Phase II Responsive Report of Matthew J. Tonkin, PhD

Responsive Opinions on the Safe Yield and Storage Properties of the Indian Wells Valley (IWV) Basin, California

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Acronyms

%	Percent
3D	three-dimensional
AFY	acre-feet per year
BBRM	Bootstrap Brute-force Recharge Model
BCM	Basin Characterization Model
DWR	California Department of Water Resources
ET	evapotranspiration
GSP	Groundwater Sustainability Plan
IWFM	Integrated Water Flow Model
IWV	Indian Wells Valley
IWVGA	Indian Wells Valley Groundwater Authority
LSM	land surface model
MFR	mountain front recharge
SSP&A	S.S. Papadopulos & Associates, Inc.
USGS	United States Geological Survey

Executive Summary

I have been retained to provide scientifically rigorous estimates of the safe yield of the Indian Wells Valley (IWV) Basin and of the volume of groundwater stored in the IWV Basin, and to review and evaluate the analyses and opinions provided by any other experts on these topics. On August 15, 2025, I prepared and submitted to the court an expert report that presents my affirmative Phase II opinions and the technical analyses that support those opinions. Following completion of my Phase II affirmative report, I received the affirmative reports of several other experts in this matter. I have since reviewed the affirmative reports of those other experts, and in doing so I have formed the following responsive opinions:

Responsive Opinion 1. Experts for the IWVGA and the USA Rely Upon Untested Methods and Assumptions that Underestimate Recharge to, and the Safe Yield of, the IWV Basin.

Responsive Opinion 2. Experts for the IWVGA and the USA Rely Upon Recharge Calculations that have not Been Produced and Cannot be Evaluated.

Responsive Opinion 3. Water Budgets of the IWVGA and the USA Experts are Incomplete Due, in Part, to Neglecting Incidental Recharge.

Responsive Opinion 4. Historical Evapotranspiration Rates Used by IWVGA and the USA to Constrain their Recharge and Yield Estimates Rely Upon Limited Data.

Responsive Opinion 5. The Groundwater Model Relied upon by Experts for the IWVGA and the USA Does not Accurately Represent Recharge Variability in the IWV Basin.

Responsive Opinion 6. My Recharge and Safe Yield Estimate Rests upon Best Available and State-of-the-Practice Methods in Accordance with DWR Guidance.

Responsive Opinion 7. Uncertainties Regarding the Role of Future Climate are Best Addressed as a Component of the Physical Solution.

My responsive report proceeds as follows:

- **Section 1** provides background and context for this responsive report.
- **Section 2** summarizes my responsive opinions.
- **Section 3** presents recommendations.

- **Section 4** lists the documents and other materials that I reviewed or relied upon in preparing this report and forming my responsive opinions.

Qualifications of Opinions

My affirmative report provided my initial opinions, and this report provides my responsive opinions. I understand that other experts may develop additional opinions and yield estimates and may use modeling or other methods to support those opinions. If other experts do develop additional opinions, I would want to understand the basis for their opinions, and I would need to study any models that they relied upon, as well as any other materials relied upon by any other experts in this matter, in adequate depth to formulate updated opinions, if necessary.

Experience and Compensation

My affirmative report details my relevant experience and professional training, and provides my curriculum vitae, with a list of publications that I have (co-) authored and a list of matters in which I have testified. Consistent with my affirmative work, S.S. Papadopulos & Associates, Inc. (SSP&A) is compensated at the hourly rate of $376.00 per hour for my responsive work in this matter.

Section 1. Background

1.1 Overview

My August 15, 2025, affirmative report describes the Indian Wells Valley (IWV) Basin, its water resources, and previous studies by others of the recharge, discharge, storage, and yield of the IWV Basin. To provide context for my safe yield and storage estimates, my affirmative report outlines a conceptual water budget for the IWV Basin, details documents that I reviewed, and presents the steps that my team and I undertook to develop my estimates of safe yield and of aquifer storage for the IWV Basin.

Following review and analyses of existing published reports, studies, and data, my team and I reviewed, executed, made modifications to, and calculated water budgets using a land surface model (LSM) developed by the U.S. Geological Survey referred to as the Basin Characterization Model (BCM), and a groundwater flow model (GWFM) of the IWV Basin developed by Ramboll (the "Ramboll Model": Ramboll, 2025). Models of land surface processes and of groundwater flow are commonly used to assess and manage water resources and together these types of models represent the "state-of-the-art" for water resource management. Because I used the BCM and the Ramboll Model together as the basis for my yield and storage calculations, my affirmative report details those models.

As part of my assignment to provide estimates of the safe yield of the IWV Basin and of the volume of groundwater stored in the IWV Basin, and to respond to opinions provided by other experts, I provided in my affirmative report the following definition for the (*total*) safe yield of a groundwater basin:

> "*… the maximum amount of water that can be withdrawn annually, from a groundwater supply under a given set of conditions, without causing an undesirable result*." (Supreme Court of California, 1975, City of Los Angeles v. City of San Fernando).

I noted in my affirmative report that the *total* safe yield can be comprised of native and non-native components or fractions, where the native fraction derives from naturally occurring or naturally sourced recharge—such as rainfall—and the non-native fraction derives from anthropogenic sources of recharge, such as water imported from another basin. The notion of native and non-native components of recharge and safe yield is reflected in definitions provided in the California Water Code, for example by the following definitions for recharge and safe yield (Chapter 350 Division 13 of the California Water Code, §37900, 2024) (***emphasis added***):

> (19) "Recharge" means the ***natural or artificial replenishment*** of groundwater storage by percolation or injection of one or more sources of water at the surface.
>
> (21) "Safe yield" means the condition of a groundwater basin when the total average annual groundwater extractions are equal to, or less than, the total average annual groundwater recharge, ***either naturally or artificially***.

The use of state-of-the-art methods to evaluate the safe yield of the IWV Basin using the foregoing definitions—including both natural and artificial (or *incidental*) fractions—underpins both my affirmative and responsive analyses and opinions.

1.2 Expert Reports Reviewed

I have received and reviewed the Phase II affirmative expert reports prepared by the following experts:

- Dr. Kincaid, on behalf of the Indian Wells Valley Groundwater Authority (IWVGA).
- Dr. McKenna, on behalf of the USA.
- Mr. Teasdale, PG, on behalf of Meadowbrook Dairy and others.
- Dr. Yeh and Ms. Wicks, PG, on behalf of Searles Valley Minerals Inc. (SVM).

Table 2-1 lists and compares the estimates of safe yield for the IWV Basin as submitted by the various experts, identifying each expert and the party they represent. Because of the material difference between my opinions of safe yield and the opinions of safe yield that were offered by Dr. Kincaid (IWVGA) and Dr. McKenna (USA), this responsive report focuses on responding to the safe yield opinions offered by these experts.

