiency, curve number for impervious area, etc.) were obtained from the Department of Water Resources, Natural Resources Conservation Service (NRCS), San Bernardino County, and the Southern California Association of Governments. Land use type parameters were not adjusted through model calibration.

3.3 Demand and Supply Plan Projections

The following subsections describe the assumptions and data used to develop future projections for water demands and supply plans for the projection scenario of the CVM.

3.3.1 Projected Groundwater Pumping

Watermaster submitted a comprehensive data request to each Appropriative Pool Party and some of the larger Overlying Non-Agricultural Pool pumpers. Watermaster staff reviewed the Parties' responses and followed up for clarification, if necessary. The data provided by the Parties represents the best estimates of their demands and associated water supply plans. Individually and in aggregate, these water demands, and associated supply plans were the most reliable planning information available at that time. Watermaster translated the Parties' groundwater pumping projections included in the supply plans based on information regarding well priorities and the timing of groundwater pumping provided by each Appropriative Pool Party.

3.3.2 Projected Managed Artificial Recharge

Projected stormwater recharge in flood control and conservation basins was estimated with the R4 model based on existing and planned 2013 RMPU facilities that are assumed to be fully operational in 2023. Projected recycled water recharge is based on IEUA projections modified in the near term based on recent recharge history. Imported water was assumed to be recharged to meet Watermaster's replenishment obligations only.

3.3.3 Projected Wastewater Discharge

With one exception, the projected wastewater discharges were based on the "Most Likely Discharge" scenario documented in the Santa Ana River Waste Load Allocation Model Update Report (Geoscience, 2020). These projected discharges were based on estimates provided by the owners of each of the Publicly Owned Treatment Works (POTWs) that discharges wastewater to the Santa Ana River or its tributaries.

3.3.4 Land Use

Land use was assumed to transition from 2018 conditions to "built-out" conditions by 2040. Built-out conditions assumes 2018 land use with vacant and non-urban land uses to converted to land uses shown in the General Plans of the counties and municipalities that overlie the Chino Basin.

3.3.5 Subsurface Inflow from Adjacent Groundwater Basins

Subsurface inflow from the Rialto Basin that occurs across the Rialto-Colton Fault and subsurface inflow from the Arlington Basin to the Temescal Basin are modeled as they were in the calibration period. Groundwater discharges from the Riverside Basin to the Chino Basin through the so-called Bloomington Divide area was set as a constant specified flow boundary was assumed equal to the average subsurface inflow from the last five years of the calibration period.

3.3.6 Unmanaged and Unintentional Recharge

Future assumptions for unmanaged and unintentional recharge (with the exceptions identified below) are identical to the assumptions used in the historical data.

3.3.7 Septic Tank Discharge

Future locations of septic tank parcels are based on the land use planning data. The leakage rates from septic systems are assumed identical to the leakage rates assumed at the end of the calibration period.

3.3.8 Applied Water

Future assumptions for outdoor applied water are derived from the future water demand and water supply estimates discussed above and the irrigation assumptions for outdoor water use developed in model calibration. Given the uncertainties of the implementation and effects of the "Making Conservation a California Way of Life" legislation, any prescribed changes due to this legislation were not considered in the 2020 SYR projection scenario.

3.3.9 Projected Replenishment Obligation

Projected future replenishment obligations are based on current and projected Safe Yield and assumptions of the transfer activity among the Parties. This process is described in detail in the 2020 SYR Report.

3.3.10 Future Management Programs

Beyond recalculation of the Safe Yield, the CVM is used to support other management goals pursuant to the Program Elements of the Chino Basin Optimum Basin Management Plan. These management goals include maximizing recharge in the basin, managing land subsidence, ensuring the management of water quality, and supporting riparian habitat. To address these management goals, future management actions may be required that would alter the projected supplies and demands (e.g., reducing pumping to mitigate subsidence).

3.4 Projected Climate Impacts on Land Surface Processes

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 impact of new conservation legislation was not included in the 2020 Safe Yield Recalculation.

4.0 POTENTIAL APPROACHES FOR CHARACTERIZING AND ADDRESSING UNCERTAINTY

This section presents a summary of the tools and approaches for characterizing model-parameter and predictive uncertainties that may exist in groundwater models, including errors introduced by model-design and process-simulation assumptions, incomplete knowledge of model parameters, and contributions to predictive uncertainty from estimated future system stresses, such as water demands, supply plans, policies, and climate (Doherty, Hunt, and Tonkin, 2011; Hunt and Welter, 2010).

Approaches to characterize uncertainty in simulation models range in complexity and include the following categories:

1. **Deterministic:** A deterministic approach assumes and simulates one possible future. For example, the 2020 CVM that was used to calculate Safe Yield assumed a single physical groundwater system realization (aquifer parameter distribution) and a future scenario that was developed based on the climate change factors provided by the DWR and the water suppliers' best estimates of the future water demand and supply plans.
2. **Robust Decision Making (RDM):** In this approach, numerous model scenarios are run with various input datasets to determine the possible outcomes against a wide range of plausible futures. The input datasets may include one or more of the following:
   - Alternate physical groundwater system realizations that meet the calibration criteria.
   - Alternate future climate projections (e.g., precipitation and ET_0 projections based on climate models).

- Alternate water demand and supply plans based on various assumptions of future population, water management policy implementation, and expected behavior of individual pumpers.
- Predetermined management actions or anticipated projects affecting the stresses in the model (e.g., additional wells or recharge basins). Most of the approved GSPs and Alternative GSPs simulate the groundwater responses to scenarios including management actions pursuant to the SGMA (e.g., Dudek, 2019; Santa Cruz Mid-County Groundwater Agency, 2019; MWH, 2016).

3. **Dynamic Planning:** In a dynamic planning framework, management actions are triggered by the state of the system, which can be a single variable or a combination of variables. For example, well field pumping can be dynamically adjusted based on the simulated groundwater level to prevent the groundwater level from dropping below a threshold level. In another example, stream flow diversion can be dynamically adjusted to ensure a minimum stream flow is maintained. Dynamic planning frameworks require a thorough understanding of potential triggers and actions which often assume centralized planning, where a single decision-maker determines management actions, which is often unrealistic in a real-world planning process (Giuliani et al., 2015). A dynamic planning framework may require iterative input from different sets of stakeholders (Quinn et al., 2017; Wu et al., 2016) and could be revised to represent a decentralized process in which multiple agents optimize for their individual benefits (Jenkins et al., 2017).

The current practice of periodic recalculations of the Safe Yield that involves periodic methodology review and stakeholder involvement is an example of a dynamic planning framework. However, the current deterministic approach of using a single calibration realization and projection scenario does not allow for an assessment of the uncertainties in model projections. The RDM approach is recommended for the development of groundwater models for SGMA compliance (Moran, 2016) without introducing additional complexities and potential uncertainties that may be present in a dynamic planning framework. Therefore, the recommended approaches in this TM are based on RDM principles.

4.1 Historical Data

Historical data includes records of precipitation, stream discharge, pumping, and other data sets described in Section 3.1. While there is some uncertainty in the historical data, it is our professional judgement that an uncertainty analysis of the historical data would be of limited value to the calibration of the model and the calculation of the Safe Yield. The 40 years of measured data used for calibration of the 2020 CVM was collected by numerous entities and it is appropriate to assume that these measurements have random errors overall. Therefore, for the uncertainty analysis of the calibration parameters, the uncertainty in observed data will not be addressed. This approach was agreed upon by the peer review committee at its October 26, 2021 meeting.

4.2 Model Parameters

The 2020 CVM (WEI, 2020) consists of HSPF and R4 surface-water models and a groundwater model based on MODFLOW-NWT (Niswonger et al., 2011). The surface-water models were calibrated manually. R4 was used to estimate DIPAW at the root zone, to estimate stormwater runoff and stormwater recharge, and to simulate the routing of water through lined and unlined channels across the model domain. The estimated DIPAW was used as groundwater recharge to the groundwater model by considering storage and travel time through the vadose zone. The estimated runoff values were diverted to applicable stream reaches. The routed water was sent to recharge basins or stream reaches. The groundwater model was calibrated by conducting a sensitivity analysis of model parameters using the parameter estimation code PEST (Doherty, 2018) to adjust sensitive parameters to improve the model representation of the groundwater system by minimizing the differences between the historical and the model-calculated groundwater level elevations and discharge of the Santa Ana River at Prado Dam. A residual analysis of the observed versus simulated data was conducted to evaluate and characterize model error.

The problem of non-uniqueness needs to be addressed because parameter and predictive uncertainty is unavoidable. Justification for the use of a model in environmental management must not rest on an assumption that the model's predictions will be correct. Rather, justification for its use must rest on the premises that its use (i) enables predictive error and/or uncertainty to be quantified and (ii) provides a computational framework for reducing this predictive error and/or uncertainty to an acceptable level, given the information that is available. As such, by quantifying the uncertainty associated with predictions of future hydrologic system behavior, associated risk can inform the decision-making process (Doherty, Hunt, and Tonkin, 2011).

4.2.1 Approaches to Characterizing Uncertainty in Model Parameters

This section presents three selected methods to quantify predictive uncertainties and discusses each method's associated computational framework. The focus of each of the methods is to efficiently generate a sufficient number of calibrated groundwater system realizations (calibrated realizations) – each realization comprises a set of model parameters that meet the model calibration criteria. Once this is done, an ensemble of projection realizations can be generated by replacing the parameters of the projection model with the parameters of the calibrated realizations. The result of the ensemble of projection realizations is an ensemble of probable outcomes that can be used to determine the central tendency of projected Safe Yield and to quantify the uncertainty of the projected Safe Yield due to uncertainties in model parameters.

4.2.1.1 Generalized Likelihood Uncertainty Estimation (GLUE)

GLUE (Beven and Binley, 1992) is a statistical method used in hydrology for quantifying the uncertainty of model predictions. GLUE assumes the concept of equifinality of models, parameters, and variables. Equifinality originates from the imperfect knowledge of the system under consideration, and many sets of models, parameters, and variables may therefore be considered equal or almost equal simulators of the system. The GLUE methodology can be implemented in the following steps.

1. Select a group of model parameters with the highest relative sensitivity and define the distribution function of each selected parameter.
2. Conduct a Monte Carlo (Eckhardt, 1987; Tarantola, 2005) sampling analysis in the following steps:
    a. Randomly pick a set of parameters within their respective bounds.
    b. Modify the calibration model with the random set of parameters.
    c. Run the modified model and check for the calibration criteria. If the calibration criteria are met, save the set of parameters as a calibrated parameter realization.
    d. Repeat steps (a) to (c) until a defined number of realizations is reached.
3. Generate projection realizations. A projection realization is based on the parameters of a calibrated parameter realization and incorporates climate, hydrology, and supply/demand projections.
4. Conduct simulation runs of the projection realizations. Develop recommendations based on the simulation results of the realizations.

White (2018) applied the GLUE method on a synthetic model (Freyberg, 1988) with 100,000 realizations of five model parameters (i.e., hydraulic conductivity, historical recharge, future recharge, historical pumping rate multiplier, and future pumping rate multiplier) to quantify the efficacy of the Monte Carlo sampling analysis and to compare it with PESTPP-IES (see below). The Monte Carlo sampling analysis identified 275 calibrated realizations (an acceptance rate of 0.275 percent) that met a predefined calibration criterion. Had this method been applied to the 2020 CVM, which took four hours to complete a model run, it would take 45 years to obtain 275 realizations for the same acceptance rate. Due to the low acceptance rate, this method is often not practical for complex models with a long run time.

4.2.1.2 Null-Space Monte Carlo (NSMC)

NSMC (Tonkin and Doherty, 2009) is a method for generating calibrated realizations. Instead of creating a single calibrated realization, NSMC can be used to create multiple calibrated realizations. The NSMC methodology can be implemented in the following steps (Doherty, Hunt, and Tonkin, 2011).

1. Prior to implementation of a NSMC analysis, it is assumed that a model has been calibrated, a set of calibrated model parameters is available, and the distribution functions of each parameter are defined.
2. Conduct a NSMC sampling analysis in the following steps with the help of multiple programs (RANDPAR, FIELDGEN, PPSAMP, PNULPAR, FAC2REAL, and TWOARRAY) included in the PEST Groundwater Data Utility (Watermark Numerical Computing, 2020).
    a. Randomly pick a set of parameters within their respective bounds.
    b. The calibrated parameters are subtracted from the stochastically generated parameters.
    c. The result of step (b) is projected onto the calibration null space.
    d. The solution-space component of the stochastically generated parameters is replaced by the parameter field arising from the calibration.
    e. Recalibrate the model and save the set of parameters as a calibrated parameter realization. Ideally, because null-space parameter components do not appreciably affect model outputs that correspond to elements of the calibration dataset, the null-space processing of the optimal parameter set in step (d) should result in a calibrated model. In practice, however, the null-space-processed parameters commonly result in a slightly de-calibrated model. Recalibration of such a model normally requires only a fraction of the number of model runs per iteration as there are adjustable parameters.
    f. Repeat steps (a) to (e) until a desired number of calibrated parameter realizations is reached.
3. Generate projection realizations. A projection realization is based on the parameters of a calibrated parameter realization and incorporates climate, hydrology, and supply/demand projections.
4. Conduct simulation runs of the projection realizations. Develop recommendations based on the simulation results of the realizations.

Overall, the NSMC sampling analysis involves many computational steps that require specific programs and input parameters. A conceptual example for implementing the second level of parameterization is given in Part B of the Groundwater Data Utility (Watermark Numerical Computing, 2020).

4.2.1.3 Iterative Ensemble Smoother (iES)

Most algorithms for model parameter estimation (PE) and uncertainty quantification (UQ) are computationally constrained by number of adjustable parameters. Because of this constraint, assumptions must be employed to reduce the number of parameters, which is a form of model simplification. This simplification can lead to model error phenomena such as parameter compensation and undetectable forecast bias (White, 2018; Doherty and Christensen, 2011).

To relax or eliminate the computational bounds induced by the number of parameters, iterative ensemble smoothers (iES) have emerged as a class of algorithms for PE and UQ. Chen and Oliver (2012, 2013) introduced an efficient iES formulation, which was implemented by White (2018) and White et al. (2020) in the open-source code PESTPP-IES. Based on the nature of the iES algorithm, the number of model runs per estimation iteration depends on the number of desired calibrated groundwater system realizations and does not depend on the number of adjustable parameters. Additionally, the iES algorithm yields an ensemble of the calibrated parameter realizations that can be used to quantify uncertainty in forecasts of interest.

PESTPP-IES can be applied in the following steps.

1. Construct a model and prepare for parameter estimation according to the input instructions of PEST and PESTPP-IES, including the pilot points as well as variograms and covariance matrices of adjustable model parameters. Covariance matrices can be generated based on the variograms of adjustable parameters.
2. Run PESTPP-IES to generate the desired number of calibrated parameter realizations. In order to achieve a good fit between model outputs and the calibration dataset, the number of the desired calibrated parameter realizations (and hence the number of model runs) must be greater than the dimensionality of the solution space of the inverse problem. The dimensionality of the solution space often must be guessed. An ensemble size of a few hundred (and often less) is suitable for most occasions (Doherty, 2019).
3. Generate projection realizations. A projection realization is based on the parameters of a calibrated parameter realization and incorporates climate, hydrology, and supply/demand projections.
4. Conduct simulation runs of the projection realizations. Develop recommendations based on the simulation results of the realizations.

In comparison with the NSMC method, the iES-based solution is relatively straightforward. The required utility programs for preparing required input data for PESTPP-IES are readily available as well.

4.2.2 Recommendation

All methods described above can be used to address parameter uncertainties. However, a comparison of the major criteria shown in Table 2 suggests that the iES is the most favorable method due to the computation time being independent of the number of adjustable parameters, which results in a relatively lower computing cost. The iES method and its software implementation PESTPP-IES are recommended to be used for quantifying parameterization-related uncertainties. Attachment A documents the use of a synthetic model to illustrate the detailed steps to generate calibrated parameter realizations with PESTPP-IES and other utility programs.

To reduce the complexity of combining calibrated realizations of the HSPF, R4, and MODFLOW models, it is recommended to run a deterministic simulation of the HSPF and R4 models, and then include the R4-estimated DIPAW and subsurface inflows to the MODFLOW model as adjustable parameters in PESTPP-IES.

Table 2. Comparison of Methods to Quantify Predictive Uncertainties

Criteria	GLUE	NSMC	iES
Simplicity of the Method	Simple	Complex	Moderate
Computing Cost (relative 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

4.3 Demand and Supply Plan Projections

Water demand and supply plans depend on various assumption of future conditions, such as population, climate, and regulatory requirements. The uncertainty associated with water demand and supply plans should be quantified because water demand and supply plans include projections of pumping, recharge, and storage which can affect groundwater levels and the net recharge of the Chino Basin.

