Rebuttal Expert Report of Sean A. McKenna, PhD

In the matter of:

Mojave Pistachios, LLC, et al.

vs.

Indian Wells Valley Water District, et al.

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INTRODUCTION

A groundwater model is a numerical tool to aid in the understanding of a physical groundwater system. To construct a groundwater model, the modeler must first define the physical setting – the geology and properties affecting the movement of water (aquifer properties). The modeler must also establish a conceptual flow budget to quantify flows of groundwater into and out of the basin. The Safe Yield in a basin is the amount of water that can be removed from the basin, e.g., through pumping, without causing undesirable results such as continued lowering of groundwater levels. In the Indian Wells Valley (IWV) the component of the flow budget of greatest concern is recharge – generally, the amount of water coming into the basin. Recharge can be viewed as a surrogate for Safe Yield because if the amount of water leaving the basin (discharge) is less than the amount of water coming into the basin (recharge), groundwater levels will not decrease.

An important component of model development is calibration. Model calibration is the process of adjusting model parameters so the output of the model provides a reasonable match to observed flows and groundwater levels. The reports supporting the Ramboll (2025) model (Ramboll, 2025; Bedekar, 2025; Tonkin, 2025) argue, in effect, that the volume of water input into the model (recharge), and the assigned aquifer properties, are acceptable because the end result of the model is a set of simulated water levels that reasonably match observed water levels. In other words, they argue that the model is calibrated to industry standards.

However, as described in Bedekar (2025), models are subject to non-uniqueness and uncertainty. That is, for a given set of observed water levels, a wide variety of aquifer parameter combinations – different volumes of recharge and values of aquifer properties – can all produce models that reasonably match the observed water levels. The idea of non-unique solutions can be understood conceptually with the example of hydraulic conductivity. Hydraulic conductivity is a property that defines how easily water moves through aquifer materials. Typically, materials such as sands and gravels will have a higher hydraulic conductivity than finer-grained materials such as silts and clays. A model simulating *high* recharge and *high* hydraulic conductivity will result in water levels that can *also* be simulated using *low* recharge and *low* hydraulic conductivity.

Groundwater models are only as reliable as the information and assumptions used to build them. A given rate of recharge can be applied to a model, and the model calibrated to a reasonable standard, but that does not mean that the given rate of recharge is actually present in the basin. One step in building confidence that a given rate of recharge is actually present is validating that a model's representation of the physical setting (i.e., the geology and aquifer properties) is reasonably accurate. It is also critical to develop a balanced conceptual flow budget where for a given rate of recharge, it must be possible to discharge the same amount of water. Under predevelopment conditions (i.e., before pumping), the vast majority of groundwater entered IWV as recharge in the mountains and discharged as evapotranspiration from plants and bare soil in the China Lake area.

Although the Ramboll model is generally calibrated to an acceptable standard (i.e., its modeled water levels reasonably match observed data), the model (1) ignores elements of the physical setting defined in Ramboll (2019) and referred to in Ramboll (2025); (2) uses inappropriate aquifer properties; (3) relies on an unrealistic conceptual flow budget that overestimates recharge and/or underestimates evapotranspiration, producing water levels 20 feet above land surface in the China Lake area; and (4) operates from a fundamentally flawed "steady-state" model.

A steady-state model represents a time period where water levels in a basin are at equilibrium: inflows are equal to outflows and there is no change in storage. The general industry practice is to model a steady-state period based on predevelopment conditions, or during a time when pumping was minimal. The water levels from the steady-state model are then used as the baseline, or initial conditions, for "transient" modeling. Transient modeling assesses dynamic impacts to water levels from pumping and other changes to water use in a basin. The Ramboll model uses average conditions from 1980-1985 as its steady-state period. Those years are not representative of either predevelopment conditions *or* current conditions because those years were both unusually wet *and* had some of the highest levels of pumping on record. Because the model uses a wholly inappropriate starting point and the model must be calibrated using those inappropriate starting conditions, it follows that the results produced by the model are fundamentally flawed. In other words, the inherent flaws in the Ramboll model mean that the model results are unreliable and cannot be used to justify the modeled rate of recharge.