1.3 Storage

Because neither Dr. Kincaid (IWVGA) nor Dr. McKenna (USA) offered affirmative opinions on the quantity of water in storage in the IWV Basin, I have not offered any responsive opinions regarding storage and the storage quantities that I provided in my affirmative report are unchanged. I note however that the most recent update of ***California's Groundwater: Bulletin 118 – Update 2025*** (DWR-118, 2025) discusses storage and the potential role of brackish water in several places. In Section 8, Groundwater Storage, DWR-118 (2025) describes storage as referring to:

> "*... the total volume of groundwater held within the pore spaces and fractures of the saturated portion of an aquifer. It is calculated as the amount of groundwater (fresh and brackish) present in the saturated pore space, extending from the water table to the bottom of the basin, where rock or sediments of very low hydraulic conductivity exist.*"

DWR-118 (2025) distinguishes usable groundwater storage as being:

> "*... the portion of groundwater storage that can be economically and practically extracted while maintaining acceptable water quality. It typically lies above the base of freshwater, though this threshold may evolve into even brackish groundwater with changes in the economic value of water.*"

In Section 13, Brackish Groundwater Resources, DWR-118 (2025) goes on to state that:

> "*Increasing water scarcity and the effects of climate change on water resources have resulted in the need to consider salty groundwater, also known as brackish groundwater, as a potential water source that can be treated and utilized.*"

Section 2.
Responsive Opinions

Based upon my review of the aforementioned reports, the work that I completed to prepare my Phase II affirmative report and opinions therein, additional work that I have completed as detailed in this responsive report, and my professional and academic experience, I have formed the following responsive opinions. I hold these opinions to a reasonable degree of scientific certainty, although I reserve the right to revise these responsive opinions subject to further review of existing and new documents and data.

2.1 Responsive Opinion 1. Experts for the IWVGA and the USA Rely Upon Untested Methods and Assumptions that Underestimate Recharge to, and the Safe Yield of, the IWV Basin.

The methods and assumptions that both Kincaid (IVWGA) and McKenna (USA) rely upon systematically underestimate the total recharge to the IWV Basin and the proportion of that total recharge that comprises the safe yield of the basin. I list below several of the methods and assumptions that lead to Dr. Kincaid and Dr. McKenna systematically underestimating the total recharge to—and the safe yield of—the IWV Basin and I expand upon the most significant of these issues in subsequent Responsive Opinions.

First, as detailed in my Responsive Opinion #2, both Kincaid (IWVGA) and McKenna (USA) replied upon the reported outputs of calculations that were made by others as presented in McGraw et al. (2016) using a simple steady state 2D groundwater model that was not available for them to review or execute, and that they were unable to provide for review in this matter. As a result, this basis for recharge and safe yield estimates has no foundation and should not be relied upon.

Second, as detailed in my Responsive Opinion #3, both Kincaid (IWVGA) and McKenna (USA) exclude from consideration as a component of recharge—and thus as a contributor to safe yield—any and all incidental sources of recharge such as irrigation returns. This is inconsistent with common water basin studies, the California Water Code, safe yield calculations in other basins and with statements presented in McGraw (2016)—upon whom Kincaid (IWVGA) and McKenna (USA) rely. As I detail in Responsive Opinion #3, this omission also results in an incomplete water budget for the IWV Basin.

Third, as detailed in my Responsive Opinion #4, both Kincaid (IWVGA) and McKenna (USA) use estimates of historical—that is, predevelopment—rates of evapotranspiration (ET) to limit or constrain the upper-bound value for the rate of natural recharge to the IWV Basin, which thereby limits the upper bound value for the safe yield of the basin. However, estimates of pre-development ET are based on a paucity of data and information regarding hydrologic conditions that existed in the IWV Basin over 100 years ago.

Fourth, neither Kincaid (IWVGA) nor McKenna (USA) appears to have reviewed or re-produced (inputs to) the calculations that McGraw et al. (2016) made using (a) the Bootstrap Brute-force Recharge Model (BBRM) method originally developed by Epstein et al., (2010) or (b) the regression equation method originally developed by Anderson et al. (1992). McKenna (USA) did identify and correct typographical and calculation errors in the tabulated outputs of those calculations as reported by McGraw et al., (2016). For the BBRM, McKenna (USA: Section 5.2.1, Table 2) modified (reduced) the estimate of McGraw et al. (2016) from 9,265 acre-feet per year (AFY) to 8,745 AFY; whereas for the Anderson et al. (1992) regression method McKenna (USA: Section 5.2.1, Table 1) modified (increased) the estimate of McGraw et al. (2016) from 4,100 AFY to 7,462 AFY. McKenna (USA) does not report the uncertainty on this estimate which—referring to Anderson et al. (1992)—results from the fact that the inputs to the regression calculation represent a large number of western basins and are not specific to the IWV Basin. Inspection of the blue line depicted on my **Figure 2-1 (lower panel)** indicates that the uncertainty in the estimate obtained using the Anderson et al. (1992) equation ranges between about ~1,800 AFY and ~25,000 AFY. Also plotted on **Figure 2-1 (lower panel, orange line)** is my estimate of 11,800 AFY for the native recharge to the IWV Basin – comprising 9,200 AFY for mountain front recharge (MFR) plus 2,600 for underflow from Rose Valley – which lies well within the range reported by Anderson et al. (1992) and corresponds well with the arithmetic midpoint between these bounds. In summary, as a surrogate for the use of state-of-the-art methods of deriving recharge rates from precipitation the Anderson et al. (1992) regression method provides useful initial estimates for multiple basins, accompanied by a wide range; however, deference should be given to the IWV Basin-specific value that I obtained using the BCM to process basin-specific climate data as I detailed in my affirmative report.

Fifth, having obtained an estimate for the total recharge to the IWV Basin, Kincaid (IWVGA) makes an arbitrary reduction of 15% from this value to determine his safe yield. Kincaid (IWVGA) at Section 4.1.1., Safe Yield, states as follows:

"It is therefore unlikely that groundwater extractions, even if relocated within the basin, can effectively intercept all of the natural flow to the playas. If safe yield is set to equal total recharge, the expectation should be continued groundwater level declines and overdraft. My proposed estimate for safe yield therefore reflects a 15% reduction from my estimate of total recharge."

No technical basis or justification is provided for this 15% reduction. The safe yield of a basin is a theoretical quantity of water that can be withdrawn—the manner used to extract that water, and whether the entire quantity or some lower fraction of it can be withdrawn, are matters for analysis and determination as part of the Physical Solution.