4.3.1 Approaches to Characterizing Uncertainty in Demand and Supply Plan Projections

Several water resource planning studies in the Santa Ana River watershed and North America have employed RDM or similar approaches to address uncertainties in future water demands and supply plans (USBR, 2012; Dennehy, 2021; Miro et al., 2021; Valley Water, 2022). The planning studies that employ RDM generally have the objective of evaluating uncertainties in future conditions to inform management or planning decisions. The amount of detail applied to develop scenarios using RDM is not prescribed and depends on the available data to characterize external drivers, management schema, and planning objectives (Groves et al., 2019).

San Bernardino Valley Municipal Water District (Valley District) recently employed RDM in their water resources planning (Miro et al., 2021), which included development of four scenarios of future demands and nine scenarios of future imported water supply. The demand futures were developed with the Valley District's retail agencies to understand the drivers in water demand and the uncertainties in projecting changes in water demand. The range in potential future imported water supplies were derived from the Metropolitan Water District of Southern California's simulated operational scenarios of the State Water Project, the imported water supply in the region.

4.3.2 Recommendation

The current Safe Yield Reset methodology would be improved by shifting from a deterministic approach to an RDM approach involving multiple discrete demand and supply plan scenarios. To quantify the uncertainty in demands and supply plans in the Chino Basin and develop demand and supply plan scenarios, a method similar to what Valley District employed to implement the RDM approach (Miro, et al., 2018; Miro, et al., 2021) is recommended. The proposed method to execute this approach includes the following:

1. Develop a list of the drivers of changes to future water demands and supplies. Examples of these drivers include population growth, land use, policies (e.g., conservation mandates), and climate change. Conduct one to three workshops with the Parties and wholesale agencies that serve the Chino Basin to ensure that the most significant drivers are considered.
2. Use the drivers identified in step 1 above to develop demand and supply plan scenarios. These scenarios will include assumptions of each driver and its effect on future demands and water supply plans.
3. Select a subset of the demand and supply scenarios developed in step 2 that will be incorporated into the projection realizations.
4. Develop quantitative water supply plans for the selected demand and supply scenarios. This will rely on a review of relevant planning information (e.g., Urban Water Management Plans, regional water resources planning studies [Groves and Syme, 2022], and data on cultural conditions collected pursuant to the 2017 Court Order) and workshops with the Parties and wholesale agencies. This effort will leverage existing planning studies to define the scenarios and will not include the development of any new planning studies (e.g., Oxnard, 2017; Miro, et al., 2018; Valley Water, 2022).
5. Conduct at least two workshops with the Parties and wholesale agencies to refine and iterate the water supply plans. If desired, the Parties may provide feedback to aid in the assignment of non-uniform likelihoods to the chosen water demand and supply plan scenarios. For example, one scenario could be chosen as the "most likely" scenario, the results of which may be assigned a higher weight than the results of other scenarios in the interpretation of the ensemble (see Section 5.0).
6. Translate the demand and supply scenarios and water supply plans into model inputs (e.g., groundwater pumping, outdoor urban water use, managed recharge, imported water, others) and integrate into projection realizations.

Demand and supply plan scenarios should be developed to be consistent with the chosen climate scenarios to capture plausible combinations of drivers (e.g., population growth, water conservation, and restriction of imported water) and their effect on water demand and supply plans.

4.4 Climate Projections

As described in Section 2.1.4, the climate directly and indirectly impacts the groundwater system through recharge and changes in groundwater use. To incorporate the climate impacts in a groundwater model projection, future precipitation and ET_0 values must be estimated. In the 2020 CVM, future precipitation and ET_0 values were obtained by adjusting the historical records by the DWR Change Factors (DWR, 2018). Since the DWR Change-Factors were derived based on the ensemble average of 20 selected model runs from CMIP5, the 2020 CVM implemented a deterministic climate scenario representing the projected central tendency of future climate. In this approach, the uncertainty in the projected Safe Yield due to individual climate projections could not be characterized.

To overcome this limitation, relevant literature was reviewed to explore the feasibility of estimating future precipitation and ET_0 values based on the available climate model datasets. The following sections document the findings and recommendations from the literature review.

4.4.1 Approaches to Characterizing Uncertainty due to Climate Change

This section provides an overview of the state of global climate model research and the available datasets from the climate models.

4.4.1.1 State of Global Climate Models (GCMs)

GCMs are numerical models and are the most advanced tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations. Many GCMs were developed in the past decades by research institutes across the world. GCMs vary in their capabilities, including algorithms, grid resolutions, and simulated earth system processes. Global climate research efforts are coordinated by the Intergovernmental Panel on Climate Change (IPCC) through a series of the Coupled Model Intercomparison Projects (CMIPs). In each iteration of the CMIPs, prescribed assumptions of future climate forcing factors and boundary conditions are implemented by various GCMs. As a result of variations in GCMs, their projected outcomes are different despite having the same prescribed forcing assumptions and boundary conditions.

The change factors provided by DWR are based on the GCMs from the fifth iteration of CMIP (CMIP5) that was completed in 2012 (Taylor and others, 2012). The sixth iteration of CMIP (CMIP6) (PCMDI, 2021) is the most recent update. The models included in CMIP6 improve the representation of atmospheric and biogeochemical processes (e.g., cloud formation), have denser grids, and are better able to simulate historical conditions than the CMIP5 models (Thorarinsdottir et al., 2020). Furthermore, there are more future scenarios available for CMIP6 that can be chosen to couple with the water demand and supply plan scenarios.

4.4.1.2 Downscaled Climate Model Datasets

All GCMs of each CMIP are required to produce a set of simulation results, including time series of precipitation and near-surface temperature at each model grid cell. Raw GCM output, however, is not always adequate to be used directly in groundwater and surface-water models. Two primary impediments to impacts studies are the coarse spatial scales represented by the GCM (grid cells are typically between 150 and 400 miles long on the ground surface), and the GCM raw output contain biases relative to observational data, which preclude its direct use. A variety of downscaling methods can be used to process and refine GCM output with the aim of producing output more suitable for planning models. The refined output aims to address the limitations of coarse resolution and/or regional biases in the GCM output.

Downscaling methods can be divided into two broad categories: dynamical and statistical. Dynamical downscaling refers to the use of high-resolution regional simulations to dynamically interpolate the effects of large-scale climate processes to regional or local scales of interest. Statistical downscaling involves the use of various statistics-based techniques to determine relationships between large-scale climate patterns resolved by global climate models and observed local climate responses. These relationships are applied to GCM results to transform climate model outputs into statistically refined products. The available downscaled climate model datasets are summarized below.

Statistical Downscaled Datasets

- NASA Earth Exchange (NEX) Downscaled Climate Projections (NEX-DCP30)
  - Description: This dataset comprises downscaled climate scenarios for the conterminous United States that are derived from the GCM runs conducted under CMIP5 and across the four greenhouse gas emissions scenarios known as Representative Concentration Pathways

  (RCPs). Each of the climate projections includes monthly averaged maximum temperature, minimum temperature, and precipitation at a resolution of 800 meters for the periods from 1950 through 2005 (Retrospective Run) and from 2006 to 2099 (Projection Run).
  - Website: https://ds.nccs.nasa.gov/thredds/catalog/bypass/NEX-CP30/bcsd/catalog.html
  - Data access: https://www.nccs.nasa.gov/services/data-collections/land-based-products/nex-dcp30

- NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP-CMIP6)
  - Description: This dataset comprises global downscaled climate scenarios derived from the GCM runs conducted under CMIP6 and across two of the four "Tier 1" greenhouse gas emissions scenarios known as Shared Socioeconomic Pathways (SSPs). Each of the climate projections includes daily averaged maximum temperature, minimum temperature, and precipitation at a resolution of 0.25 degrees (approximately 17.5 miles at equator) for the periods from 1950 through 2014 (Retrospective Run) and from 2015 to 2100 (Projection Run).
  - Website: https://ds.nccs.nasa.gov/thredds/catalog/AMES/NEX/GDDP-CMIP6/catalog.html
  - Data access: https://www.nccs.nasa.gov/services/data-collections/land-based-products/nex-gddp-cmip6

Dynamical Downscaled Datasets

- CMIP6 Downscaling Using the Weather Research and Forecasting model (WRF-CMIP6).
  - Description: This dataset comprises dynamically downscaled climate scenarios derived from the GCM runs conducted under CMIP6 using the WRF model. Each of the climate projections consists of 37 daily variables including temperature, precipitation, evapotranspiration, wind speed at a resolution of 2 miles (3 km) for the periods from 1980 through 2100.
  - Website: https://dept.atmos.ucla.edu/alexhall/downscaling-cmip6
  - Data access: https://dept.atmos.ucla.edu/sites/default/files/alexhall/files/aws_tiers_dirstructure_Jan22.pdf

4.4.2 Recommendation

Given the range of improvements in the CMIP6 models and the greater variety of scenarios, using data sets derived from the CMIP6 models is the most defensible approach to apply to the CVM. Two options for applying the CMIP6 datasets to the CVM are using the Change Factors or using the dynamically downscaled datasets. The former is infeasible as CMIP6-based Change Factors are not yet available. The remaining option is to use the dynamically downscaled datasets.

The two available CMIP6-based downscaled datasets are the NEX-GDDP-CMIP6 and WRF-CMIP6 datasets. The statistically downscaled dataset NEX-GDDP-CMIP6 is only available at a spatial resolution of 0.25 degrees, which is not sufficient to capture the topographic and orographic drivers of precipitation and temperature patters across the Chino Valley watershed. The dynamically downscaled dataset WRF-CMIP6 is available at a 3-km resolution and is appropriate to apply to the CVM. The development of the WRF-CMIP6 datasets is an ongoing project. Currently, the downscaled datasets of nine GCM scenarios are available, and it is expected that additional datasets for other GCM scenarios will be available when the projections for the forthcoming Safe Yield recalculation will be developed.[11] Therefore, the WRF-CMIP6 datasets are recommended to be used in the updated Safe Yield calculation methodology to account for the effects of future climate variations.

Results of available historical runs of UCLA WRF-CMIP6 models will be compared to historical PRISM dataset over the concurrent time period. The results of each comparison will be used to rank the WRF-CMIP6 models. The ranking will be used for model selection. The proposed selection of GCMs and scenarios will be presented at a peer review workshop for feedback prior to implementation.

As climate conditions are coupled with water demands and supplies, combinations of climate scenarios and the water demand and supply plan scenarios should be chosen to ensure consistency. For example, a warmer and drier climate generally drives increased demand, assuming no additional water conservation. Therefore, the WRF-CMIP6 model projections that are warmer and drier should be coupled with demand and supply plan scenarios that reflect a warmer and drier climate. The proposed selection of projection scenarios (climate and water demand and supply plans) will be presented at a peer review workshop for feedback prior to implementation.

The following method is proposed to implement the dynamically downscaled CMIP6 data into the CVM.

1. Review and select a subset of the available dynamically downscaled datasets (i.e., combinations of GCMs and scenarios). The selected subset should be representative of plausible future patterns of precipitation, ET_0, and temperature of the CVM watershed. Watermaster will host a peer review workshop to present the proposed selected datasets and gather feedback.
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. As the Chino Basin is expected to be built out by 2040, and the land use change from agricultural to urban uses is not expected to significantly affect DIPAW, it is practical to assume a single future land use to combine with the selected range of applied water patterns to characterize representative future cultural conditions.
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. The results of the HSPF and R4 simulation (including DIPAW, stormwater discharge to streams, and stormwater recharge) will be used as input data of the MODFLOW model of CVM.
    - Develop SAR discharges from the upper SAR watershed at Riverside Narrows based on results from other regional models that include the same or similar climate projections as part of the model input. If appropriate regional models are unavailable, then a method will be developed to estimate future discharges. The estimated SAR discharges at Riverside Narrows will be used as input data to the MODFLOW model of CVM.

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[11] Correspondence with Stefan Rahimi-Esfarjani, March 31, 2022

5.0 RECOMMENDED PROCESS TO CALCULATE THE SAFE YIELD

Section 4.0 outlined the potential approaches and recommended methods for addressing uncertainty in the model parameterization, future water demands and supply plans, and future climate scenarios. This section describes the proposed updated Safe Yield Reset methodology.

5.1 Update Model and Generate Calibration Realizations

The process to update the model and generate calibration realizations will include the following steps:

- Update the HSPF and R4 surface-water models for the historical period. The HSPF and R4 models may not need to be recalibrated for this model update; at a minimum, surface-water model outputs will be compared to measured data (e.g., discharge, applied water, stormwater recharge) to verify the models.
    - Note: To simplify the uncertainty analysis and the model update, the proposed process includes deterministic runs of the HSPF and R4 models to generate MODFLOW model input data (e.g., DIPAW, boundary fluxes) which will be treated as adjustable parameters during model calibration using PESTPP-IES.
- Update the MODFLOW model for the historical period based on observation data and the results of HSPF and R4.
- Select adjustable model parameters (e.g., horizontal hydraulic conductivity) and prepare input files to incorporate characteristics of those parameters for PESTPP-IES (such as pilot points, variograms, and covariance matrices).
- Prepare observation data as calibration targets, such as time series of groundwater elevations at wells and stream discharge.
- Use PESTPP-IES to estimate model parameters and generate a set of calibrated model realizations. Prepare statistics and water budgets to characterize each realization.
- Review the outputs and water budgets from the calibrated realizations to rank the calibration realizations. Determine which calibration realizations should be selected and whether more calibrated realizations should be added. Conduct peer review process to share calibration results. Repeat the PESTPP-IES process and review outputs until enough calibrated model realizations are developed.

5.2 Prepare Projection Realizations

Implementing the recommended methods in Section 4.0 will result in the development of multiple projection scenarios, which are unique combinations of future demands, water supply plans, and climate scenarios. The chosen projection scenarios must comprise consistent combinations of demands, water supply plans, and climate/hydrology as defined in Section 4.2.2. The peer review process will be critical to the successful development of the projection scenarios, particularly to define the plausible range of future water demands and supply plans.

A projection realization is a unique combination a calibrated model realization and a projection scenario. An “ensemble of projection realizations” will be developed which will be equal to the product of the calibrated model realizations and the projection scenarios.

5.3 Simulate Ensemble of Projection Realizations

The steps to simulate the ensemble of projection realizations are:

1. Specify a minimum number of projection realizations to be simulated.
2. Simulate projection realizations in a random order and calculate the average net recharge of all simulated realizations.
3. Simulate an additional projection realization and calculate the average net recharge of all simulated realizations.
4. Check for convergence of average net recharge.
5. Repeat steps 3 and 4 until the convergence of average net recharge is reached or a specified maximum number of projection realizations are simulated. The upper limit of projection realizations will be determined with input from the peer review committee prior to implementation.

5.3.1 Computational Feasibility of Simulating Projection Realizations

The following hypothetical example illustrates the computational feasibility of simulating the ensemble of projection realizations. A total of 40 calibrated model realizations and 15 projection scenarios would result in 40 x 15 = 600 projection realizations. If the simulation of each realization takes a day to complete, a single computer CPU will need 600 days to simulate the ensemble of 600 realizations. Simulating several hundred projection realizations will require significant computing power, which can be acquired from commercial cloud computing services. For example, Amazon Web Services (AWS) currently charges a monthly cost of $94 for a 4-CPU-WorkSpace that can simulate three realizations simultaneously (1 CPU is needed for the operating system). A total number of 40 4-CPU-WorkSpaces will be needed to complete the simulation of 600 realizations in five days. The total monthly cost for 40 4-CPU-WorkSpaces will be $3,760. It is anticipated that three to six months of the computing services will be needed. Minimal staff time will be required to maintain and debug the model runs on the remote workspaces.

5.3.2 Storing Input and Output Files for the Model Ensemble

Since a projection realization can produce about 50 gigabytes of simulation results, it is impractical to store complete model outputs for several hundred to thousands of simulations. Therefore, an automated process will need to be developed to simulate all realizations and to extract/post-process only the model results necessary to quantify net recharge, potential Material Physical Injury (MPI), and the state of hydraulic control. After the simulation of each projection realization, the time series of annual water budget components (e.g., change in storage) and net recharge will be calculated, the potential MPI will be assessed, and the state of hydraulic control will be determined based on the same approach that has been implemented in prior Chino Basin modeling studies (WEI, 2018b; WEI, 2020; WY, 2021). To preserve the reproducibility of the model results without having to store all input and output files, computer scripts or tools that are used to develop input files will be saved.

5.4 Quantify Results of Projection Realizations

The water budget, net recharge, Safe Yield, the potential for MPI, and the state of hydraulic control will be quantified for each projection realization. The model results will be stored for each projection realization for subsequent statistical analyses.