Several tests were performed to better understand the impact of these flaws on the results of the model, and to provide additional evidence that the simulated flows and aquifer properties do not reasonably represent conditions in the IWV basin. These tests examine (1) the Ramboll (2025) conceptual flow budget under predevelopment conditions; (2) the impact of using an abnormally wet period for the steady-state model; and (3) the length of time required for water levels in the IWV basin to reach equilibrium using the recharge applied in the Ramboll steady-state model.

The results of these tests are: (1) Ramboll's conceptual flow budget under predevelopment conditions produces a large perennial lake which has never been observed, demonstrating that either Ramboll's estimated long-term average recharge is too high, the Ramboll simulated ET is too low, or both; (2) the calibrated hydraulic conductivity values in the Ramboll (2025) model are too high; and (3) it would take thousands of years of abnormally high recharge to reach the water levels presented in the Ramboll (2025) steady-state model, given Ramboll's calibrated aquifer properties. These results confirm that the Ramboll 2025 model results are unreliable and therefore cannot be used to support estimates of Safe Yield.

By definition, Safe Yield cannot be larger than the total amount of recharge that a basin receives from all sources, because discharging more water than is recharged will result in declining water levels. Calibrated values of specific yield are in part a function of the recharge rate, and the recharge rate is defined by the modeler. As a consequence, when calibrated specific yield values are used to estimate Safe Yield, the estimate of Safe Yield is effectively pre-determined by the assigned recharge rate. A similar criticism can be applied to estimates of total basin storage, which rely on calibrated specific yield values. However, it is important to understand that when considering the value of Safe Yield, the total volume of water held in storage is irrelevant. For any quantity of water in storage, if water is removed at a faster rate than it is replenished, water levels will decline.

OPINIONS

Opinion 1: The Ramboll groundwater model relies heavily on calibration to provide parameter values that control storage and the movement of groundwater, resulting in a groundwater flow model that can accommodate a larger amount of recharge than can be supported by the Hydrogeological Conceptual Framework (HCF).

Opinion 2: The horizontal hydraulic conductivity (HK) values used in the Ramboll model for the clay unit (HGZ2: Layers 3 and 4) are unreasonably high. Additionally, the specific yield (Sy) values used in the Ramboll model are not consistent with (1) mapping of sediment types in Ramboll (2025); (2) other Sy values measured and inferred in IWV and in similar depositional settings; and (3) a direct measurement of Sy taken in the basin.

Opinion 3: There is no credible evidence for anthropogenic recharge as discussed in my previous report. There is also no reason to include infiltration from the wastewater treatment ponds or releases from the LA Aqueduct as recharge to groundwater.

Opinion 4: The estimate of recharge for the IWV using the USGS Basin Characterization Model (BCM) is an overestimate. Half of the recharge in the Argus Range and all of the recharge from the Coso Range originate outside of the IWV, and should be treated as interbasin flow rather than mountain front recharge, which would reduce the total inflow into IWV. Additionally, Ramboll's application of the BCM incorrectly assumes that 15% of the runoff would become recharge. The 15% appears to be a misconception based on how earlier versions of the BCM handled runoff and recharge.

Opinion 5: The Ramboll model does not close the natural, predevelopment, water balance. With a specified natural recharge of 10,740 acre-feet-per-year (AFY) and a maximum natural discharge rate of 2,980 AFY the model provides no mechanism for natural discharge of the remaining 7,760 AFY. Consequently, the Ramboll model does not produce reliable results, including those properties used to estimate Safe Yield.

Opinion 6: The model has either grossly underestimated the potential for discharge through phreatophytes and bare soil evapotranspiration (ET), or overestimated natural recharge – or both.