2.2 Responsive Opinion 2. Experts for the IWVGA and the USA Rely Upon Recharge Calculations that have not Been Produced and Cannot be Evaluated.

Kincaid (IWVGA) and McKenna (USA) each use more than one line of evidence as the basis for their recharge estimates and safe yield opinions. However, perhaps the most pivotal line of evidence that both relied upon is the output from calculations that were previously made by McGraw et al., (2016) using a simple steady state two-dimensional (2D) groundwater flow model. This steady state 2D model is an entirely separate and distinct model from the transient three-dimensional (3D) groundwater flow model that is also described by McGraw et al., (2016) and that the IWVGA previously used in support of their Groundwater Sustainability Plan (GSP).

Kincaid (IWVGA) states in his report at "*Section 4.4.2.2. McGraw, et al., 2016*" as follows:

"McGraw's group developed a two-dimensional steady-state groundwater model to refine both the total magnitude and the spatial distribution of mountain front recharge to the IWVGB. They did so by adjusting the magnitude and spatial distribution of assigned recharge until there was general agreement between the simulated and measured predevelopment (1920 to 1921) groundwater levels and their refined estimates of ET as described above in Section 5.4.1.3."

McKenna (USA) similarly cites the same McGraw et al., (2016) steady state 2D groundwater model as providing a reliable estimate for recharge. However, McKenna (USA) makes the following acknowledgement in his expert report regarding the availability of this model for review and execution (Section 5.2.1 at page 21):

> "*It was not possible to access the model used in these calculations, and therefore, no additional calculations using the model were made.*"

Review of Table 4 of McGraw et al. (2016)—reproduced here as my **Table 2-2**, with highlighting added—shows that this table lists several previous recharge estimates by other researchers, together with the value obtained using the steady state 2D model. Review of Table 6 of McGraw et al (2016)—reproduced here as my **Table 2-3**, with highlighting added—shows that the historical estimates are discarded in favor of the values developed using the steady state 2D groundwater model that, as noted by McKenna (USA) is not available for review. Inspection of my **Table 2-2** demonstrates that the values listed for MFR from the 2D model are inconsistent with and are outliers compared to the historical estimates: the values inferred for MFR for the North and South Sierras using the steady state 2D model lie well below the estimates listed for all but one previous study and at the low end even of that single study (average of previous studies ≈ 6,190 AFY, value estimated using steady-state 2D model = 3,600 AFY, a difference of ≈ 2,590 AFY). The reason for this difference between the recharge calculated using the steady state 2D model versus values from previous independent researchers cannot be determined because the 2D model was not produced.

There is insufficient information provided in McGraw et al., (2016), Kincaid (IWVGA), and McKenna (USA), to reproduce the calculations made using the steady state 2D model—including how the model was calibrated to historical pre-development conditions; what, and how much, data were available to calibrate the model; whether the available data and the model reasonably represented average conditions including wet periods; and whether the parameters of the 2D model were consistent with or differed greatly from those used in the 3D transient groundwater model also developed by McGraw et al. (2016) and relied upon by Kincaid (IWVGA) and McKenna (USA). Therefore, to the extent that any recharge estimates and safe yield opinions rely upon this steady state 2D model, they should not be considered.

2.3 Responsive Opinion 3. Water Budgets of the IWVGA and the USA Experts are Incomplete Due, in Part, to Neglecting Incidental Recharge.

Both Kincaid (IWVGA) (e.g., Section 4.2.1) and McKenna (USA) (e.g., Section 4.5) discuss the importance of developing a water budget as one basis for estimating recharge rates and the safe yield of the IWV Basin. However, both experts discard material sources of recharge that have been described by others—including McGraw et al. (2016)—and that include irrigation return flows, leakages from the Los Angeles Aqueduct and water distribution leakage. These forms of recharge are referred to by the California Department of Water Resources (DWR) as incidental recharge:

> "*Incidental recharge is an unintentional and unaccounted byproduct of a project where some water taken for a different use is lost to seepage and enters the groundwater system (California State Water Resources Control Board 2024a). A variety of mechanisms result in incidental recharge and are generally grouped here by typical sources in urban, agricultural, and rural areas*." (DWR-118, 2025)

DWR-118 (2025, Section 4.3.1) goes on to describe baseline recharge as comprising both natural sources and incidental contributions:

> "*Baseline recharge refers to water that reaches an aquifer through either (1) natural processes, known as natural recharge; or by (2) incidental recharge, which occurs when water is unintentionally recharged into the aquifer due to human activities*."

Figure 2-2 depicts components of the water budget relevant to agricultural water uses, urban water uses, and other land uses, illustrating several components of incidental recharge. The basis for Kincaid (IWVGA) and McKenna (USA) discarding these incidental recharge sources appears to be three-fold. I list and then respond to each below.

1. The quantities of water involved are negligible. This is refuted by calculations and documentation presented in Ramboll (2025), and other analyses of incidental recharge. For example, infiltration of excess water used for irrigation—also referred to as irrigation return flows—is an established and material source of incidental recharge to many California groundwater basins. Although irrigation efficiencies have increased over time—so that the fraction of over-irrigation has reduced—historically efficiencies were often 60%-70% with most of the excess water infiltrating in areas where runoff was limited. The 10% net infiltration rate that Kincaid (IWVGA) discusses is at the lower bound of the ranges described in literature (e.g., DWR, 2020; Burt et al., 1997; Tindula et al., 2010) and which already account for the subsequent soil evaporation described by Kincaid (IWVGA).
2. Incidental recharge cannot be relied upon to occur. The timing and magnitude of some components of incidental recharge—such as recharge from excess irrigation—can be

reasonably relied upon and predicted. For other incidental sources, challenges encountered predicting the occurrence of events should not be conflated with the reliability of cumulative occurrences. For example: in basins dominated by MFR processes, a significant proportion of the *natural* recharge can be highly variable in response to variable weather (primarily, precipitation) patterns, yet using sufficiently long time frames it can be relied upon. Such is also the case for the infrequent components of incidental recharge.

3. The time required for incidental recharge to reach groundwater is too long to be considered. The process of transiting the vadose zone can produce a temporal lag between the percolation of water beneath the base of the root zone and the arrival and accrual of recharge at the water table. This lag can "damp" the recharge signal, such that it can become challenging to infer from groundwater level hydrographs. However, the presence of a lag does not mean that incidental recharge should be discounted: rather the lag could be incorporated into modeling analyses.

In summary, when incidental sources of recharge are documented to comprise a material fraction of the water budget—on the order of 15% as described by Ramboll (2025)—discarding them results in an incomplete accounting of the basin water budget that cannot be used as the basis for basin management.