5.5 Conduct Statistical Analyses of the Results of Projection Realizations

The statistical analyses will be conducted to include:

- The annual water budget for the Chino Basin including the annual net recharge and annual change in groundwater storage over the planning period, including the range and distribution of ensemble results. The planning period will be no less than 50 years which is consistent with the planning period required by SGMA and long enough to evaluate the long-term response of the Chino Basin to evaluate for MPI and undesirable results.
- Determination of the Safe Yield over a specified 10-year period (e.g., 2026-2035) as the 10-year average of the ensemble mean annual net recharge. If the water demand and supply plan scenarios are weighted with non-uniform likelihoods, then the Safe Yield would be calculated as the likelihood-weighted 10-year average of the ensemble mean annual net recharge.
- The potential for MPI. The statistics will include the extent of potential MPI as well as details of the projection realization, including type of demand/supply plans, climate/hydrology, or parameter realizations. These statistics will allow for identifying the factors causing MPI.
- The state of hydraulic control. The statistics will include the projection scenarios and their projected time series of groundwater discharge from the Chino-North Groundwater Management Zone to the Prado Basin Management Zone. Hydraulic control is maintained if the groundwater discharge is less than the de minimis threshold of 1,000 acre-ft per year.

5.6 Evaluate the Risk of MPI and Undesirable Results

The risk of potential MPI and undesirable results associated with the ensemble of projection realizations will be evaluated based on the statistics generated in 5.5. If the water demand and supply plan scenarios are weighted with non-uniform likelihoods, then the risk of potential MPI and undesirable results would be calculated as the weighted ensemble statistics. If the risk of MPI and undesirable results is significant (based on a defined threshold), then Watermaster will “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.” Mitigation measures should be guided by an examination of the projection realizations that indicate MPI and/or undesirable results.

5.6.1 Considerations for Interpreting Ensemble Results

Figure 1 shows a hypothetical time series of calculated annual net recharge for all projection realizations in the ensemble. The solid blue line represents the ensemble mean annual net recharge, and the shaded blue band indicates the spread in annual net recharge of all the projection realizations. The solid red line represents the annual mean net recharge of the ensemble for the period of 2026 through 2035.

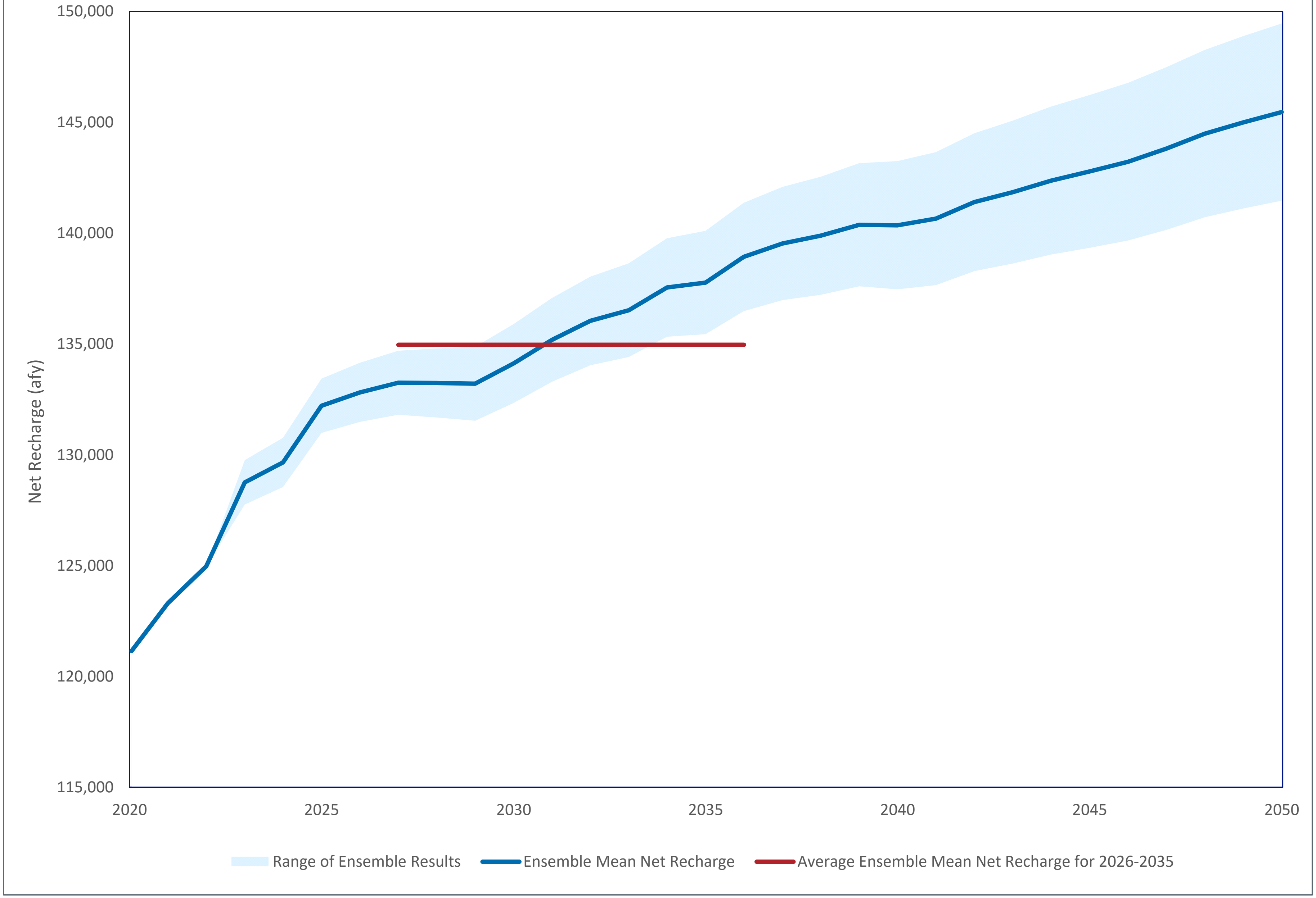
For a single projection realization, the Safe Yield for a given period (e.g., 2026 to 2035) will be calculated as the annual mean net recharge of that realization over the given period. The Safe Yield for the ensemble of projection realizations will be calculated as the 10-year average of the ensemble mean net over the given period, weighted by likelihood (see the solid red line on Figure 1). The range and standard deviation of the Safe Yield for the ensemble will be calculated based on the Safe Yield of individual projection realizations.

The probability of MPI and undesirable results will be derived from the likelihood-weighted time series of the state of hydraulic control and the potential for MPI. The results of the projection realizations will be examined to determine the drivers of any losses of hydraulic control or the occurrences of MPI (e.g., high groundwater pumping, lower precipitation, etc.). This analysis can inform planning for potential mitigation actions. To guide the analysis, thresholds of significance will be defined to determine the risk of MPI and undesirable results. For example, if less than five percent of the projection realizations in the ensemble indicate a loss of hydraulic control, then the risk that hydraulic control would be lost at the ensemble mean Safe Yield would be considered insignificant.

5.7 Identify Data Gaps

The BMPs for modeling under SGMA (see Section 2.2) point out that an uncertainty analysis can “identify high-value data gaps” that can improve the model’s ability to “[provide] useful information to support effective basin management decisions.” During the execution of the proposed updated Safe Yield Reset methodology, it is likely that data gaps will be identified that would improve the model calibration, reduce the uncertainty of an aspect of the model, or both. These data gaps will be documented in the final model documentation.

Figure 1. Hypothetical Projected Net Recharge Using Ensemble Approach



5.8 Comparison of the Current and Proposed Safe Yield Reset Methodologies

Table 3 compares the major differences between the current and proposed Safe Yield Reset methodologies.

Table 3. 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 one calibrated 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 water supply plans. Minimal stakeholder engagement beyond clarifying the collected data.	Collecting the same data sets as in 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/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 water supply plans, and future climate and hydrology.
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 like the current SY Reset methodology, but the method is automated and applied to the ensemble of projection scenarios. Ensemble statistics are generated to characterize the potential for MPI and state of hydraulic control and identify the drivers that may cause MPI or loss of hydraulic control.
Calculation of Safe Yield based on model results	Safe Yield is calculated as the 10-year average of net recharge for a 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, possibly weighted by assigned likelihood of water demand and supply plan scenarios.

6.0 COST ESTIMATE AND SCHEDULE

Implementing the proposed updated Safe Yield Reset methodology will occur as part of the Court-ordered reevaluation of the Safe Yield that must be completed by June 30, 2025[12] (2025 Safe Yield Reevaluation). A cost estimate to implement the 2025 Safe Yield Reevaluation has been prepared and is based on (i) an understanding of the cost of implementing the uncertainty analysis (based on the process documented in Attachment A), (ii) prior modeling experience in the Chino Basin, and (iii) estimates of future billing rates. A table detailing the anticipated tasks and their estimated costs is included as Attachment D. The cost estimate is broken down into seven tasks:

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[12] Page 17 of the 2017 Court Order

- Task 1. Update Hydrogeologic Conceptual Model and Surface Water Models
- Task 2. Recalibrate Groundwater Model and Generate Calibration Realizations
- Task 3. Prepare Ensemble of Projection Scenarios
- Task 4. Simulate Ensemble of Projection Scenarios and Calculate Safe Yield
- Task 5. Prepare Safe Yield Reevaluation Report
- Task 6. Support Court Approval Process for Updated Safe Yield
- Task 7. Project Management

Task 6 will only be necessary if this work causes the Watermaster to recommend to the Court that the Safe Yield be changed by an amount greater (more or less) than 2.5 percent of the current Safe Yield[13]. The cost estimate to perform the entire scope of work is $1.46 million over three years. The annual costs are expected to occur as follows:

- **FY 2022/23**: $259,000
- **FY 2023/24**: $540,000
- **FY 2024/25**: $659,000

These cost estimates are preliminary. Some tasks are dependent on the results of prior tasks and recommendations coming out of the peer review process. Before each fiscal year, Watermaster will refine the cost estimates as part of its normal annual budgeting process.

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[13] Pages 15-16 of the 2017 Court Order

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Attachment A

Applying PESTPP-IES to Generate Calibrated Parameter Realizations

ATTACHMENT A. APPLYING PESTPP-IES TO GENERATE CALIBRATED PARAMETER REALIZATIONS

Attachment A documents the effort to understand and demonstrate the applicability of using PESTPP-IES to calibrate and generate calibrated realizations of the Chino Valley Model (CVM), as demonstrated on a smaller, idealized (synthetic) model. Our goal is to understand (1) how to generate horizontal hydraulic conductivity (HK) distribution fields from pilot points that can be used by PEST and PESTPP-IES as input parameters, (2) how to generate calibrated parameter realizations with PESTPP-IES, and (3) how to run a model using the ensemble of calibrated parameter realizations.

This synthetic model, adapted from Using PESTPP-IES (Doherty, 2021), is used as an example to illustrate the steps generate an ensemble of calibrated parameter realizations and to conduct model simulations with the ensemble of calibrated parameter realizations.

A.1 Overview of the Synthetic Model

The model has three layers and several observation points in each model layer, as shown in Figure A-1. The elevation of the top of the first model layer ranges from 137.5 to 178 meters and each model layer has a constant thickness of 50 meters. The western (left) boundary of the first model layer is a constant head boundary with the head value of 150 [m]. The model cells in an impervious area on the eastern (right) boundary are set as inactive cells and excluded from the flow simulation. All other model boundaries are impervious boundaries. The model is configured for a steady-state simulation with a single stress period. The model domain has a constant recharge rate of 0.002 [m/day]. There are two pumping wells in layer 3 with the pumping rates of 30,000 [m3/day] and 40,000 [m3/day], respectively.

The observed head values at the observation points are specified. The values and distribution of the horizontal hydraulic conductivity (HK) and vertical hydraulic conductivity (VK) in the model layers need to be adjusted to minimize the difference between the model-calculated and observed head values. A variogram is available and is assumed to be applicable to HK and VK in all model layers.

The parameter estimation software PESTPP-IES will be used to calibrate the model and generate calibrated parameter realizations. Many commercial graphical user interface software (GUI) for MODFLOW can be used to develop model input files. The files of the present example are available upon request.

A.2 The Pilot Point Method

Conventional calibration uses the method of parameter zones. This methodology involves defining a limited number of zones in each model layer and assigning parameters within each zone as constant values. Parameters are then adjusted to calibrate the parameters until the fit between model-calculated and observed data is as good as possible. If the goodness of fit obtained based on these zones was not acceptable, then extra zones would be introduced into the model domain and calibration process would be repeated.

There are several shortcomings associated with the parameter zone approach. First, the procedure can be time-intensive. Second, zones of piecewise uniformity are a coarse approximation of the nature of the aquifer material, and using zones limits the ability to explore the effects of small-scale heterogeneities on model predictive uncertainty.

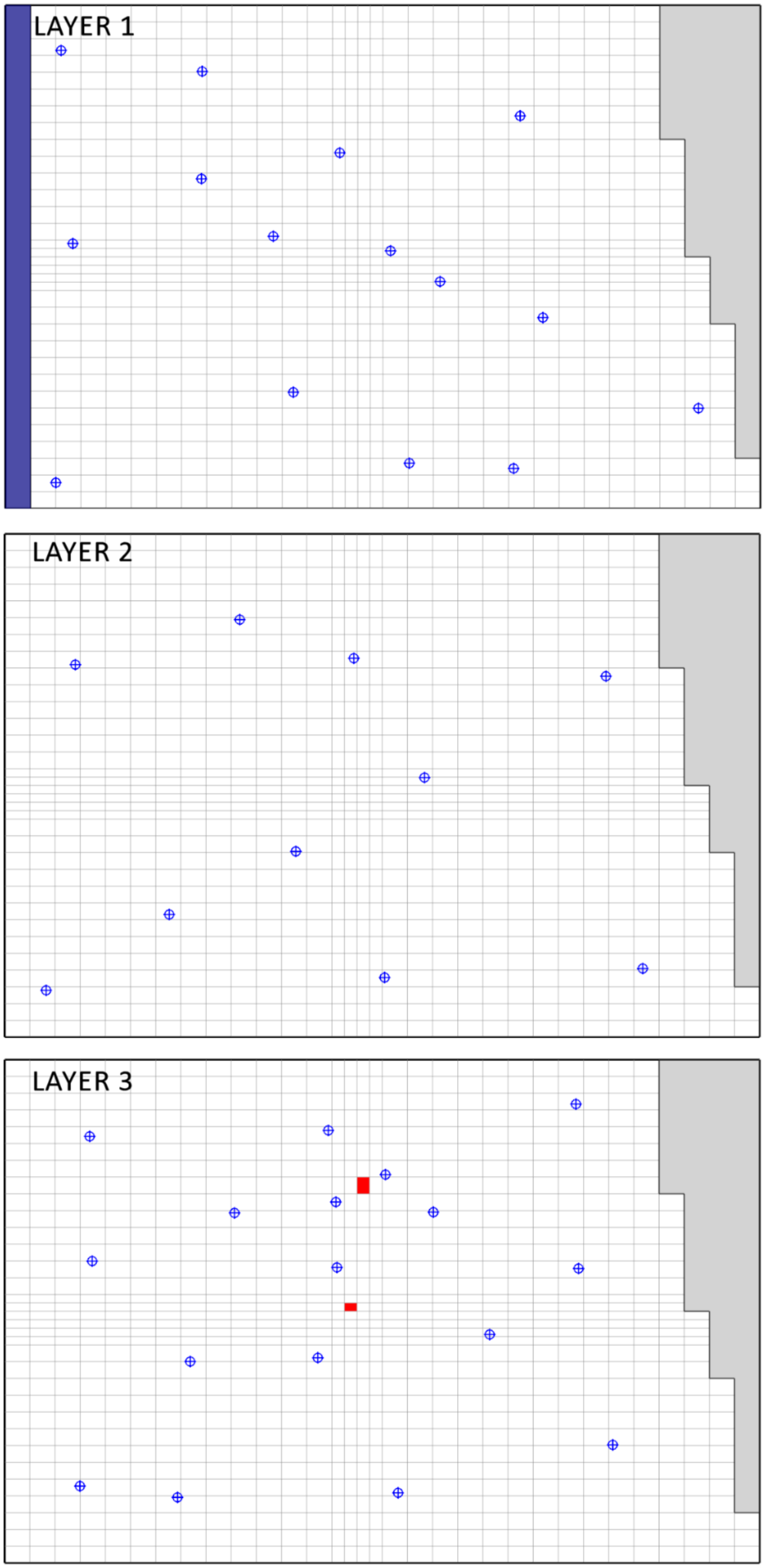

Figure A-1. Layers and Head Observation Points of the Synthetic Model. Red blocks in Layer 3 represent the pumping wells.

The Pilot Point Method can be used to overcome these problems. In this method, several points with hydraulic parameters (i.e., HK and VK values in the present example) are introduced to the model domain, such as shown in Figure A-2. PEST is used to adjust the hydraulic parameters at each pilot point.

Two utility programs, PPK2FAC and FAC2REAL, from the PEST Groundwater Data Utility suite (Watermark Numerical Computing, 2020) can be used to spatially interpolate hydraulic properties associated with the pilot points to the model cells based on the Kriging method. Details of these utility programs are given in the next section.

PPK2FAC undertakes the first stage of the Kriging method. PPK2FAC generates a set of Kriging factors based on the pilot point locations and user-supplied, nested variograms, each with an arbitrary magnitude and direction of anisotropy. Individual pilot points can be assigned to different zones within the model domain. Only those points assigned to a particular zone can be used in calculating parameter values throughout that zone using the Kriging interpolation procedure. The variogram upon which Kriging is based can be different in each zone, reflecting differences in the geology, or in the level of heterogeneity, expected within each geological unit. If only one pilot point is assigned to a particular zone, then a uniform parameter value is assigned to all cells within that zone.

FAC2REAL undertakes the second stage of the Kriging method. FAC2REAL calculates the interpolated value at each model cell as the sum of the products of the Kriging factor and hydraulic property of the pilot points within the search range of the cell. Upper and lower limits can be applied to interpolated values if desired. The calculation results are saved in a MODFLOW-compatible real array file.

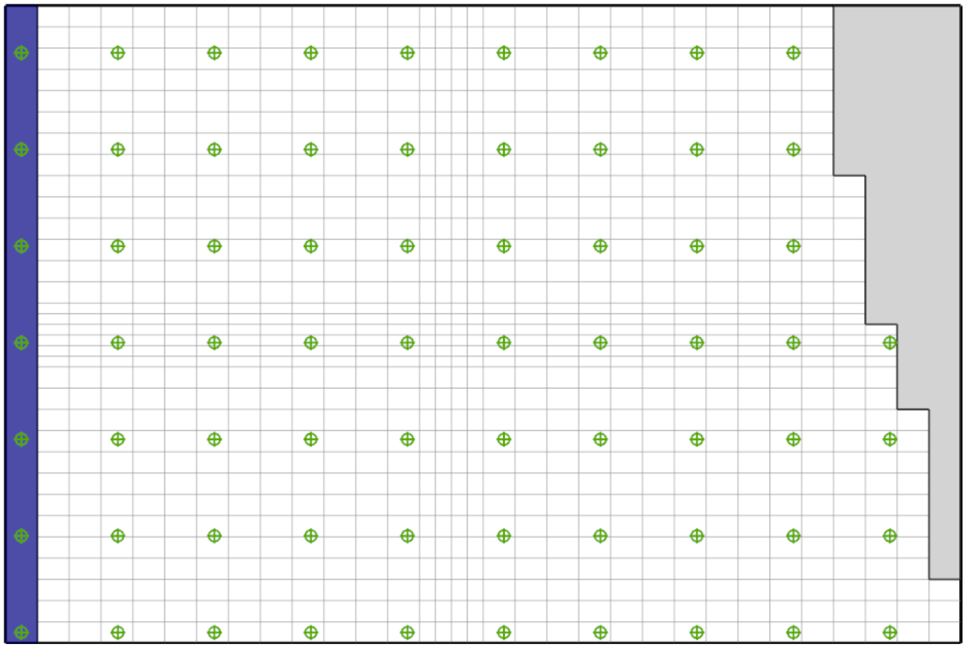

Figure A-2. Pilot points

A.3 Spatial Interpolation with Pilot Points

This section demonstrates the use of the utility programs PPK2FAC and FAC2REAL. First, PPK2FAC will be used to create a Kriging factor file, and then FAC2REAL will be used to spatially interpolate HK values associated with pilot points to model cells. The required input data files for these programs are shown below. The formats of these files are specified in the PEST suite (Doherty, 2018) and PEST Groundwater Data Utility suite (Watermark Numerical Computing, 2020).

- PPK2FAC input files:
  - Grid specification file: defines the grid location and column/row spacing.
  - Pilot points file: defines the location of pilot points.
  - Zonal integer array file: an integer array containing the pilot point zones.
  - Structure file: defines structures with variograms.
- FAC2REAL input files:
  - Kriging factor file: contains kriging factors calculated by PPK2FAC
  - Pilot points file: defines the location of pilot points.

Calculation of Kriging factors can be a very time-consuming task if the number of pilot points is large. Fortunately, Kriging factors are independent of the values assigned to the pilot points and therefore just need to be calculated once for each set of pilot points.

A.3.1 Running PPK2FAC

The utility program can be started by double-clicking the executable file “ppk2fac.exe” in Windows Explorer. Once the program is started, it will prompt for user’s input. Figure A-3 shows the prompts and the corresponding user’s inputs in red. In the present example, the calculated kriging factors are stored in the file “krigingfactor1.dat.”

The utility program can also be started in a Windows Command Prompt by typing “ppk2fac < ppk2fac.in” followed by Enter. This instructs PPK2FAC to read the user’s input from the text file “ppk2fac.in” that contains the pre-recorded user’s inputs.

Generation of MODFLOW and MT3D input arrays based on PPK2FAC-generated Kriging factors is carried out by FAC2REAL. Separation of the time-consuming, factor-generation process from the array construction process facilitates automatic parameter estimation based on pilot points using software such as PEST, for Kriging factors are unchanged as values assigned to the pilot points are adjusted through the parameter estimation process (Watermark Numerical Computing, 2020).

A.3.2 Running FAC2REAL

The utility program FAC2REAL can be started by double-clicking the executable file “fac2real.exe” in Windows Explorer. Once the program is started, it will prompt for user’s input. Figure A-4 shows the prompts and the corresponding user’s inputs in red. The pilot point file “points1.dat” and the output file “krigingfactor1.dat” from PPK2FAC is used as input to FAC2REAL. The interpolation results are stored in the file “kx1.dat”. Figure A-5 shows a contour map based on the interpolation results of the synthetic model.

The utility program can also be started in a Windows Command Prompt by typing “fac2real < fac2real.in” followed by Enter. This instructs FAC2REAL to read the user’s input from the text file “fac2real.in” that contains the pre-recorded user’s inputs.

The hydraulic property values assigned to the pilot points can be different from those provided in the pilot points file read by PPK2FAC. Nevertheless, it must list the same points in the same order, and each point must be assigned to the same zone.

```
Program PPK2FAC calculates point-to-cell factors by which kriging is
undertaken from a set of pilot points to the finite-difference grid.

Enter name of grid specification file: pest.gridspecification
          – grid specifications read from file pest.gridspecification
Enter name of pilot points file: points1.dat
          – data for 67 pilot points read from pilot points file points1.dat

Enter minimum allowable points separation: 0
Enter name of zonal integer array file: zones.dat
Is this a formatted or unformatted file? [f/u]: f
          – integer array read from file zones.dat
Enter name of structure file: struct.dat

The following zones have been detected in the integer array:
          For zone characterized by integer value of 1:-
          Enter structure name (blank if no interpolation for this zone): struct1
          Perform simple or ordinary kriging [s/o]: o
          Enter search radius: 2970
          Enter minimum number of pilot points to use for interpolation: 1
          Enter maximum number of pilot points to use for interpolation: 12

Enter name for interpolation factor file: krigingfactor1.dat
Is this a formatted or unformatted file? [f/u]: f
Enter name for output standard deviation array file: standarddeviation.dat
Write a formatted or unformatted file? [f/u]: f
Enter name for regularization information file: regularizationinfo.dat

Carrying out interpolation for integer array zone 1....
          Number of pilot points for this zone    =    67
          Mean data value for these pilot points   =   44.849
          Data standard deviation for these points =   31.894
          Working…
```

Figure A-3. Screen prompts of the utility program PPK2FAC and the user’s inputs in red.

```
Program FAC2REAL carries out spatial interpolation based on interpolation
factors calculated by PPK2FAC and pilot point values contained in a pilot
points file.

Enter name of interpolation factor file: krigingfactor1.dat
Is this a formatted or unformatted file? [f/u]: f

Enter name of pilot points file [points1.dat]: points1.dat
            – data for 67 pilot points read from pilot points file points1.dat

Supply lower interpolation limit as an array or single value? [a/s]: s
Enter lower interpolation limit: 1e-10

Supply upper interpolation limit as an array or single value? [a/s]: s
Enter upper interpolation limit: 1e10

Enter name for output real array file: kx1.dat
Write a formatted or unformatted file? [f/u]: f
```

Figure A-4. Screen Prompts of the utility program FAC2REAL and user's inputs in red

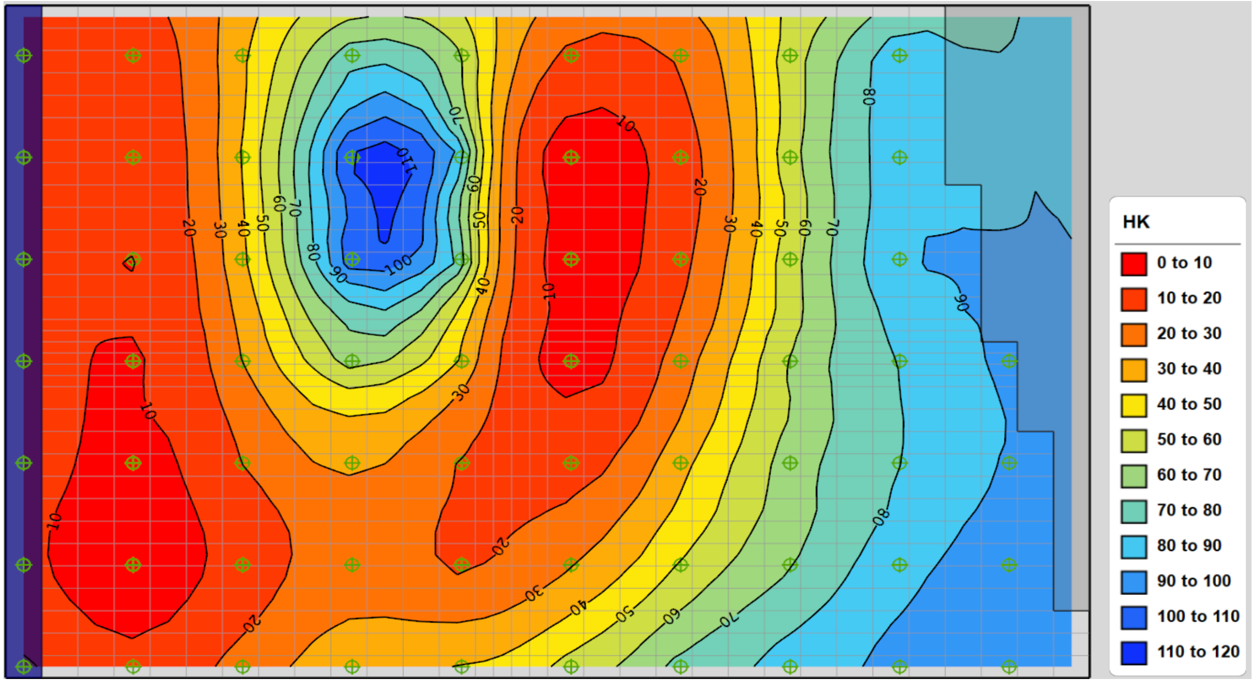

Figure A-5. A contour map based on the interpolation results created by FAC2REAL

A.4 Using the Pilot Point Method with PEST

Pilot points are integrated to a model by creating a batch file and inserting the name of a batch file to the "* model command line" section of a PEST control file. The batch file contains several instructions that together form a "composite model" used by PEST. Such a "composite model" includes instructions to manipulate data (such delete files, invoke utility programs, start model run, and postprocess model results) for a PEST iteration.

A.4.1 A Simple Composite Model

A simple composite model can consist of just a few instruction lines shown below.

```
del hk1.dat
fac2real < fac2real.in
mf2005 mymodel.nam
targpest
```

The lines of the simple composite model are as follows.

- The first line "del hk1.dat" deletes the "hk1.dat" file that contains the interpolated HK values from the previous calibration iteration.
- The second line "fac2real < fac2real.in" instructs FAC2REAL to read input values from the fac2real.in file. FAC2REAL generates the hk1.dat file based on the values associates with the pilot points that are updated by PEST for the current iteration of the calibration process. Note that the same kriging factor file cited in fac2real.in is reused for each iteration.
- The line "mf2005 mymodel.nam" starts MODFLOW-2005 with the Name file "mymodel.nam". The hk1.dat file is included in the "mymodel.nam" file as a part of the model input.
- The last line "targpest" runs the utility program Targpest, which extracts the model output data and save them in a form that can be read by PEST through specific instruction files need to be designed to match the output format of targpest. TARGPEST is distributed with the commercial software Groundwater Vistas. See its manual for details.

A.4.2 A Complex Composite Model

The batch file shown in Figure A-6 is an example of a complex composite model. Note that "mod2obs.exe," "layerweight.exe," "streamgage.exe," and "lakestage.exe" are utility programs of Processing Modflow (Chiang, 2022) that are designed to extract the model results and store the extracted data in the formats that can be read by PEST. Specific instruction files are designed in Processing Modflow to match the output of those utility programs.

```
del kx_array
del kz_array
fac2real < fac2real1.in
fac2real < fac2real2.in
MODFLOW-NWT_64.exe mymodel.nam
mod2obs.exe < pest.mod2obsheadinput
layerweight.exe pest.boreinfo pest.mod2obsheadoutput pest.headoutput
mod2obs.exe < pest.mod2obsdrawdowninput
```

Figure A-6. A complex composite model

The lines of the above example are as follows.

- The lines “del kx_array” and “del kz_array” respectively delete the kx_array and kz_array files that contain the interpolated HK and VK values from the previous calibration iteration.
- The line “fac2real < fac2real1.in” instructs FAC2REAL to read input values from the “fac2real1.in” file. FAC2REAL generates the kx_array file based on the values associates with the pilot points that are updated by PEST for the current iteration of the calibration process.
- The line “fac2real < fac2real2.in” instructs FAC2REAL to read input values from the “fac2real2.in” file. FAC2REAL generates the kz_array file based on the values associates with the pilot points that are updated by PEST for the current iteration of the calibration process.
- The line “MODFLOW-NWT_64.exe mymodel.nam” starts MODFLOW-NWT with the Name file “mymodel.nam.” The kx_array and kz_array files are cited in the “mymodel.nam” file as a part of the model input.
- The line “mod2obs.exe < pest.mod2obsheadinput” instructs MOD2OBS to read input values from the pest.mod2obsheadinput file. MOD2OBS interpolates model calculated cell-based head values to specific observation point locations and times.
- The line “layerweight.exe pest.boreinfo pest.mod2obsheadoutput pest.headoutput” instructs LAYERWEIGHT to read input values from the files cited in the line. LAYERWEIGHT calculates layer-weighted average head values for multi-layer head observations.
- The line “mod2obs.exe < pest.mod2obsdrawdowninput” instructs MOD2OBS to read input values from the pest.mod2obsdrawdowninput file. MOD2OBS interpolates model calculated cell-based drawdown values to specific observation point locations and times.
- The line “layerweight.exe pest.boreinfo pest.mod2obsdrawdownoutput pest.drawdownoutput” instructs LAYERWEIGHT to read input values from the files cited in the line. LAYERWEIGHT calculates layer-weighted average drawdown values for multi-layer drawdown observations.
- The line “streamgage.exe modflow.streamout pest.reach pest.strflowobstimes pest.streamout” instructs STREAMGAGE to read input values from the files cited in the line. STREAMGAGE calculates the weighted streamflow values at the times of interest for each observation point.

- The line “lakegage.exe modflow.lakeout pest.lakeobspt pest.stageobstimes pest.lakeoutput” instructs LAKEGAGE to read input values from the files cited in the line. LAKEGAGE calculates the weighted stage values at the times of interest for each observation point.

A.4.3 A Complete PEST Control File

Figure A-7 shows a complete PEST control file that includes the batch file “modelrun.bat” in the “* model command line” section. The modelrun.bat represents a complex composite model as shown in Figure A-6.

The lines in the “parameter data” section of the PEST control file list the names, initial values, and minimum/maximum bounds of parameters.

The first six lines in the “model input/output” section of the PEST control file list two pairs of “pilot point template file and pilot point file.” A template file contains the parameter names that PEST will replace with estimate values of the corresponding parameters. Once the parameter names in a template file are replaced with values. PEST writes the results to the corresponding pilot point file. The pilot point files with updated parameter values are interpolated to model cells by FAC2REAL in the next iteration.