2.4 Responsive Opinion 4. Historical Evapotranspiration Rates Used by IWVGA and the USA to Constrain their Recharge and Yield Estimates Rely Upon Limited Data.

As I describe in my affirmative report, the primary natural groundwater discharge mechanism in the IWV Basin is ET, which combines evaporation from dry soils and lake beds with transpiration via vegetation. These processes are focused along arroyos in the valley floor and the evaporative playa near the core of the IWV Basin. Although these physical processes are well established, ET rates can be difficult to estimate even under present conditions—yet both Kincaid (IWVGA) and McKenna (USA) use estimates of the *pre-development* ET that occurred over a century ago before the basin was developed to constrain their recharge and safe yield estimates.

Presuming that the upper-bound value for the IWV Basin safe yield equals the total rate of recharge to the IWV Basin, Kincaid (IWVGA) at Section 4.2.1 presents "The Recharge Method" for determining the total recharge rate, and refers to Equation 2 which states that when there is no change in storage, the sum of inflows (i.e., total recharge) must equal the sum of the outflows. Kincaid (IWVGA) states that:

> "*For that early time period, understanding the groundwater budget for the IWVGB comes down to estimating either total recharge or total discharge.*"

Using this approach, inflows must equal the ET rate under predevelopment conditions when the only—or more precisely, the predominant—outflow occurs via ET. That is, the total recharge rate is constrained to be no larger than pre-development ET. This conceptually appealing approach rests upon obtaining a highly accurate estimate of the ET rate in the IWV Basin over a century ago, at which time the area was sparsely populated and very little information is available regarding ET locations and rates. Therefore, the 3D groundwater model developed by the IWVGA and upon which Kincaid (IWVGA) and McKenna (USA) rely must use a presumed value for the pre-development ET—that value being 7,600 AFY—as a starting condition, thereby forever constraining natural recharge to be no larger than this value.

It is more likely that the pre-development ET rate was higher than assumed in the IWVGA model. I illustrated this in my affirmative report by running the Ramboll Model with groundwater pumping removed from the simulation (i.e., set to zero). In doing so, simulated groundwater elevations rose and the rate of loss via ET-type processes was substantially larger than 7,600 AFY—reaching about 16,000 AFY. When adjusted for the incidental recharge of about 2,600 AFY that is simulated by the Ramboll Model, this discharge quantity of about 13,400 AFY is more consistent with documented occurrences of distributed ET processes plus discrete surface springs in the pre-development era. The lowering of groundwater levels over time likely reduced the rate of natural discharge from the basin by capturing groundwater that otherwise discharged via ET, springs, and related processes.

2.5 Responsive Opinion 5. The Groundwater Model Relied upon by Experts for the IWVGA and the USA Does not Accurately Represent Recharge Variability in the IWV Basin.

As detailed in my affirmative report and as also recognized by the IWVGA, Kincaid (IWVGA) and McKenna (USA), among others, the primary natural recharge mechanism in the IWV Basin is MFR. Important components of MFR include (a) surface infiltration through the basin fill from mountain-sourced streams (i.e., run-off derived recharge); (b) focused recharge which occurs through faults and fractures or in alluvium beneath mountain-sourced streams; and (c) diffuse recharge which occurs via hydraulic exchange across the mountain front. Because of the fairly steady nature of some of these processes, the aquifer response to diffuse recharge and—to a lesser degree—focused recharge can sometimes be challenging to infer from groundwater level hydrographs. However, the groundwater response to intense periodic events can sometimes be discerned and is important to identify and incorporate into modeling analyses if it represents a substantial fraction of the water budget.

The BCMv8 land surface model that was used to estimate recharge rates for the Ramboll Model computes recharge via subflow processes—including focused and diffuse recharge—and computes the run-off that occurs within streams. Run-off calculated using the BCMv8 can be compared with measured or gaged streamflow to verify that the timing and quantities reasonably correspond with measured data. In my affirmative report I presented as Figure 4-3 a graphical multi-year comparison of the run-off calculated using the BCMv8 with gaged stream flows on the Northern Sierra. **Figure 2-3** presents further comparisons of the run-off calculated using the BCM against gaged stream flows along the sierras for periods when data are available: the upper panel presents a comparison for Sand Canyon, and the lower panel presents a comparison for Grapevine Canyon. The comparison is presented for both the statewide BCMv8 that was used to calculate recharge for the Ramboll Model, and for the IWV Basin BCM that was also prepared by the United States Geological Survey (USGS) but for which complete documentation is not available. At both Sand Canyon and Grapevine Canyon, the timing and quantities of run-off calculated by the BCM models compare well with gaged data.

As I describe in my affirmative report, 15% of the run-off quantity calculated using the BCMv8 was assumed to recharge the IWV Basin (the basis for 15% was also provided in my affirmative report). If a material proportion of groundwater recharge occurs via intermittent high flow events, then this is important to represent in groundwater modeling. **Figure 2-4** compares the recharge simulated by the Ramboll Model with that simulated by the IWVGA Model. From **Figure 2-4** it is evident that recharge rates simulated by the IWVGA Model changes very little despite very large changes in precipitation that are documented to occur in the IWV Basin as I demonstrated in my affirmative report. This apparent relative lack of sensitivity to precipitation is highly implausible for a basin that is recognized as being dominated by MFR processes.

2.6 Responsive Opinion 6. My Recharge and Safe Yield Estimate Rests upon Best Available and State-of-the-Practice Methods in Accordance with DWR Guidance.

It is widely recognized that groundwater recharge to the IWV Basin is dominated by MFR—including run-off and underflow from the Sierra Nevada and other elevated areas surrounding the basin interior. The most common method for estimating the rates and locations of recharge in such settings is land surface modeling (LSM) combined, when necessary, with groundwater flow modeling. There are established, state-of-the-art land surface models and one of these—the BCM—was used to calculate the recharge for input to the Ramboll Model. The BCM uses various climate inputs— primarily precipitation—together with data on soil properties and the permeability of underlying bedrock to calculate groundwater recharge and surface runoff. The BCM was selected for use in the IWV Basin because it is a physically based LSM that was specifically developed to estimate run-off and recharge in semi-arid environments including mountain-bounded basins of California. The BCM provides a full account of the water budget with time-varying outputs that can be compared to measured data to corroborate its reliability.

The BCM is also one of the methods that is specifically recommended by the DWR for calculating groundwater recharge, particularly in areas that do not already possess a groundwater model (DWR, 2020). The BCM is not a groundwater flow model—it does not simulate subsurface flows within aquifers. However, it can be linked to a groundwater flow model for this purpose, to provide transient calculations of groundwater elevation changes in response to MFR together with pumping and other stresses. The BCMv8 was linked with the Ramboll Model for this purpose in the IWV Basin. Calculations using the BCMv8 were originally performed by experts at the USGS. However, I reviewed inputs and outputs from those calculations, re-executed those calculations, and independently compared the calculated run-off to gaged stream flows.