The last line in the “model input/output” section of the PEST control file list pairs of the instruction file and corresponding output file from the composite model. This instruction file is tailored to instruct PEST to correctly read desired model output data from the matching output file. Those model output data are compared with the observed counterparts during the parameter estimation process. For details of the PEST control file, template file, and instruction file, see the PEST manual (Doherty, 2018).

```
pcf
* control data
restart estimation
          402      42       2        0        3
6 1 single point 1 0 0
20 -3.0 0.3 0.01 7 999 lamforgive
10 10 0.001
0.1 1 noaui noboundscale
50 0.01 3 3 0.01 3
0 0 0 PARSAVEITN
* singular value decomposition
     1
     402 5.0e-007
     1
* parameter groups
Kp        relative   0.01 0    switch 2 parabolic
Kz        relative   0.01 0    switch 2 parabolic
* parameter data
KpKp1 log factor 100 1 10000 Kp 1.0 0.0 1
     [lines deleted]
KzKz200 log factor 10 0.1 1000 Kz 1.0 0.0 1
KzKz201 log factor 10 0.1 1000 Kz 1.0 0.0 1
* observation groups
head1
head2
head3
* observation data
o1 163.04 1 Head1
o2 154.00 1 Head1
[lines deleted]
o42 156.90 1.5 Head3
* model command line
modelrun.bat
* model input/output
points1.tpl points1.dat
points2.tpl points2.dat
```

Figure A-7. A Complete PEST Control File

A.5 Steps to Calibrate Model and Generate Calibrated Parameter Realizations

PESTPP-IES can be used to calibrate a model and generate calibrated parameter realizations for the model at the same time. Two types of files are required to enable this feature of PESTPP-IES — a Parameter Uncertainty File and a Covariance Matrix File. The Parameter Uncertainty File acts a container of all covariance files of a model. The Covariance Matrix File contains the covariance of pairs of parameters.

A.5.1 Covariance Matrix File

Covariance matrix files can be generated by using the PPCOV utility from the PEST Groundwater Data Utility suite. The utility program PPCOV can be started by double-clicking the executable file “ppcov.exe” in the Windows Explorer. Once the program is started, it will prompt for user’s input. Figure A-8 shows the prompts and the corresponding user’s inputs in red. The pilot point file “points1.dat” and the “struct.dat” files are used as input to PPCOV and the calculated covariance matrix is stored in the “cov_kx1.mat” file.

```
Program PP2COV prepares a covariance matrix file for pilot point parameters
based on a geostatistical structure file.

Enter name of pilot points file: points1.dat

          – data for 67 pilot points read from pilot points file points1.dat

Enter minimum allowable separation for points in same zone: 0

Enter name of structure file: struct.dat

Enter structure to use for pilot point zone 1: struct1

Enter name for output matrix file: cov_kx1.mat

Enter pilot point prefix for parameter name (<Enter> if none): kp

Filling covariance matrix....

               – file cov_hk1.mat written ok.

Warning: in any future processing of this covariance matrix, sensitivities
for parameters with a log-variogram must be taken with respect to the log
of the parameters.
```

Figure A-8. Screen prompts of the utility program PP2COV and the user’s inputs in red.

A.5.2 Parameter Uncertainty File

PESTPP-IES requires a parameter uncertainty file that defines the covariance matrices of the estimable parameters. Figure A-9, for example, shows a parameter uncertainty file that contains two covariance matrix files for the first model layer of the example model – “cov_kx1.mat” for the HK parameters and “cov_kz1.mat” for the VK parameters. The product of a matrix and the corresponding variance_multiplier is the covariance between parameter pairs that is used by PESTPP-IES.

```
START COVARIANCE_MATRIX
    file cov_kx1.mat
    variance_multiplier 0.25
END COVARIANCE_MATRIX

START COVARIANCE_MATRIX
    file cov_kz1.mat
    variance_multiplier 0.25
END COVARIANCE_MATRIX
```

Figure A-9. A Parameter Uncertainty File that defines covariance matrices of estimable parameters

A.5.3 Running PESTPP-IES

Once a parameter uncertainty file and its related covariance matrix files are created, they can be included in a PEST control file that can be used by PESTPP-IES to calibrate and generate calibrated parameter realizations in the following way.

First, insert the lines shown in Figure A-10 to the end of a PEST control file. The line “++ies_num_reals(80)” set the desired number of calibrated parameter realizations; the line “++parcov(param.unc)” informs PESTPP-IES the name of the Parameter Uncertainty file; the line “++ies_subset_size(2)” instructs PESTPP-IES to devote two realizations to determining the best Marquardt lambda and line search factor to use during each iteration; the last line “++ies_save_binary(true)” instructs PESTPP-IES to record iteration-specific, updated parameter ensembles, as well as corresponding iteration-specific, updated model output ensembles, in binary JCB files (use “++ies_save_binary(false)” to save ASCII files). If the parcov() control variable is omitted from a PEST control file, then PESTPP-IES calculates prior uncertainties from parameter bounds supplied in that control file.

```
++ ies_num_reals(80)
++ parcov(param.unc)
++ ies_subset_size(2)
++ ies_save_binary(true)
```

Figure A-10. Lines to invoke the iterative ensemble smoother of PESTPP-IES

Once the lines shown in Figure A 10 are inserted to the PEST control file, PESTPP-IES can be started by running the following command in Command Prompt. This line starts the executable “ipestpp-ies.exe” and instructs it to read the PEST control file “example.pst”.

```
ipestpp-ies example.pst
```

A.6 PESTPP-IES Output Files

All output files written by PESTPP-IES use the same filename base as the PEST control file. In our present example, some of the output files are JCB files as the line "++ies_save_binary(true)" was included in the PEST control file. The JCB files contain parameter and observation values comprising each parameter and observation realization; the iteration number to which these values pertain is included in the filename extension, "example.N.par.jcb" and "example.N.obs.jcb" respectively, where N is the iteration number.

PESTPP-IES also writes the "example.phi.actual.csv" file that stores the iteration-by-iteration history of the objective functions. Inspecting of this file allows the modeler to determine the goodness of the fit.

A.7 Inspecting Parameter Ensembles

The program JCB2CSV (a member of the PEST suite of utility support programs) can be used to convert the contents of a JCB file to a CSV file. To obtain a CSV file listing parameter values comprising all realizations updated during iteration 10, use the command:

```
jcb2csv example.10.par.jcb example.10.par.csv nt
```

The "nt" component of the above command stands for "no transpose". Each row of the resulting CSV file contains a single parameter realization. If you prefer that parameter realizations be ascribed to columns rather than rows, use the above command with "t" (for transpose) instead of "nt".

If you import file "example.10.par.csv" into EXCEL, you will note that realizations are named "base" and then "0" to "78", this amounting to 80 realizations in all. Initial parameter values for the base realization are initial parameter values in the PEST control file.

A.8 Running a Model using Ensembles

Individual parameter realizations stored in a JCB file can be extracted and applied to a calibration or projection model in the following steps. A simple script (for example, written in Python) can be used to automate the process.

1. The JCB2PAR utility (supplied with the PEST suite) is used to extract an individual parameter realization from a JCB file and save the parameters in a PEST parameter value file (i.e., a PAR file). The following command, for example, extract the 60th parameter realization from iteration 10 to the PEST parameter value file "realization60.par".

   ```
   jcb2par example.10.par.jcb 60 realization60.par
   ```

2. Replace the parameter values in the pilot points files (for the present example, "points1.dat", "points2.dat", etc.) with the parameter values in the PEST parameter value file.
3. Use FAC2REAL as shown in Section A.3.2 to create MODFLOW-compatible parameter matrix files with the updated Pilot Points files.
4. Finally, the parameter matrix files can be applied to a MODFLOW model with the REPARRAY utility program or through the MODFLOW Open/Close option in the model's NAME file.

5. The model result (for example, a safe yield time series) of the parameter realization is calculated.
6. Repeat the steps 1 to 5 for all parameter realizations.

Running a model using the ensemble of parameter realizations will yield an ensemble of model results that can be used to quantify the predictive mean and uncertainties.

Attachment B

Comments and Responses on the May 5, 2022 and July 12, 2022 Draft TMs

STATE OF CALIFORNIA DEPARTMENT/JOHN WOOD GROUP PLC (RICHARD REES, PG, CHG)

Comment No. 1 (May 5, 2022 Draft)

The Revised Safe Yield Reset Methodology Watermaster and its Engineer have proposed in the Technical Memorandum (TM) appears to be a technically sound response to previous comments and requests made by parties, but it is relatively complex. We believe that groundwater modeling should follow the simplest approach that meets the modeling objectives. Based on the scale and complexity of the Chino Basin and the various requests made by parties, we understand the initially proposed methodology is complex, but believe that the proposed methodology could be simplified during implementation, with additional complexity added only if necessary.

Response: We generally agree with the comment. We have updated the Draft TM to address your and others' requests for simplification.

Comment No. 2 (May 5, 2022 Draft)

(Section 3: Uncertainty in the CVM and its Use in the Safe Yield Reset) This section describes the nature and sources of available data for model inputs and uncertainties associated with the data. Based on previous work, Watermaster and its Engineer should be very familiar with the model and should have a clear picture of the model's sensitivity to each parameter or type of input. Although a description of sensitivity is provided for some parameters, it is not described for most parameters. It would be very helpful to include information in this section to indicate the relative importance and sensitivity associated with each parameter or type of data. This would help the reader understand the extent to which uncertainty associated with an individual parameter or type of data would be expected to have a major influence on model results. For example, some parameters with a high level of uncertainty may not matter (e.g., stream properties), while other parameters are much stronger drivers of model results such that even relatively small changes in parameter value makes a notable difference in model results (e.g., storage coefficient). Some discussion of this nature is included in Section 4, and is helpful, but introducing this information in Section 3 would provide context for the rest of the TM.

Response: The relative sensitivity of the model parameters is discussed in Section 3.2. Beyond the discussion provided in Section 3.2, we have not performed a sensitivity analysis of the historical data or data used for projections.

Comment No. 3 (May 5, 2022 Draft)

(Section 4: Potential Approaches for Characterizing and Addressing Uncertainty) of the three approaches to uncertainty described (deterministic, robust decision-making [RDM], and dynamic), we agree RDM appears to be the appropriate approach. The details and level of complexity that go along with this approach may vary, however, from those recommended in the TM.

Response: This comment does not require a response.

Comment No. 4 (May 5, 2022 Draft)

(Section 4.2: Model Parameters) We agree an Iterative Ensemble Smoother (iES) is an appropriate tool for use in addressing uncertainty in model parameter values. The TM states, “Based on the nature of the iES algorithm, the number of models runs per estimation iteration depends on the number of desired calibrated groundwater system realizations and does not depend on the number of adjustable parameters.” Please examine whether limiting the number of adjustable parameters (perhaps to those selected based on previous sensitivity analysis results) could reduce the complexity and effort of future steps? Also, this section appears focused on parameters in the groundwater flow model but does not appear to explain parameters and uncertainties associated with the HPSF and R4 models. During the May 19th Workshop, there was some discussion on how parameters of the HPSF and R4 model output would be incorporated into the model. Additional information on this approach should be provided.

Response: As stated in the draft TM, increasing the number of adjustable parameters does not increase the effort of implementing iES for the uncertainty analysis. We do not plan to conduct an uncertainty analysis on the HSPF and R4 models. We plan to update the HSPF and R4 models and use them similar to our current methodology. It is not recommended that the HSPF or R4 models be subject to the uncertainty analysis. Rather, the HSPF/R4 estimated DIPAW and subsurface inflows to CVM will be included as adjustable parameters in PESTPP-IES. We have updated the draft TM to clarify the proposed process.

Comment No. 5 (May 5, 2022 Draft)

(Section 4.3: Demand and Supply Projections) The process described in this section seems reasonable. The number of scenarios (up to 6) resulting from this process may be greater than necessary and may lead to unnecessary effort in this and subsequent steps (only 3 demand and supply scenarios are noted in the example given in Section 5.1). We recommend a smaller number of scenarios be targeted with more scenarios added only if necessary. Also, in this and subsequent sections, consider whether the selected demand and supply scenarios should be weighted differently in subsequent steps based on whether the participating agencies deem them to be more likely/best estimates or less likely/bracketing scenarios.

Response: We agree with your recommendation to target a smaller number of scenarios. The number of demand and supply projection scenarios will be recommended based on workshops with the Parties and wholesale agencies. As reflected in Section 5.2 of the updated draft, we propose to first simulate a limited subset of projection realizations, adding additional simulations only if necessary. We will define the limit of projection realizations prior to simulations with input from the peer review committee. We respond to your recommendation of weighting scenarios in response to Comment No. 7.

Comment No. 6 (May 5, 2022 Draft)

(Section 4.4: Climate Projections) The procedure recommended in the TM includes, “Review and select a subset of the available dynamically downscaled datasets (i.e., combinations of GCMs and scenarios). The selected subset should be representative of plausible future patterns of mean precipitation, ET0, and temperature of the CVM watershed." For consistency with the previous section, we recommend that an approximate or maximum number of datasets be proposed, as this will impact the level of effort for subsequent steps. We also suggest that some explanation be provided for how plausibility will be determined and agreed. In addition, we note that other modeling being conducted by Watermaster's Engineer to support an update to the Salt and Nutrient Management Plan for the Chino Basin involves incorporation of assumed future climate conditions as requested by the RWQCB. We recommend that those same assumed future climate conditions be included in one or more of the simulations conducted as part of the Safe Yield Reset process.

Response: We have updated the draft TM to describe our proposal to select climate scenarios and gradually increase the number of simulated projection realizations until the results of the simulated net recharge of the ensemble converge. We will present the available climate datasets and our proposed selected datasets at a peer review workshop to gather feedback before implementation. We will ensure consistency in the planning scenarios, including future climate, across other Chino Basin planning studies.

Comment No. 7 (May 5, 2022 Draft)

(Section 5.1: Recommended Implementation of Ensemble Approach) While the approach described seems reasonable for some types of uncertainties, it may not consider likelihood or weighting that might be appropriate for others. Specifically, it may be feasible for parties to assign a degree of likelihood or certainty to various water demand and supply projections. If so, would the recommended approach include weighting or other methods to account for this? What is the basis for the stated 40 calibrated model realizations? Would it be possible to start with a smaller number of realizations, review results, add more realizations, and identify statistically when increasing the number of realizations resulted in a change in the overall range of results that did not exceed a pre-determined threshold?

Response: We have added text in the referenced section and other sections to include provisions for weighting the likelihood of the water demand and supply plan scenarios. It is possible for Parties to assign likelihoods to the demand and supply plan scenarios, which may aid in constraining the plausible outcomes when recalculating the Safe Yield. Weighting the likelihood of these demand and supply plan scenarios would add some complexity to the interpretation of the model results but may be valuable.

40 calibration realizations were suggested as an example to demonstrate the process to generate calibrated realizations and the scale of resources necessary to implement the proposed methodology. There is no way to know the distribution of potential model results before conducting the uncertainty analysis, and there is therefore no way to identify an adequate number of model realizations to characterize the plausible range of model parameters beforehand. The actual number of calibrated realizations will be determined based on the pattern of results. We propose to start with a smaller number of calibrated realizations, review the results with the peer review committee, and add complexity only if necessary. We have updated the draft TM to clarify the proposed process.

Comment No. 8 (May 5, 2022 Draft)

(Section 5.1.1: Simulation Process and Results) Although saving complete output files for all simulations may not be practical or necessary, saving output files for specific simulations (or at least saving input files or enough information to allow re-creating the results) may provide value for purposes not specifically related to the Safe Yield Reset envisioned at this time. As noted in the following comment on Section 5.2, we recommend that time-series storage and change in storage values be saved for each realization.

Response: We agree with your comment. We plan to save the software codes and adequate data to re-create the input files sufficient to regenerate the results of the model ensemble. We have updated the draft TM to clarify.

Comment No. 9 (May 5, 2022 Draft)

(Section 5.2: Proposed Updated Methodology to Calculate the Safe Yield) Section 5.2 indicates the water budget will be quantified for each realization. It is not clear whether this includes time-series output for all individual water budget terms. We recommend the methodology in this topic be clarified and that time-series storage and change in storage be saved for each realization. In addition, the methodology used for calculation of Safe Yield should account for any weighting of more-likely or less-likely scenarios as noted above in the comments on Section 5.1.

Response: We propose to save the time series of storage and storage change as one of the water budget components saved in each realization. We have updated the draft TM to clarify.

Comment No. 10 (July 12, 2022 Draft)

P. 9, first enumerated paragraph. This paragraph identifies that the uncertainty analysis can also identify high-value data gaps that could be “prioritized to improve confidence in the model outputs.” We believe that Watermaster is evaluating data gaps every time it updates the model. Consider adding identification of high-value data gaps as a step in the methodology in Section 5.3 to take credit for work that Watermaster already plans to do. Data gap evaluation could be added as a final step of the methodology as suggestions to improve the model in future iterations if high-value data gaps are identified.

Response: We have added Section 5.7 to the TM to explicitly include the identification of data gaps into the proposed updated Safe Yield Reset methodology.

Comment No. 11 (July 12, 2022 Draft)

P. 24, last paragraph, fourth sentence. Should this be “… converge or a specified maximum number of projection realizations is reached”?

Response: You are correct. We have updated the TM accordingly.

Comment No. 12 (July 12, 2022 Draft)

P. 27, first paragraph, last sentence. This sentence is a double negative. It should be "…if less than five percent of the models in the ensemble indicate a violation…"

Response: You are correct. We have updated the TM accordingly.

Comment No. 13 (July 12, 2022 Draft)

P. 27, enumerated bullet number 5. Similar to the comment on page 24, should this be "Repeat steps 3 and 4 until convergence is reached or a specified maximum number of projection realizations are simulated."

Response: You are correct. We have updated the TM accordingly.

APPROPRIATIVE POOL (THOMAS HARDER, PG, CHG)

Comment No. 1 (May 5, 2022 Draft)

In general, the Watermaster's engineer, West Yost (WY), is following an approach and methodology for applying uncertainty analysis to reevaluate the Chino Basin Safe Yield that is responsive to my recommendation following the previous Safe Yield Reset process (letter dated April 23, 2020) and is consistent with the California Department of Water Resources (CDWR) Best Management Practices for predictive model analysis. What was not anticipated was that the cost to implement the analysis is estimated to be $1.75 million to $2.3 million over the cost of analyzing the Safe Yield without it. At the workshop, most of our comments to the proposed methodology were associated with recommendations to streamline the uncertainty analysis with the goal of reducing the amount of time, and therefore the cost, to conduct the analysis, considering the planning estimate. Those recommendations, and some additional ones, are described below.

While we have not had access to the detailed work breakdown that resulted in the planning level cost estimate for the uncertainty analysis, two aspects of the Chino Valley Model (CVM) appear to be factoring into long analysis times, which presumably result in higher cost of analysis. These are:

- The relatively long runtime of the MODFLOW model (approximately four hours), and
- The complicated configuration of the CVM (it is comprised of four models – MODFLOW, R4, HSPF, and HYDRUS).

Response: We agree that the uncertainty analysis should be streamlined where practical. To clarify the reference to the cost estimates:

- The total cost of the 2020 Safe Yield Recalculation was about $1 million.

- The total cost to implement the updated Safe Yield Reset methodology is estimated to be about $1.75 million to $2.3 million over three years.[1]

The planning-level cost estimate was partially based on the proof-of-concept of the PESTPP-IES method documented in Attachment A of the first draft TM. We anticipate the cost due to the additional runtime of the ensemble to be a small, as there is little staff time necessary to track and debug the model runs once, they are initiated. The primary reasons for the increase in cost and effort to implement the proposed updated SY Reset methodology compared to the 2020 SY Recalculation are the following:

- Conversion of the CVM to a pilot point method of calibration to facilitate the use of PESTPP-IES.
- Development and application of PESTPP-IES tools.
- Development of tools to generate scenarios for projection realizations.
- Development of tools and methods to systematically assess MPI and undesirable results for the ensemble of projection realizations.
- Additional peer review to ensure stakeholder understanding during the uncertainty analysis, development of the projection scenarios, and the interpretation of the ensemble results.
- Added complexity and content of reporting.

The uncertainty analysis is proposed to only cover the MODFLOW model. The other models will be used as they have in the past for calibration. The HSPF and R4 models will be used to simulate the effects of the chosen climate datasets and water demand and supply plan scenarios. The HYDRUS model was used to determine the vadose zone travel times across the Chino Basin. We propose to use the existing data from the HYDRUS model. The draft TM has been updated to clarify the proposed use of the HSPF, R4, and HYDRUS models.

Comment No. 2 (May 5, 2022 and July 12, 2022 Drafts)

The following are recommendations to speed up run times and simplify the configuration.

Comment No. 2.1

Increase the cell size - The current cell size is a uniform 200 ft by 200 ft across the model area. Increasing the cell size would reduce the number of cells through which the model has to perform calculations, which will reduce run times.

Response: The cell size of the CVM was determined based on a balance of tractable computation time with the precision necessary to adequately represent the locations of wells, recharge basins, and streams. Choosing a cell size larger than this would reduce its precision and applicability to be used for other studies, such as the simulation of salinity transport or subsidence management alternatives. Based on our

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[1] This cost estimate has been revised since the responses to comments on the May 5, 2022 Draft TM. See Attachment D.

prior modeling experience, the work to coarsen the model grid is greater than the additional cost of conducting the uncertainty analysis using the current grid cell size.

Response by Thomas Harder on July 12, 2022 Draft: We disagree with this assessment. While this model, or a version thereof, may be used in other applications, its primary purpose here is for updating the Safe Yield of the Basin, which does not have a water quality or land subsidence component. Increasing the cell size from 200 foot squares to 400 foot squares would significantly reduce the number of model computations and associated run time without compromising the representation of wells (very few wells in the basin are located within 400 feet of each other and if they are, their combined pumping can be simulated in a single cell), recharge basins, and streams (the Stream Flow Routing package in MODFLOW simulates stream width independent of cell size). Increase the cell size - The current cell size is a uniform 200 ft by 200 ft across the model area. Increasing the cell size would reduce the number of cells through which the model has to perform calculations, which will reduce run times.

Response: We have developed a cost estimate to coarsen the model grid at about $90,000 to $100,000. The steps to coarsen the model grid would include the following:

- Updating the model geometry and aquifer properties
- Updating each of the MODFLOW packages for the calibration and the projection scenarios. The MODFLOW packages that would need to be updated include DRN, ETS, FHB, HFB, RCH, WEL, and SFR
- Running the model and debugging as necessary
- Comparing the results of the calibration model and the projection scenario to the model used in the 2020 SYR to verify the efficacy of the coarsened model

It would be necessary to manually review and revise the coarsened layer geometry along the faults in the model, and to compare the results of the coarsened model grid to the results of the 2020 SYR model, as the model coarsening and the assumptions made in the processing may result in differences in the model results. These differences and this comparison should be documented to support the use of the new model.

While it is possible to coarsen the model grid as described above, we do not recommend doing so for several reasons. First, a coarser model grid does not allow for a more precise assessment of MPI. By averaging groundwater-level impacts due to transient groundwater pumping over a larger area, potential drawdown due to transient groundwater pumping may be less visible. Coarsening the model renders the CVM a less useful tool to quantify MPI, which is a required element to calculate the Safe Yield.

Second, coarsening the model grid will result in a new separate model, rather than an update to the existing model as contemplated in the 2025 Safe Yield Reevaluation (see Attachment D). A new separate model may lead to challenges to conclusions derived from prior models. Furthermore, this would result in the maintenance of multiple models for multiple applications (e.g., one model with 200-ft cells for salinity modeling and one model with 400-ft cells for the Safe Yield evaluations). This would increase the work required to maintain and document these models and would increase the cost to the Parties.

Finally, the cost of coarsening the model will likely be greater than the cost savings of the reduced run times due to a coarser model. As noted in the TM, the costs of staff time due to model run time are minimal; most of the cost savings would be due to saving time in model debugging and some post-processing. We estimate that the time saved with a coarser model would amount to around $80,000, which is less than the estimated cost of coarsening the model (i.e., $90,000 to $100,000).

For the reasons stated above, West Yost does not recommend coarsening the model.

Comment No. 2.2

Reduce the number of model layers - The model currently has five layers. Two of the layers were added during the 2020 SYR to accommodate simulation of land subsidence in the MZ-1 area. As use of the CVM for land subsidence simulations is no longer proposed, the layers could be removed, which would increase model run times significantly. Based on conversations at the Workshop, it is understood that removing model layers would, in and of itself, require time and effort. However, if cost savings from run times outweigh the cost increase to remove the layers, this may still be a cost-effective step to consider.

Response: The cost of reducing the model layers will increase the overall cost of the modeling and may be greater than the cost of increased simulation time if the layering was not simplified. Reducing the number of model layers will increase the numerical dispersion of the salinity transport simulations that are conducted for the salt and nutrient management planning. Therefore, reducing the number of model layers will result in a less realistic vertical mix of groundwater and increase the uncertainty of the simulation results.

Response by Thomas Harder on July 12, 2022 Draft: It is acknowledged that this structural change to the model could result in work that costs more than the time saved in reduced simulation time. However, it is emphasized that the primary purpose of this model is for updating the Safe Yield of the Basin, not for salt and nutrient management.

Response: This does not necessitate a response.

Comment No. 2.3

Discontinue use of the HSPF and R4 surface water routing models – These ‘ancillary models’ provide estimates of deep infiltration of precipitation and applied water, which are used as input to MODFLOW via the standard packages. Incorporating them into the PEST calibration will slow down the process significantly. Alternatively, use the HSPF and R4 values from previous model runs as “initial values” in PEST and let IES vary the parameters during calibration.

Response: The HSPF and R4 models will need to be updated and run to estimate DIPAW for the historical calibration period and develop DIPAW projections for the projection realizations. We do not plan to include these models in the PEST calibration. We have updated the draft TM to reflect this response.

Response by Thomas Harder on July 12, 2022 Draft: It's our understanding the HSPF and R4 models provide input to MODFLOW packages. It's our further understanding that the parameters within those MODFLOW packages are varied within plausible ranges as part of PESTPP-IES. If our understanding is correct, we agree with the recommendation to use a single realization of HSPF and R4. This should simplify the uncertainty analysis significantly.

Response: Your understanding is correct. No further response is required.

Comment No. 2.4

Reduce timesteps – Some models can run successfully with one time step per stress period. If this is the case with the CVM, it would reduce model run time.

Response: The CVM currently runs with one time step per stress period.

Comment No. 2.5

Change the configuration of the solver – The MODFLOW portion of the CVM utilizes the NWT solver. Start with the 'SIMPLE' configuration of the NWT solver and ramp up to 'MODERATE' and 'COMPLEX' settings as necessary.

Response: Thank you for the suggestion. We will consider using this in our calibration and uncertainty analysis.

Response by Thomas Harder on July 12, 2022 Draft: In the upcoming detailed cost estimate we are requesting for implementing the revised Safe Yield Reset Methodology, we would like it noted in the estimate if it reflects our recommendation.

Response: We intend to implement this recommendation. It is reflected in Task 2 of our cost estimate (Attachment D).

Comment No. 2.6

Implement PLPROC Kx relationship equations - These seem to do a good job of stabilizing the model and reducing run times.

Response: Thank you for the suggestion. We will consider using this in our calibration and uncertainty analysis.

Response by Thomas Harder on July 12, 2022 Draft: In the upcoming detailed cost estimate we are requesting for implementing the revised Safe Yield Reset Methodology, we would like it noted in the estimate if it reflects our recommendation.

Response: We have reviewed the PLPROC documentation, and several of the functions in PLPROC may be applicable to our model. Our cost estimate assumes that we can identify efficiencies to reduce run times, possibly including PLPROC.

Comment No. 2.7

Remove outlier observations – Assign a zero weight to groundwater level observations that are considered outliers. This will help constrain IES and reduce run times.

Response: Thank you for the suggestion. We will consider using this in our calibration and uncertainty analysis.

Response by Thomas Harder on July 12, 2022 Draft: In the upcoming detailed cost estimate we are requesting for implementing the revised Safe Yield Reset Methodology, we would like it noted in the estimate if it reflects our recommendation.

Response: We will not use outlier observations when selecting groundwater level calibration targets.

Comment No. 3 – Incorporation of Distribution System Losses into the Water Budget for the Model (May 5, 2022 and July 12, 2022 Drafts)

As stated in my review letter on the Draft Data Collection and Evaluation Report for Fiscal Year 2020/21, dated April 28, 2022, and discussed at the Workshop, the AP would like to account for water distribution losses explicitly in the water budgets for the model analysis to reset the Chino Basin Safe Yield. Adding this input, which is currently missing from the water budget, would make the other less constrained aspects of the model (e.g., boundary conditions) more representative. We would like a cost estimate to incorporate system losses into the CVM for the upcoming Safe Yield Reset.

Response: As discussed in the May peer review meeting, any potential work to include system losses (water main leaks) in the updated CVM is not necessary to finalize the Safe Yield Reset methodology.

To incorporate water main leaks into the CVM, we would need to develop defensible assumptions for the location and magnitude of recharge resulting from these leaks over the calibration and planning periods. While the ability of the water agencies to calculate the location and magnitude of these leaks is improving,[2] there remains a high degree of uncertainty in developing historical and projected estimates. We have yet to receive sufficient information to quantify water main leaks, and information that we have reviewed in the Basin (e.g., 2020 Urban Water Management Plans) does not indicate enough certainty in the magnitude and location of water main leaks to warrant inclusion in the CVM.

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[2] Amanda Coker (on behalf of Cucamonga Valley Water District) suggested at the May 19, 2022, peer review meeting that the data for water main leaks has improved recently. We will follow up with Amanda to acquire more detail and determine whether this could be considered in our CVM update.

We will develop a cost estimate in FY 2022/23 to include water main leaks in the CVM during the forthcoming model update. The ability to incorporate water main leaks in the model update is contingent on receiving reliable data on the magnitude and location of water main leaks from the Appropriative Pool Parties. This process will include additional data collection, data processing, and peer review to develop estimates of the location and magnitude of the historical and projected water main leaks that result in groundwater recharge.

Response by Thomas Harder on July 12, 2022 Draft: Application of water distribution losses explicitly into the water budgets for groundwater flow models can be accomplished and the required assumptions do not result in any less certainty than other recharge components that are already explicitly included in the model water budget (e.g. individual septic return flow, vadose zone travel times via HYDRUS, horizontal flow barrier permeability at the Redhill Fault, etc.). We look forward to providing input into how this water budget component can be added to the Safe Yield Reset model and reviewing the cost estimate to incorporate water distribution system losses into the model.

Response: We have developed a cost estimate to update the CVM to explicitly include recharge from water distribution losses, which is summarized in the table below:

Cost estimate to update the CVM to explicitly include recharge from water distribution losses

Task	Description	Labor Hours	Budget, dollars
1.1	Prepare data request for information on historical/future water main leaks	16	3,080
1.2	Collect historical data and future projections of water main leaks (location, magnitude)	20	3,664
1.3	Review data and determine applicability to CVM	30	6,288
1.4	Prepare draft TM documenting data and recommendations	48	10,048
1.5	Prepare presentation materials	34	7,120
1.6	Meet with Watermaster staff to review presentation materials	12	3,056
1.7	Conduct workshop	32	7,528
1.8	Review stakeholder comments with Watermaster staff	12	3,056
1.9	Prepare responses to comments	20	5,000
1.10	Develop method and tools to convert data to RCH package	44	8,936
1.12	Update RCH file for calibration scenario	20	4,440
1.13	Update RCH file for projection scenario	20	4,440
1.14	Prepare report appendix documenting process and data to incorporate water distribution losses into the CVM	40	8,384
		Total (Plus 20 percent contingency)	**$90,048**

This cost estimate is dependent on receiving sufficient data to develop defensible estimates of historical and future water distribution losses in the Chino Basin. The cost estimate also assumes that this work would occur in FY 2022/23 concurrent with the update of the hydrogeologic conceptual model, and a budget amendment would be required.

Comment No. 4 – 2022/23 Budget for Conceptual Model Updates (May 5, 2022 Draft)

In the January 24, 2022, letter from WY entitled "Planning-Level Scope, Schedule, and Budget for Engineering Support of the Implementation of the 2017 Court Order through Fiscal Year 2025," a budget of $270,000 is described for Task 3 "Update Model and Reevaluate Safe Yield" in Table 1 (pg. 6). On page 4 of the same letter, while there are seven subtasks under Task 3, the only subtask that appears to be scheduled for FY 2023 is Task 3.01 – Update Hydrogeologic Conceptual Model. As such, it is assumed that the budget of $270,000 for Task 3 in Fiscal Year 2023 is for the hydrogeological conceptual model. During the Workshop, I requested the details of what specific work was included for the $270,000 budgeted for this task. To date, we have not received that detail.