LSMs are commonly used in California, including in basins neighboring the IWV Basin. For example, in the adjacent Owens Valley the BCM was used as one basis for the Owens Valley GSP (2021); and in the adjacent Rose Valley the Deep Percolation Water Model (DPWM)—an LSM that shares many characteristics with the BCM—was used to estimate recharge and runoff (DBS&A, 2011). The DWR also uses a rainfall-runoff formulation that is a simplified computationally efficient LSM to represent the time-varying MFR processes that occur in the multiple small watersheds that surround the California Central Valley as represented in various releases of the C2VSIM model (e.g., Brush et al., 2013) and describe this procedure in the IWFM documentation as follows:

> "*Small stream watersheds surrounding the study domain are modeled as dynamic boundary conditions, and contribute surface water and groundwater flows to the model domain.*"

A key input for calculating the recharge from these small watersheds is the precipitation rate, and as a result MFR simulated using the IWFM varies in response to changes in precipitation. Because experts for the IWVGA and USA elected not to use a LSM to represent MFR processes, groundwater recharge rates that they opine on—as simulated using the IWVGA model—do not reflect variable precipitation rates in a realistic manner.

2.7 Responsive Opinion 7. Uncertainties Regarding the Role of Future Climate are Best Addressed as a Component of the Physical Solution

Historical data incorporate the measured effects of variations in climate on recharge and safe yield. In my affirmative report, I opined that the combination of the BCMv8 LSM and the Ramboll Model represent historical conditions over a sufficiently long period that reasonable estimates of recharge and safe yield can be obtained. This was illustrated, for example, by Figure 3-6 in my affirmative report which depicted how estimates of average precipitation rates converge over time.

Historical data do not, of course, include the effects of future climate change; yet consideration of climate change is important to future basin management. Therefore, future management strategies must be designed to be robust and adaptable in the face of uncertain weather. The 2025 release of Bulletin 118 (DWR-118, 2025) provides adaptation strategies for consideration by GSPs and other basin managers as does the 2024 California Climate Adaptation Strategy (https://www.climateresilience.ca.gov/overview/index.html). An anticipated outcome of climate change is increased variability, as described for example in Bulletin 118 (DWR-118, 2025):

> "*Additionally, **climate change is projected to intensify short-duration, high-intensity winter rainstorms, creating brief periods of high flows** in the Delta.*"

DWR Bulletin 118 also summarizes California's Water Supply Strategy and methods for adapting to a hotter, drier, future. As cited by (DWR-118, 2025):

> *"At the heart of California's Water Supply Strategy is the goal to increase water storage capacity by 4 million acre-feet (maf) by 2040. This effort includes boosting annual groundwater recharge by 500,000 acre-feet, a critical step to address longstanding groundwater depletion and improve resilience to drought.* ***The strategy recognizes the essential role of groundwater as a buffer against dry periods and emphasizes managed aquifer recharge (MAR) initiatives that utilize stormwater and flood flows to replenish depleted aquifers."***

The analysis and "capture" of recharge from extreme events will be critical to future basin management in the IWV Basin specifically. The combined use of the BCMv8 LSM together with the Ramboll Model has demonstrated that recharge stemming from these flood-type run-off processes can be simulated in a comprehensive model of water resources within the IWV Basin used for future basin management purposes.

In addition, the USGS has made substantial progress in furthering the application of the BCMv8 to accommodate possible future climate change impacts. The USGS science base website (https://www.sciencebase.gov/catalog/item/61e069f3d34e8911d9fe9dba) describes the use of Localized Constructed Analog (LOCA) Scenarios and the BCMv8 to represent future climate and hydrology. The data release provided by the USGS contains BCMv8 climate and hydrologic variables for multiple LOCA (Pierce et al., 2014) downscaled Global Climate Models (GCMs) for California. The LOCA climate scenarios span water years 1950 to 2099 with adjusted climate forcing representing greenhouse-gas effects beginning in 2006. Because the Ramboll Model (2025) used the BCMv8 as the primary method for representing recharge processes in the IWV Basin, the Ramboll Model is also ideally positioned to incorporate the effects of climate change on future basin management scenarios using these—or other—LOCA downscaled BCMs.

Section 3.
Summary and Recommendations

The IWVGA (Kincaid) and the USA (McKenna) base their recharge estimates and safe yield opinions on several lines of evidence. However, a critical line of evidence—the steady-state 2D groundwater model—is not available for review and must be discounted for that reason. Furthermore, when McKenna (USA) corrects the recharge estimates reported by McGraw et al. (2016) using the Anderson (1992) regression equation, the upper-and lower uncertainty bounds neatly bracket my estimate of natural recharge.

The most noteworthy difference between my recharge estimates and those of the IWVGA and USA appears in wet years: the methods upon which the IWVGA and USA experts relied do not appear to reflect the varying recharge rates experienced in terminal basins driven by MFR processes. In my affirmative report, I presented data and information indicating that the patterns and rates of recharge to the IWV Basin can vary widely and are often unpredictable in response to variable weather conditions—particularly, the rates of precipitation at higher elevations surrounding the basin floor. In that report, I provided recommendations that emphasized obtaining further data and information to improve knowledge and understanding of the IWV Basin and improve the predictive capability of the Ramboll Model as a tool for management of basin resources.

My review of the groundwater model developed by the IWVGA that is relied upon by experts on behalf of the IWVGA and the USA indicates that the IWVGA model does not accurately simulate how recharge to the IWV Basin varies in response to changing precipitation. This difference is material to understanding past conditions and to future basin management decisions. The variability in precipitation in elevated areas that are the source of most recharge presents challenges—due to prolonged dry spells—but also opportunities for the use of managed aquifer recharge (MAR) and related technologies to replenish groundwater during intermittent wet periods. Because the IWVGA groundwater model and the methods used to estimate recharge rates for use in that model do not accurately represent the effect of precipitation-based variability on recharge rates, that model should not be relied upon to estimate the safe yield of the IWV Basin nor to evaluate water resource management alternatives for the IWV Basin in later phases of this matter.