Response: The planning-level budget for FY 2022/23 that you reference has been superseded by Watermaster's Engineering budget for FY 2022/23 that was approved by the Watermaster Board on May 26, 2022. The approved budget included about $260,000 budget for the update of the CVM, which generally comprises the following tasks:

- Routine collection and evaluation of data/reports related to the Chino Basin hydrogeology, such as borehole data, remote sensing data, water quality data, and studies of the area conducted by outside agencies.
- Identification of assumptions that may be updated in the hydrogeologic conceptual model based on new information.
- Begin reconfiguration of the CVM to use pilot points and facilitate the uncertainty analysis tool (PESTPP-IES).
- Collection of data to update the R4 model (zero cost – data are already collected through existing Watermaster tasks).
- Extend the HSPF and R4 models over the historical period to calculate initial estimates of DIPAW (some overlap with concurrent Watermaster efforts; cost of overlapping scope is not included in this budget).
- Develop initial estimates of subsurface inflow from adjacent basins and mountain/hillside boundaries.
- Prepare materials for and facilitate peer review meeting to present the updated hydrogeologic conceptual model.
- Prepare materials for and facilitate one stakeholder workshop to identify drivers of changes to future water demands and supplies.

Comment No. 5 – Additional Recommendations (July 12, 2022 Draft)

Based on Section 5.2 Recommended Implementation of Ensemble Approach in the July 12, 2022 TM, it appears that WY is planning on running 40 calibrated model realizations against 15 projection scenarios. While multiple calibrated model realizations will be obtained during the PESTPP-IES process for the historical model calibration, there is only a need to use one historical calibration realization for the projection scenarios. Our recommended approach to determine the historical calibration for use in analyzing the projection scenarios is as follows:

- Assuming our recommendations regarding cell size are implemented, we recommend an ensemble size of no less than 500 for the PESTPP_IES model calibration. In the PESTPP_IES setup, suppress as much output as possible as this will reduce run times because the model doesn't have to write large files during the process. For example, configure the output control file to not write the head and drawdown files and suppress writing arrays to the list file.
- Assuming a 3-hour model run time during parallel processing and 25 agents, one iteration is expected to be on the order of 60 hours of run time. Further assuming the model is sufficiently

calibrated after 5 iterations, the total run time for the calibration is expected to be on the order of 300 hours (12.5 days or two weeks; models run 24/7). This is a conservatively long estimate as some members of the ensemble will likely drop out during the process thereby reducing the run time required to complete each iteration.

- Given our understanding of the model, it is reasonable to expect that approximately half of the original members of the original ensemble will drop out during the calibration process.

- After PESTPP_IES has completed the calibration process, each of the remaining calibrated members of the ensemble (realizations) will need to be run in MODFLOW to process the water budget information necessary to estimate the historical Safe Yield from the data. Assuming the PESTPP_IES process results in 250 acceptable calibrated realizations and each model requires three hours to run, the total model run time is expected to be on the order of 750 hours or 62.5 days. Assuming 25 agents can be run in parallel, this run time is reduced to 2.5 days. Again, suppress as much output as possible. Everything needed to estimate historical Safe Yield for each run is available from the List files and spreadsheets of imported water deliveries.

- The historical Safe Yield for each calibrated model realization should be plotted on a cumulative probability curve. The Safe Yield value selected from the probability curve would be the value used for analysis of the 15 projection simulations.

- Typically, the 50th percentile historical Safe Yield is selected for use in the projection simulations. However, we would like to review the results of the historical calibration prior to analyzing the projection scenarios.

This process will be far less work than is implied by Section 5.2 of the TM, which suggested running 40 calibrations against 15 projection scenarios (600 projection realizations). The approach described above will result in 1 model calibration run against the 15 projections (15 projection realizations).

Response: As we note in Section 5.2, the 40 calibration realizations and 15 projection scenarios are used as a hypothetical number to demonstrate the computational feasibility of the proposed approach. As outlined in the proposed methodology and emphasized in response to others' comments (see response to Rick Rees' Comment 7), we propose to select a smaller number of calibration realizations initially, review with the peer review committee, and add more calibration realizations if necessary, as we aim to make the process as efficient as possible.

To address the uncertainty in the Safe Yield calculation, the uncertainty in the model parameters should be included in the analysis. Using only one calibration realization undermines the objective of the uncertainty analysis, and therefore we disagree with the use of only one calibrated realization. Our recommended process efficiently achieves the desired outcome of an uncertainty analysis.

Regarding bullet 1: We will be suppressing outputs as much as possible.

Regarding bullets 1 through 4: We have considered these estimates in the development of our cost estimate and schedule in response to your subsequent comment.

Regarding bullet 5: We plan to use multiple calibration realizations in the projection simulations to characterize the uncertainty in model parameters. We plan to select calibration realizations based on statistics derived from the model results.

Regarding the final two paragraphs: We will be reviewing the calibration results with the peer review committee before choosing the calibration realizations that will be included in the projection realizations. As noted earlier, 600 projection realizations is a hypothetical number used for demonstration. We believe that our recommended process is responsive to the Court Order and the Parties' comments, is cost-efficient, and is consistent with best management practices.

Comment No. 6 – Final Comments (July 12, 2022 Draft)

As Watermaster finalizes the Safe Yield calculation methodology with the uncertainty analysis, we would like to see a detailed scope of work, cost estimate and schedule to implement the methodology. This would include a detailed work breakdown structure of line items for the uncertainty analysis and their associated cost. Based on discussions at the most recent workshop, it is our understanding that a fully functional IES setup can be developed in the range of three to four weeks. The above approach should require on the order of an additional month to accomplish. That is, it is expected that a cumulative probability curve of historical safe yield values can be developed in roughly 2 months. The projection simulations used to estimate the Safe Yield of the Chino Basin for the next 10 years would follow.

Response: We have updated the TM to include the requested scope, schedule, and budget estimate to implement the methodology. See Attachment D.

CITY OF CHINO/GEOPENTECH (DAVE CROSLEY, PE; ERIC FORDHAM, PG, CEG, CHG) – MAY 5, 2022 DRAFT

Paragraph 1

Comments previously provided to the Watermaster regarding the Safe Yield Reset methodology, identified, and requested the need to include uncertainty analysis in the groundwater flow modeling process as a best management practice. All conceptual and numerical models have some level of uncertainty that is the result of simplifying a complex hydrologic system. The Chino Valley Model (CVM) is no different and includes parameter and prediction uncertainty despite the quality of model calibration. The CVM model is used to assess the basin's safe yield for various planned demand and supply scenarios and whether hydraulic control is maintained, and material physical injury (MPI) would occur. The benefits and risks of the various demand and supply scenarios should be weighed by decision makers that are able to consider a quantified understanding of the safe yield uncertainty and probability of associated outcomes associated with those predictions.

Response: This paragraph does not necessitate a response.

Paragraph 2

Watermaster's consultant is planning on updating the existing CVM model by extending the calibration period to include recently collected data for the hydrologic models (HSP4 and R4) and the MODFLOW flow model, selecting adjustable parameters for calibration and assigning values to those parameters using improved numerical methods that incorporate pilot points, variograms and covariance matrices. The model should also be updated by including water distribution system losses as quantified by the Chino Basin water purveyors. The addition of this recharge function to the CVM would likely influence the resulting basin net recharge and aquifer parameter calibration. The recharge associated with distribution system losses is an important part of the Chino Basin water budget.

Response: Our response to the recommendation to include system losses in the CVM remains the same as prior responses (see the response to Thomas Harder's Comment 3 herein and our response to Thomas Harder's Comment 2 on the *Data Collection and Evaluation Report for FY 2020/2021*[3]).

Paragraph 3

Watermaster's consultant plans to conduct the calibration process using PESTPP-IES, a robust and efficient numerical solver that will estimate model parameter probability distributions and generate a specified number of calibrated model realizations with associated net groundwater recharge. The calibrated model realizations will then be run with up to three (3) supply plan scenarios and five (5) climate scenarios to generate multiple model results that will provide net recharge probability distributions that can be used to evaluate safe yield and compare against hydraulic control and MPI. While we agree with this approach for model calibration and uncertainty assessment, Watermaster's consultant may be over scoping the process to achieve the intended results as they provide an estimate to implement the analysis at $1.75 million to $2.3 million.

Response: This paragraph does not necessitate a response.

Paragraph 4

To successfully conduct an uncertainty analysis for the Chino Basin safe yield, and associated demand and supply scenarios, we request that Watermaster's consultant seek out means and methods to minimize the implementation cost. Mr. Tom Harder, in his June 23, 2022, letter to the Appropriative Pool provides 7 recommendations that should be considered to streamline the model analysis and reduce cost. We also recommend exploring means to reduce the number of calibrated model realizations to develop the net recharge probability distribution. Rather than using up to 40 realizations as an example suggested by

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[3] The Data Collection and Evaluation Report for FY 2020/2021 can be found here https://cbwm.syncedtool.com/shares/folder/PaauzoQapiZ/?folder_id=303197856. Comments and responses can be found in Appendix C of the report.

Watermaster's consultant, a subset of the calibrated realizations could be ranked by net recharge and used for the analysis. An example would be to include realizations representing the maximum, mean and minimum modeled net recharge to sufficiently bracket the range of safe yield outcomes. In this case the number of model realizations could be reduced from 40 to perhaps 9 model realizations and when combined with the demand and supply scenarios (3) and climate predictions (5), would result in 135 projection realizations versus the 600 envisioned. Fewer projection realizations would reduce computing time, storage requirements, and post processing while preserving the intention of the uncertainty analysis by providing the range and probability of possible safe yield outcomes.

Response: We have responded to each of Mr. Harder's recommendations for reducing the cost and runtime of the uncertainty analysis above. We agree that it is desirable to limit the number of calibrated realizations while conducting a complete uncertainty analysis that covers the plausible range of parameters and model results. Please refer to our response to Rick Rees' Comment No. 7 herein.

Paragraph 5

In addition, it is our understanding that Watermaster's consultant has not conducted an uncertainty analysis for a hydrologic model as complicated as the CVM and unfamiliarity with the process may have led to an overly conservative scoped level of effort and associated costs. We recommend the consultant conduct independent research and process development to better understand the mechanics of their planned approach such that only the essential steps required for the CVM uncertainty analysis are recognized and the associated level of effort and costs can be defined. A detailed cost estimate should be prepared to conduct the CVM uncertainty analysis for the basin's safe yield that should be presented to the Chino Basin groundwater producers for their consideration.

Response: The draft TM documents the results of our research and process development on the proposed methodology to calculate the Safe Yield. The purpose of the TM and the current peer review process is to develop an updated Safe Yield Reset methodology to address Party comments and the requirements of the 2017 Court Order. While we have a confident understanding of the implementation process, there are inherent unknown variables in the process (e.g., number of calibration realizations) that warrant the range in cost estimate. More detailed annual budgets, such as the current budget for FY 2022/23, are presented for approval by the Advisory Committee and Board in the spring prior to the new FY. We present these budgets with clear assumptions on scope, schedule, and deliverables, and we will continue to do so during the implementation of the updated Safe Yield Reset methodology.

Attachment C

2022 Reset Technical Memorandum

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RESET TECHNICAL MEMORANDUM

DATE: September 1, 2022

Project No.: 941-80-22-32
SENT VIA: EMAIL

TO: Peter Kavounas, Chino Basin Watermaster

FROM: Garrett Rapp, PE, RCE #86007
Andy Malone, PG

SUBJECT: Methodology to Reset the Safe Yield of the Chino Basin

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2022 UPDATED SAFE YIELD RESET METHODOLOGY

This technical memorandum summarizes the methodology to calculate the Safe Yield of the Chino Basin for the 2025 Safe Yield Reevaluation and subsequent Safe Yield evaluations. The methodology: (i) is consistent with professional custom, standard, and practice; (ii) incorporates current best management practices and hydrologic science; and (iii) is consistent with the definition of Safe Yield in the Judgment and the Physical Solution.

1. Use data collected since the implementation of the OBMP to re-calibrate the Watermaster's groundwater-flow model. The re-calibration period should be long enough to include wet and dry periods relative to the long-term historical precipitation record.

2. Conduct an uncertainty analysis of the re-calibrated groundwater-flow model to identify a plausible range of calibrated models.

3. Describe current and projected future cultural conditions, including but not limited to land use and water-management practices, such as: pumping, managed recharge, managed groundwater storage, impervious land cover, water recycling, and water conservation practices. Identify a possible range of projected future cultural conditions.

4. Using the most current research on future climate and hydrology, identify a possible range of projected future climatic conditions in the Santa Ana River watershed.

5. Using the results of [3.] and [4.] above, prepare an ensemble of multiple projection scenarios of combinations of future climate/hydrology and cultural conditions (herein called the "Projection Ensemble"). Assign likelihoods to each scenario in the Projection Ensemble.

6. Simulate the range for the potential future water budget and groundwater conditions in the Chino Basin over no less than a 50-year future period. This is accomplished by using:

    i. The range of calibrated models developed in [2.], and

    ii. The Projection Ensemble developed in [5.] as model input data.

7. Using the results of [6.] above, characterize the range in the model results for:
    - i. Groundwater conditions, including: groundwater elevations, groundwater in storage, and groundwater flow directions, and
    - ii. The water budget, including: basin inflows, outflows, change in storage, and net recharge.
8. Using the set of net recharge results from [7.ii], determine a tentative Safe Yield as the likelihood-weighted average net recharge over the 10-year prospective period for which the Safe Yield is being redetermined (Tentative Safe Yield).
9. Evaluate whether the groundwater production at the Tentative Safe Yield estimated in [8] above will cause or threaten to cause "undesirable results" or "Material Physical Injury." If groundwater production at Tentative Safe Yield will cause or threaten to cause "undesirable results" or "Material Physical Injury," then Watermaster will identify and implement prudent measures necessary to mitigate "undesirable results" or "Material Physical Injury," set the value of Safe Yield to ensure there is no "undesirable results" or "Material Physical Injury," or implement a combination of mitigation measures and a changed Safe Yield.

Attachment D

Cost Estimate for the 2025 Safe Yield Reevaluation

Table D-1. Cost Estimate for 2025 Safe Yield Reevaluation

Task/Subtask	Description	Year Completed	Is the Subtask Strictly Necessary for Uncertainty Analysis?	Labor Hours	Labor Cost^1	Other Direct Costs^2	Total Cost
Task 1. Update Hydrogeologic Conceptual Model and Surface Water Models							
1.1. Update geology - collect/compile/review historical information							
1.1.1	New well information (location, borehole lithology, geophysical logs, well construction, aquifer stress test, others)	FY 2022/23	No	40	$8,880		$8,880
1.1.2	New groundwater level, pumping and water quality data	FY 2022/23	No	56	$11,216		$11,216
1.1.3	Data collection and investigations conducted by others (USGS, OCWD, ACOE, RWQCB, DTSC, HCP, others)	FY 2022/23	No	52	$11,860		$11,860
1.1.4	Remote sensing data (InSAR, aerial photographs, others)	FY 2022/23	No	18	$3,388		$3,388
1.2. Update geology along Rialto/Colton boundary							
1.2.1	Review reports and GIS shape files from USGS	FY 2022/23	No	20	$3,944		$3,944
1.2.2	Review other new data and reports	FY 2022/23	No	20	$4,348		$4,348
1.2.3	Integrate new information into hydrostratigraphic sections	FY 2022/23	No	32	$7,528		$7,528
1.3. Update surface topo along the SAR and lower tributaries							
1.3.1	Acquire Lidar data sets from USGS, ACOE, and OCWD	FY 2022/23	No	28	$5,328		$5,328
1.3.2	Review Lidar data sets and prepare information for updating the geometry of SAR	FY 2022/23	No	48	$10,048		$10,048
1.4. Review geology, groundwater level, and chemistry data to infer flow system dynamics							
1.4.1	MZ1/subsidence (Includes new Pomona extensometer data)	FY 2022/23	No	40	$10,560		$10,560
1.4.2	Prado basin area	FY 2022/23	No	48	$11,664		$11,664
1.4.3	Groundwater basin boundaries subsurface inflows	FY 2022/23	No	8	$2,224		$2,224
1.4.4	Mountain and hillside surface water discharge and subsurface inflow	FY 2022/23	No	16	$3,888		$3,888
1.4.5	Stringfellow area paleo channel	FY 2022/23	No	8	$2,224		$2,224
1.4.6	Others	FY 2022/23	No	32	$7,248		$7,248
1.5. Update historical hydrology for calibration period (FY1978-2022) - collect/compile/review historical information							
1.5.1	Land use data (completed via other work)	FY 2022/23	No	0	$0		$0
1.5.2	Groundwater pumping data (completed via other work)	FY 2022/23	No	0	$0		$0
1.5.3	Artificial recharge data (completed via other work)	FY 2022/23	No	0	$0		$0
1.5.4	Non-tributary and tributary discharges (completed via other work)	FY 2022/23	No	0	$0		$0
1.5.5	Precipitation, evaporation, ET (completed via other work)	FY 2022/23	No	0	$0		$0
1.5.6	Livestock population data (completed via other work)	FY 2022/23	No	0	$0		$0
1.5.7	Supplemental water source and use data (completed via other work)	FY 2022/23	No	0	$0		$0
1.5.8	Riparian vegetation mapping and ET requirements	FY 2022/23	No	40	$8,136		$8,136
1.6. Update historical hydrology for calibration period (FY1978-2022) - Update recharge and discharge estimates							
1.6.1	Update groundwater pumping and artificial recharge estimates (completed via other work)	FY 2022/23	No	0	$0		$0
1.6.2	Update DIPAW	FY 2022/23	No	36	$8,328		$8,328
1.6.3	Update initial estimates of subsurface inflow from adjacent basins	FY 2022/23	No	32	$8,336		$8,336
1.6.4	Update subsurface inflow estimates from mountain and hillside boundaries	FY 2022/23	No	32	$7,496		$7,496
1.7. Update hydrostratigraphic characterization and convert to pilot points							
1.7.1	Finalize hydrostratigraphic sections, develop layering scheme	FY 2022/23	No	56	$12,024		$12,024
1.7.2	Generate pilot points on model area and assign initial parameter values	FY 2022/23	No	40	$11,120		$11,120
1.7.3	Determine variograms for aquifer parameters	FY 2022/23	No	76	$16,808		$16,808
1.8. Conduct workshop for stakeholders/consultants on conceptual model update							
1.8.1	Prepare materials for for review by peer reviewers	FY 2023/24	No	58	$13,924		$13,924
1.8.2	Prepare presentation materials	FY 2023/24	No	56	$13,345		$13,345
1.8.3	Meet with Watermaster staff to review presentation materials	FY 2023/24	No	16	$4,189		$4,189
1.8.4	Conduct workshop	FY 2023/24	No	40	$9,851	$200	$10,051
1.8.5	Review stakeholder comments with Watermaster staff	FY 2023/24	No	16	$4,189		$4,189
1.8.6	Prepare responses to comments	FY 2023/24	No	28	$7,222		$7,222
Subtotal for Task 1							**$229,516**