Section 4.
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FIGURES
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TABLES

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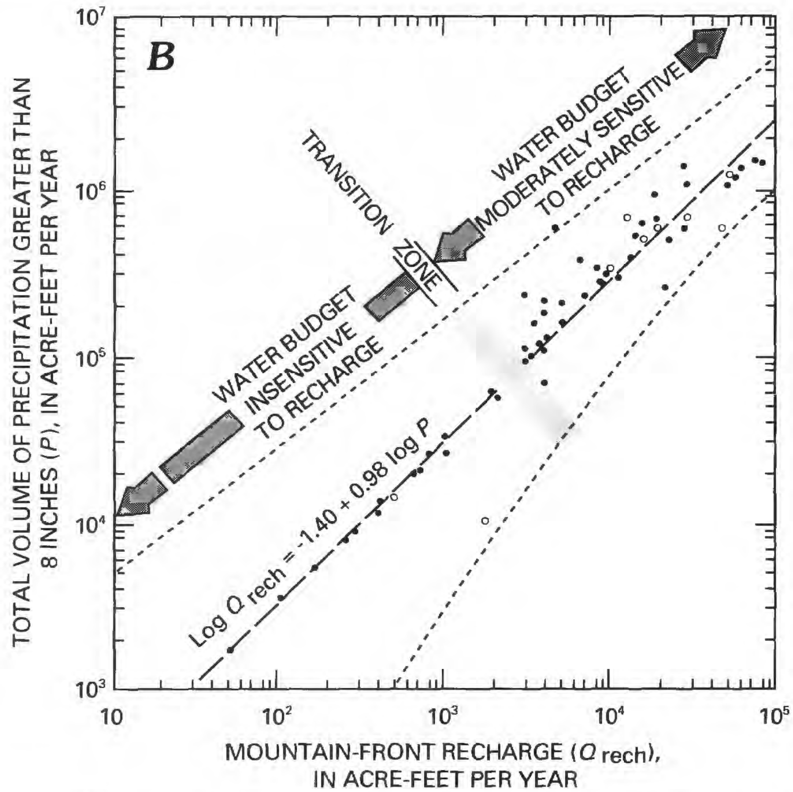

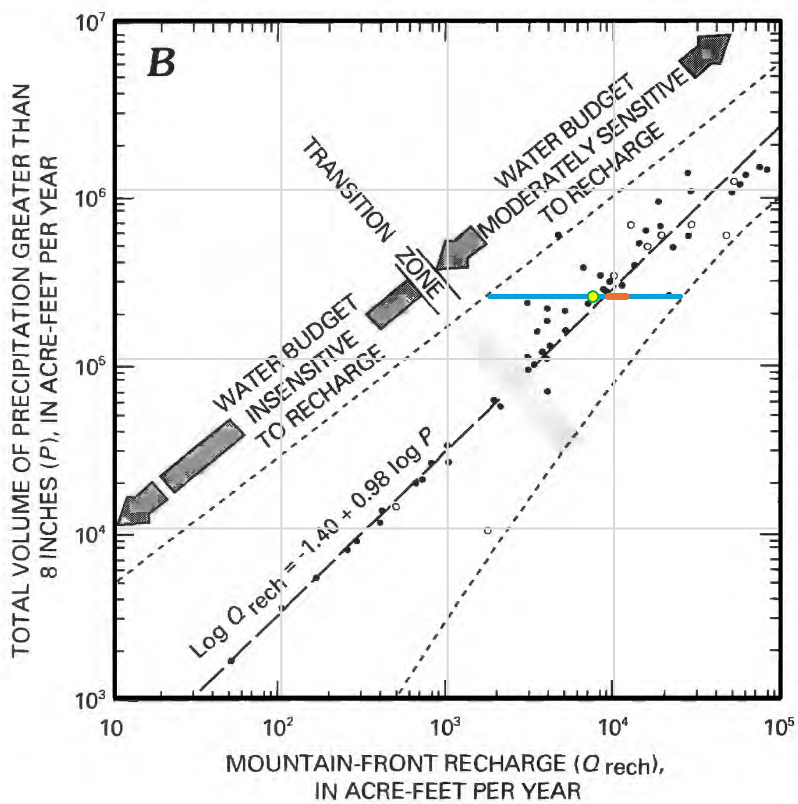

Figure 2-1: Recharge and Uncertainty using the Anderson et al. (1992) Regression Equation

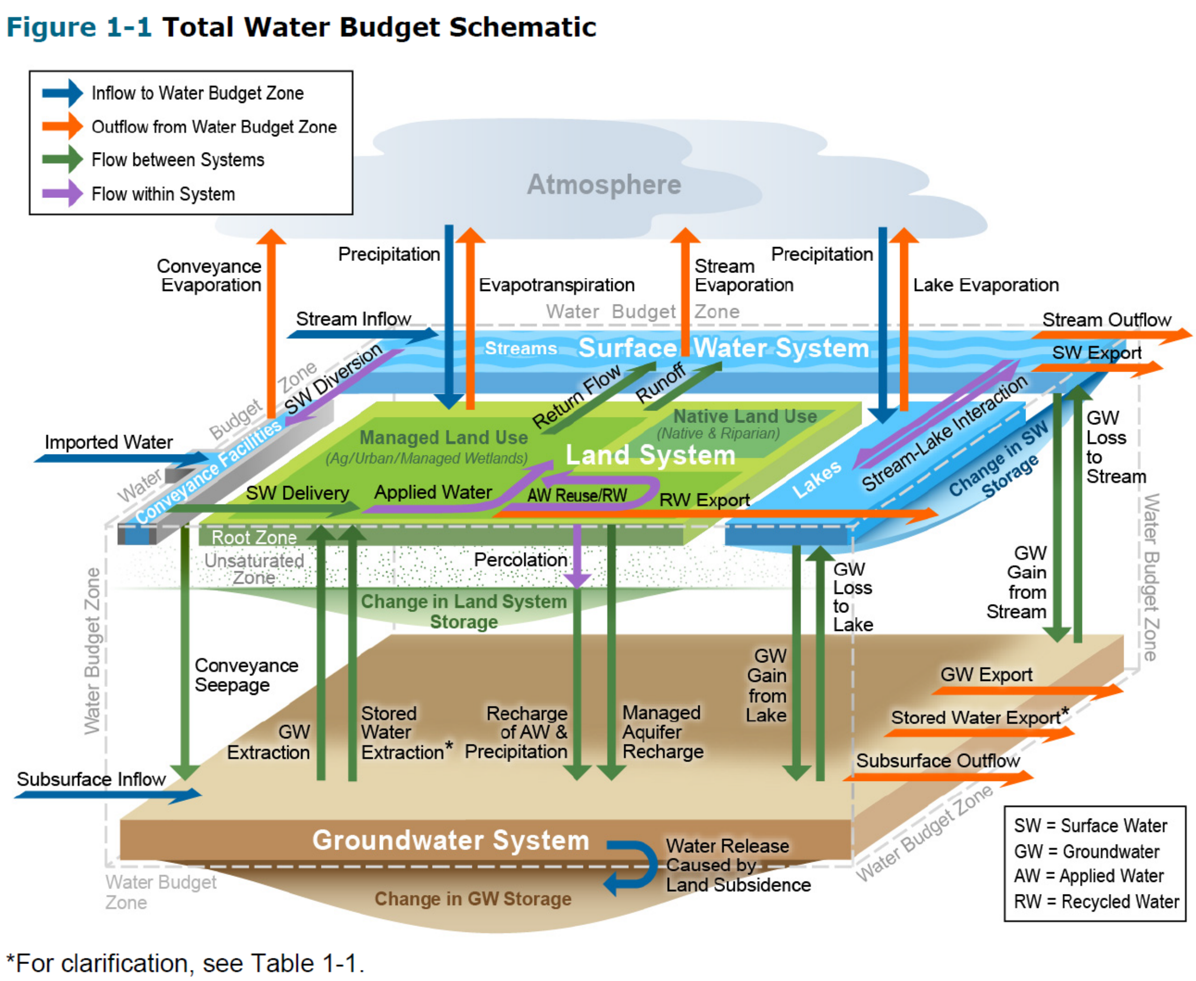

Figure 2-2: Common Water Budget Components Illustrating Several Sources of Incidental Recharge (after DWR, 2020, Figure 1)

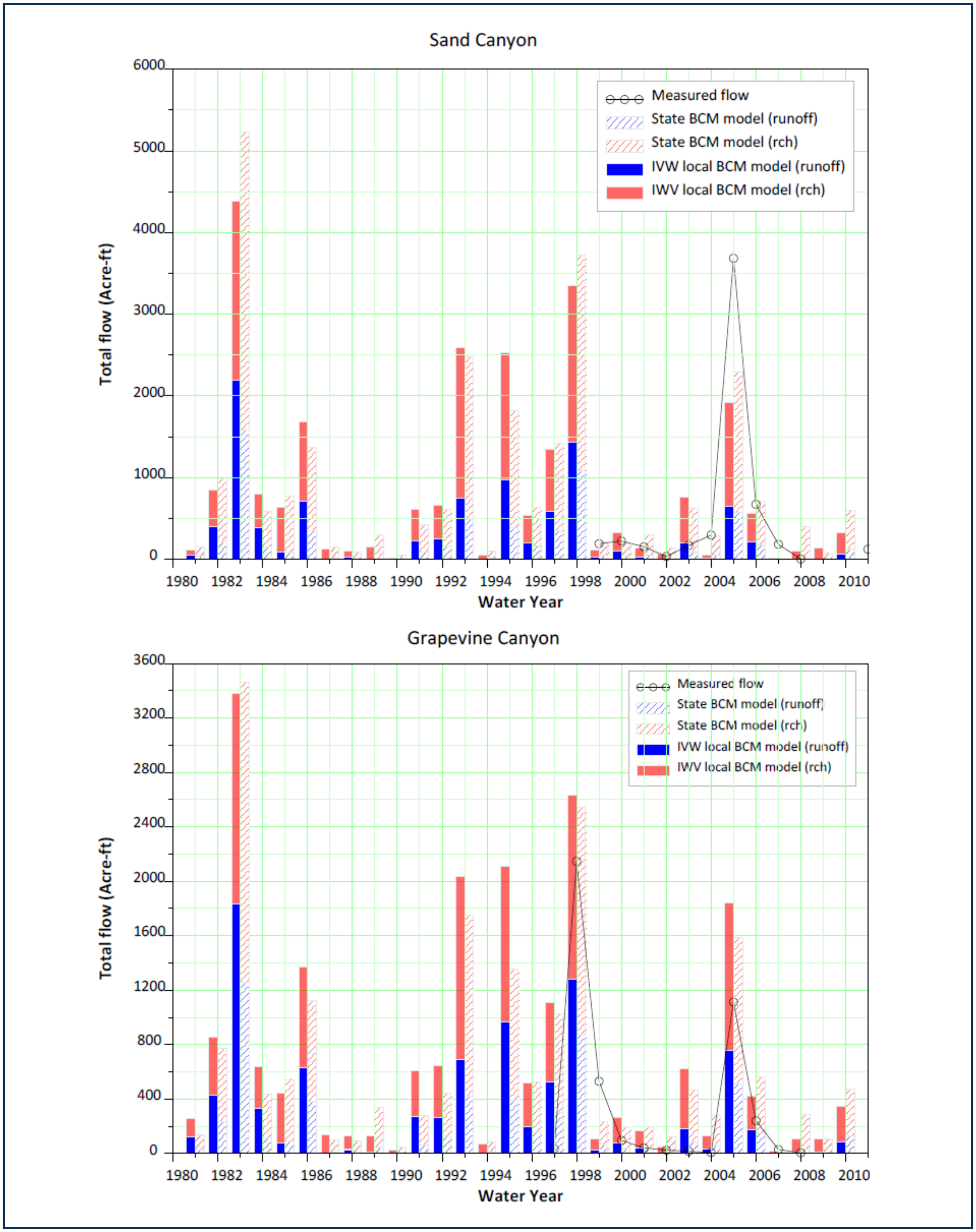

Figure 2-3: Comparison of Runoff Calculated using the BCM with Gaged Stream Flows