Table D-1. Cost Estimate for 2025 Safe Yield Reevaluation

Task/Subtask	Description	Year Completed	Is the Subtask Strictly Necessary for Uncertainty Analysis?	Labor Hours	Labor Cost[1]	Other Direct Costs[2]	Total Cost
Task 2. Recalibrate Groundwater Model and Generate Calibration Realizations							
2.1. Extend the calibration period from FY 2018 to FY 2022							
2.1.1	Convert the WEL Package to Multi-Node (MNW) well package through FY 2022	FY 2022/23	No	64	$15,248		$15,248
2.1.2	Revise and extend the SFR package through FY 2022	FY 2022/23	No	48	$12,072		$12,072
2.1.3	Extend the DRN Package through FY 2022	FY 2022/23	No	8	$2,012		$2,012
2.1.4	Extend the ETS Package through FY 2022	FY 2023/24	No	26	$6,415		$6,415
2.1.5	Extend the FHB Package through FY 2022	FY 2023/24	No	40	$9,801		$9,801
2.2. Generate calibrated realizations							
2.2.1	Establish calibration targets (time series of head and stream discharge observations)	FY 2023/24	No	58	$15,115		$15,115
2.2.2	Prepare input files to PEST/PESTPP-IES	FY 2023/24	No	84	$21,420		$21,420
2.2.3	Get PESTPP-IES to run, debug as needed	FY 2023/24	No	108	$27,477		$27,477
2.2.4	Execute PESTPP-IES to generate calibrated realizations	FY 2023/24	No	100	$26,046		$26,046
2.2.5	Run flow simulation with the calibrated realizations and conduct residual analysis of calibrated realizations and develop a script to automate the process. Results will be used for selecting a subset of calibrated realizations.	FY 2023/24	No	110	$28,386		$28,386
2.2.6	Ranking calibrated realizations based on the results of residual analysis and other criteria	FY 2023/24	No	32	$8,039		$8,039
2.3. Prepare draft TM on calibration and generate calibration results							
2.3.1	Prepare draft TM with exhibits from Task 2.2	FY 2023/24	No	64	$16,299		$16,299
2.3.2	Create maps of selected parameters of selected realizations	FY 2023/24	No	36	$8,644		$8,644
2.3.3	Create maps of residuals of selected calibrated realizations	FY 2023/24	No	34	$8,176		$8,176
2.3.4	Groundwater hydrographs and scatter plots of selected calibrated realizations	FY 2023/24	No	34	$8,176		$8,176
2.3.5	Surface water hydrographs and scatter plots of selected calibrated realizations	FY 2023/24	No	20	$4,900		$4,900
2.3.6	Assess calibration statistics and water budgets and select set of calibrated realizations	FY 2023/24	No	44	$10,957		$10,957
2.4. Workshop to review draft TM on model calibration							
2.4.1	Prepare exhibits and presentation materials for workshop	FY 2023/24	No	58	$14,753		$14,753
2.4.2	Meet with Watermaster staff to review presentation materials	FY 2023/24	No	6	$1,624		$1,624
2.4.3	Conduct workshop	FY 2023/24	No	24	$6,498	$200	$6,698
2.4.4	Review stakeholder comments with Watermaster staff	FY 2023/24	No	16	$4,295		$4,295
2.4.5	Respond to comments	FY 2023/24	No	24	$6,498		$6,498
2.5. Follow-up workshop, finalize TM							
2.5.1	Prepare exhibits and presentation materials for workshop	FY 2023/24	No	52	$13,129		$13,129
2.5.2	Meet with Watermaster staff to review presentation materials	FY 2023/24	No	6	$1,624		$1,624
2.5.3	Conduct workshop	FY 2023/24	No	32	$8,228	$200	$8,428
2.5.4	Respond to comments and prepare final TM	FY 2023/24	No	22	$5,809		$5,809
2.5.5	Meet with Watermaster staff to review final TM	FY 2023/24	No	12	$3,249		$3,249
2.5.6	Finalize TM and distribute to Parties	FY 2023/24	No	22	$5,040		$5,040
Subtotal for Task 2 with 20 percent contingency							**$360,401**
Task 3. Prepare Ensemble of Projection Scenarios							
3.1. Initial workshop to identify drivers for water demand and supply plans							
3.1.1	Prepare exhibits and presentation materials for workshop	FY 2022/23	Yes	52	$12,624		$12,624
3.1.2	Meet with Watermaster staff to review presentation materials	FY 2022/23	Yes	12	$3,124		$3,124
3.1.3	Conduct workshop	FY 2022/23	Yes	32	$7,912	$200	$8,112
3.1.4	Review stakeholder comments with Watermaster staff	FY 2022/23	Yes	12	$3,124		$3,124
3.2. Assess climate data for development of scenarios							
3.2.1	Download and organize available WRF-CMIP6 data	FY 2023/24	No	8	$1,731		$1,731
3.2.2	Prepare and test tools for processing and visualizing WRF-CMIP6 data for the Chino Basin watershed	FY 2023/24	No	68	$17,014		$17,014
3.2.3	Characterize WRF-CMIP6 data for the Chino Basin watershed	FY 2023/24	No	36	$9,085		$9,085
3.2.4	Review and select climate scenarios for use in model	FY 2023/24	No	44	$11,398		$11,398
3.3. Develop supply and demand scenarios, document in draft TM, and conduct workshop							
3.3.1	Develop qualitative descriptions of projection scenarios (water demands/supply plans and climate)	FY 2023/24	Yes	8	$1,872		$1,872
3.3.2	Develop quantitative water supply plans for selected projection scenarios	FY 2023/24	No	68	$16,149		$16,149
3.3.3	Prepare draft TM documenting proposed projection scenarios	FY 2023/24	Yes	52	$11,960		$11,960
3.3.4	Review draft TM with WM staff	FY 2023/24	Yes	8	$2,057		$2,057

Table D-1. Cost Estimate for 2025 Safe Yield Reevaluation

Task/Subtask	Description	Year Completed	Is the Subtask Strictly Necessary for Uncertainty Analysis?	Labor Hours	Labor Cost[1]	Other Direct Costs[2]	Total Cost
3.3.5	Finalize draft TM and distribute to Parties	FY 2023/24	Yes	10	$2,232		$2,232
3.3.6	Prepare exhibits and presentation materials for workshop	FY 2023/24	No	28	$7,143		$7,143
3.3.7	Meet with Watermaster staff to review presentation materials	FY 2023/24	No	6	$1,624		$1,624
3.3.8	Conduct workshop	FY 2023/24	No	32	$8,228	$200	$8,428
3.3.9	Prepare responses to comments	FY 2023/24	No	14	$3,607		$3,607
3.3.10	Review stakeholder comments with Watermaster staff	FY 2023/24	No	6	$1,624		$1,624
3.4. Follow-up workshop, finalize TM							
3.4.1	Prepare exhibits and presentation materials for workshop	FY 2023/24	Yes	24	$6,207		$6,207
3.4.2	Meet with Watermaster staff to review presentation materials	FY 2023/24	Yes	12	$3,249		$3,249
3.4.3	Conduct workshop	FY 2023/24	Yes	32	$8,228	$200	$8,428
3.4.4	Respond to comments and prepare final TM	FY 2023/24	Yes	12	$3,249		$3,249
3.4.5	Meet with Watermaster staff to review final TM	FY 2023/24	Yes	6	$1,624		$1,624
3.4.6	Finalize TM and distribute to Parties	FY 2023/24	Yes	10	$2,232		$2,232
Subtotal for Task 3 including 20 percent contingency							**$177,479**
Task 4. Simulate Ensemble of Projection Scenarios and Calculate Safe Yield							
4.1. Prepare model runs							
4.1.1	Define the required results and define file formats for storing the results	FY 2024/25	No	20	$5,555		$5,555
4.1.2	Convert the Well package of the projection period to the MNW package	FY 2024/25	No	52	$13,113		$13,113
4.1.3	Develop method to generate future flows at Riverside Narrows (RN) based on climate projections	FY 2024/25	No	32	$8,246		$8,246
4.1.4	Prepare MODFLOW input files for the initial projection scenario	FY 2024/25	No	52	$13,113		$13,113
4.1.5	Prepare MT3D input files for the initial projection scenario	FY 2024/25	No	32	$8,246		$8,246
4.1.6	Prepare ZoneBudget input files for the hydraulic control assessment	FY 2024/25	No	20	$5,096		$5,096
4.2. Develop tools to generate projection realizations							
4.2.1	Tool to update the input file to the UPW package with the aquifer parameters from a calibrated realization (generate matrices based on the calibrated pilot point data, replace the matrices in UPW with the new ones)	FY 2024/25	Yes	72	$17,981		$17,981
4.2.2	Tool to update HSPF input file with climate data (precip & ET) and execute HSPF	FY 2024/25	Yes	48	$12,140		$12,140
4.2.3	Tool to update R4 input file with climate data (precip, ET, flow at RN), water demand (applied water assumptions), and HSPF output, and to execute R4	FY 2024/25	Yes	56	$14,087		$14,087
4.2.4	Tool to update input files to the RCH, FHB, and SFR packages with R4 output and flow at RN	FY 2024/25	Yes	56	$14,087		$14,087
4.2.5	Tool to update input file to the ETS package with climate data	FY 2024/25	Yes	48	$12,140		$12,140
4.2.6	Tool to update the input files to the MNW and FHB packages based on water supply plan	FY 2024/25	Yes	72	$17,981		$17,981
4.3. Develop tools to conduct flow simulations and process results							
4.3.1	Tool to execute MODFLOW-NWT, including iterations to calculate net recharge time series, to stabilize imported water estimates, and to calculate safe yield	FY 2024/25	No	28	$7,043		$7,043
4.3.2	Tool to update MT3D input file (with specific yield as effective porosity in the BTN package), to execute MT3D, and to extract the desired simulation results	FY 2024/25	No	28	$7,043		$7,043
4.3.3	Tool for Hydraulic Control assessment (i.e., calculate groundwater discharge from Chino North MZ to Prado with ZoneBudget)	FY 2024/25	No	24	$6,299		$6,299
4.3.4	Tool for pumping and subsidence sustainablity assessment (i.e., calculate sustainability metric values)	FY 2024/25	No	18	$4,495		$4,495
4.4. Execute the developed tools for the first scenario							
4.4.1	Generate projection realization (executing, reviewing generated files, and debugging)	FY 2024/25	No	96	$23,536		$23,536
4.4.2	Conduct flow and transport simulation and postprocess results (executing, reviewing results, and debugging)	FY 2024/25	No	96	$23,536		$23,536
4.5. Execute the developed tools for the remainder of the ensemble							
4.5.1	Generate projection realization on AWS (setting up AWS instances, executing, reviewing generated files, and debugging)	FY 2024/25	Yes	92	$23,856		$23,856
4.5.2	Conduct flow and transport simulation and postprocess results on AWS (setting up AWS instances, executing, reviewing results, and debugging)	FY 2024/25	Yes	92	$23,856	$40,000	$63,856
4.5.3	Evaluate results, create statistics of safe yield, prepare output charts and graphics	FY 2024/25	Yes	108	$27,152		$27,152
4.4. Workshop to review the results of the model runs							
4.6.1	Prepare exhibits and presentation materials for workshop	FY 2024/25	No	60	$15,380		$15,380
4.6.2	Meet with Watermaster staff to review presentation materials	FY 2024/25	No	16	$4,279		$4,279
4.6.3	Conduct workshop	FY 2024/25	No	32	$8,558	$200	$8,758
4.6.4	Review stakeholder comments with Watermaster staff	FY 2024/25	No	24	$6,758		$6,758
4.6.5	Prepare responses to comments	FY 2024/25	No	36	$9,907		$9,907
Subtotal for Task 4 with 20 percent contingency							**$448,420**

Table D-1. Cost Estimate for 2025 Safe Yield Reevaluation

Task/Subtask	Description	Year Completed	Is the Subtask Strictly Necessary for Uncertainty Analysis?	Labor Hours	Labor Cost[1]	Other Direct Costs[2]	Total Cost
Task 5. Prepare Safe Yield Reevaluation Report							
5.1. Prepare Safe Yield Reevaluation Report							
5.1.1	Develop report outline and submit to Watermaster for review	FY 2024/25	No	24	$6,758		$6,758
5.1.2	Finalize report outline	FY 2024/25	No	8	$2,176		$2,176
5.1.3	Prepare admin draft report and submit to Watermaster staff for review	FY 2024/25	No	200	$48,888		$48,888
5.1.4	Review admin draft report with Watermaster staff and agree on changes	FY 2024/25	No	24	$6,758		$6,758
5.1.5	Prepare draft report and submit to stakeholders for review	FY 2024/25	No	60	$14,991		$14,991
5.1.6	Prepare presentation materials for Watermaster Board workshop	FY 2024/25	No	48	$12,910		$12,910
5.1.7	Conduct workshop	FY 2024/25	No	32	$8,558	$200	$8,758
5.1.8	Review stakeholder and Board member comments with Watermaster staff	FY 2024/25	No	24	$6,758		$6,758
5.1.9	Prepare responses to comments	FY 2024/25	No	96	$25,820		$25,820
5.1.10	Prepare final report	FY 2024/25	No	36	$8,540	$1,000	$9,540
Subtotal for Task 5 with 10 percent contingency							**$157,693**
Task 6. Support Court Approval Process for Updated Safe Yield							
6.1. Support Court approval process for updated Safe Yield							
6.1.1	Support Court approval process for updated Safe Yield	FY 2024/25	No	104	$28,978	$600	$29,578
Subtotal for Task 6 with 20 percent contingency							**$35,494**
Task 7. Project Management							
7.1. Project management							
7.1.1	PM FY 2022/23	FY 2022/23	No	66	$14,988		$14,988
7.1.2	PM FY 2023/24	FY 2023/24	No	66	$16,436		$16,436
7.1.3	PM FY 2024/25	FY 2024/25	No	66	$17,094		$17,094
Subtotal for Task 7							**$48,518**
Totals							
Total Estimated Cost for Subtasks in FY 2022/23 [3]							**$259,163**
Total Estimated Cost for Subtasks in FY 2023/24							**$539,656**
Total Estimated Cost for Subtasks in FY 2024/25							**$658,700**
Total Estimated Cost of Tasks 1 through 7							**$1,457,519**

[1] Staff billing rates are based on the Watermaster Engineer's approved billing rates for FY 2022/23 and assumes a four percent increase in rates for FY 2023/24 and FY 2024/25.

[2] Other direct costs include travel for workshops (multiple subtasks), renting cloud computing (subtask 4.5.2), and printing copies of final report (subtask 5.1.10).

[3] The currently approved engineering budget for groundwater modeling in FY 2022/23 is about $260,000.