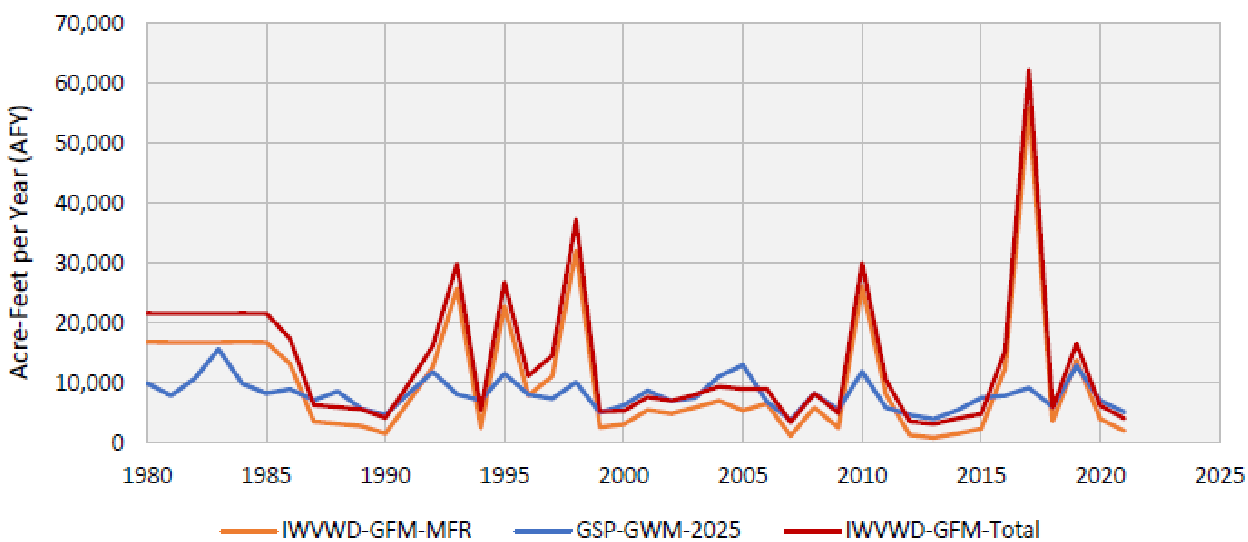

Figure 5. Comparison of transient total recharge assigned in the GSP-GWM-2025 and IWVWD-GWM relative to the portion of total inflows assigned as mountain front recharge in the IWVWD-GWM.

Figure 2-4: Recharge Simulated by (a) the Ramboll Model and (b) the IWVGA Model (*after Kincaid, Figure 5*)

TABLES

Expert	Party	Affirmative Opinion of Safe Yield	Recharge Components and Total				Evapo-transpiration (ET)
			Mountin Front Recharge (MFR)	Rose Valley Underflow	Incidental Recharge	Total Recharge	
Teasdale	MBD	15,400	n/a	n/a	n/a	n/a	4,500–4,600
Yeh and Wicks	SVM		n/a	n/a	n/a	n/a	
Parker	IWVWD	14,300	n/a	n/a	n/a	n/a	n/a
Tonkin	IWVWD	12,300–14,400	9,200	2,600	2,600	14,400	2,300--1,600
Kincaid	IWVGA	6,100–8,400	5,731	1,919	0	7,200–9,900	n/a
McKenna	USA	7,650	5,731	1,919	0	4,300–6,355 7,462–8,745 7,650	4,000

Notes:

Safe yield calculation period unknown for McKenna (USA) and Kincaid (IWVGA).

McKenna (USA) states "< 7,650 AFY if the safe yield is less than total recharge.
Tonkin (IWVWD) safe yield based on BCM and IWVWD model simulating 1981-2023.

ET in the IWVGA / DOJ-NAWS models ranges between 2,850—7,600 AFY depending on the version:
McGraw et al., (2016)
Pohlmann et al., (2020)
Rybarski and Bacon (2025)

Table 2-1: Tabulation of Affirmative Opinions of Safe Yield by Various Experts

3.5.1.3 Recharge Summary

Table 4 summarizes the groundwater recharge estimates for the various studies. Excluding anthropogenic recharge sources, the range in the total estimate from all mountain sources is 4,100 to 11,000 afy. Four of the studies produced confidence intervals ranging from 700 to 15,000 afy. The mean

Table 4. Summary of recharge estimates for Indian Wells Valley.

MOUNTAIN BLOCK RECHARGE									
	SIERRA NEVADA								
Source	South (afy)	North (afy)	Rose Valley (afy)	Coso (afy)	Argus (afy)	El Paso (afy)	Total (afy)	Total Lower Bound (afy)	Total Upper Bound (afy)
Kunkel and Chase, 1969								11,000	15,000
Bloyd and Robson, 1971	6,200		45	3,200		400	9,800		
Dutcher and Moyle, 1973							11,000		
St. Amand, 1986							11,000		
Bean, 1989	6,300		400	2,000	1,000	400	10,000[1]		
Berenbrock and Martin, 1991	6,300			3,200		400	9,900		
Watt, 1993	8,900			1,000			9,900		
Bauer, 2002			3,300						
Daniel B. Stephens, 2011			3,700[3]						
Brown and Caldwell, 2006			2,100						
Brown and Caldwell, 2009	5,900		1,000	300	1,600	50	8,900		
Anderson *et al.*, 1992							4,100	700	15,000
Todd Engineers, 2014	3,100 - 5,900		1,000	300	1,600	50	7,500[4]	6,100	8,900
Epstein *et al.*, 2010	5,200				4,100		9,300	5,800	12,000
Numerical Analysis	1,500	2,100	2,400	1,200			7,100		
Best Estimate	1,500	2,100	2,400	1,600		50	7,700		

Notes:

1. Total does not include the additional 2,500 afy from the Sierra Nevada Range west of the topographic divide and anthropogenic sources (2,400 afy).
2. All numbers are rounded to two significant figures.
3. Midpoint of range provided (3,500-3,900 afy).
4. Assumes midpoint for Sierra Nevada North and South recharge and excludes their estimates of recharge from excess irrigation and Indian Wells Valley water distribution leakage.

mountain block recharge from all studies is 8,900 afy. The mean recharge estimate from the Sierra Nevada South and Sierra Nevada North zones is 5,900 afy. The mean recharge estimate for Rose Valley

Table 2-2: Reproduction of Table 4 from McGraw et al. (2016) with Highlights Added

3.5.5 Basin-wide Budget 1920 Conditions (Predevelopment)

Section 3.5 of this report describes the hydrologic conditions of the Indian Wells Valley aquifer system prior to significant development of well fields and pumping for consumptive use after 1920. It is important to carefully and accurately capture predevelopment hydrologic conditions and to build a model that represents these steady-state conditions because the steady-state hydrologic model is the foundation for all subsequent modeling. Table 6 represents the best estimates for recharge and outflow from the Indian Wells Valley hydrographic basin prior to 1920. The Indian Wells Valley hydrographic basin is assumed to be in hydrostatic equilibrium, or steady state, which means that all water inflows are equal to all water outflows.

Table 6. Steady-state water budget for Indian Wells Valley.

Inflow	AFY	Source
Mountain Block Recharge		
Sierra Nevada North	1,500	BBRM method applied to 2-D groundwater model
Sierra Nevada South	2,100	BBRM method applied to 2-D groundwater model
Rose Valley	2,400	BBRM method applied to 2-D groundwater model
Coso/Argus Ranges	1,600	BBRM method applied to 2-D groundwater model
El Paso	50	Brown and Caldwell (2009); Todd Engineers (2014)
Total	**7,650**	

Outflow	AFY	Source
ET	7,450	Balance budget
Interbasin	200	TDS mass balance; 2-D groundwater model
Pumping Wells	0	Assumed pre-groundwater development
Total	**7,650**	

Table 2-3: Reproduction of Table 6 from McGraw et al. (2016) with Highlights Added