Opinion 7: Best practices call for defining the boundary conditions for the steady-state model based on long-term averages as found in predevelopment conditions. The Ramboll model is not calibrated to predevelopment conditions and instead uses average conditions over the six-year period from 1980-1985. This period is too short to define the initial conditions and had significantly higher than average recharge and high pumping rates that are not representative of long-term conditions.

Opinion 8: In a properly configured model, the boundary conditions and aquifer properties should be capable of simulating the predevelopment discharge rate. The Ramboll model is not capable of doing this. The limited ability for the model to discharge water along with the assigned recharge rates and aquifer properties artificially raise the simulated water levels.

Opinion 9: A water-balance analysis done by DRI shows the Ramboll model does not produce an accurate representation of predevelopment conditions in Indian Wells Valley. The groundwater model has too little ET and/or too much recharge and therefore grossly overestimates groundwater conditions to the point that the model supports the existence of a 2.5 square mile perennial lake that has never been observed.

Opinion 10: Modeling done by DRI demonstrates that the inappropriate use of a wet-period recharge rate in the Ramboll steady-state model results in simulated water levels several hundred feet higher than what would be simulated if the model were correctly designed using long-term average recharge rates. Using Ramboll's long-term recharge rate, the Ramboll model would not be able to match observed water levels using the relatively high calibrated HK values.

Opinion 11: Modification of the calibrated HK values to more appropriate values would require recalibration of the model and would almost certainly require changes to the Sy values in order to simulate observed water levels in the basin. The result is that any estimates of Safe Yield supported by the Ramboll model results are unreliable, since these estimates are based on the calibrated Sy values.

Opinion 12: Estimates of Safe Yield based on change in storage derived from the Theissen Polygon Method are very sensitive to the estimated value of Sy. Additionally, when change in storage is estimated using Sy, the result is only appropriate for a water table aquifer (unconfined aquifer).

Opinion 13: Calibrated Sy values are a function of the recharge rate applied to a model. When Safe Yield is estimated using calibrated Sy values, it is effectively pre-determined by the modeler's choice of recharge rate.

RAMBOLL CONCEPTUAL MODEL

Standard groundwater modeling practice is to build a conceptual model of the hydrogeologic system that includes the hydrogeologic features (e.g., sedimentary layers, faults, basin geometry, contact with the bedrock, etc.), construct a numerical model that represents those features, and then, through the calibration process, merge that representation of the conceptual model with observed water levels, pumping rates, imposed recharge and measured discharge. This merging is often done in an iterative manner to achieve a calibrated groundwater model that represents the key features of the hydrogeologic framework and fits the observations. This practice requires maintaining a balance between fidelity to the conceptual model and an adequate fit with the observations.

Ramboll (2019) and Parker (2025) describe the development of the Hydrogeologic Conceptual Framework (HCF). The HCF defines the physical setting and structure of the IWV along with the geologic features and descriptions of the depositional setting and the sediments deposited in the basin. The HCF makes use of the airborne electromagnetic (AEM) data to inform the hydrogeologic framework for the basin. AEM is a remote-sensing technique, and the resulting data are subject to interpretation. In construction of the HCF, interpretation of the subsurface units revealed by the AEM data must be consistent with measurements from the well logs and surface observations of faults and outcropping rock units detailed in Ramboll (2019) and Parker (2025, Appendix B). The HCF drives development of the Ramboll numerical groundwater model for the IWV Basin (Ramboll, 2025).

In my opinion, the Ramboll (2025) groundwater model does not maintain the balance between fidelity to the geological setting and features of the HCF and a reasonable calibration to match groundwater observations. First, the Ramboll model ignores elements of the underlying HCF and relies mainly on the model calibration to provide parameter values that control storage and the movement of groundwater. Second, the parameter values are not what I would expect in this type of basin. This bias towards greater reliance on the calibration process results in a groundwater flow model that can accommodate a larger amount of recharge than can be supported by the HCF. I find several significant inconsistencies between the HCF development as reported in Ramboll (2019) and Parker (2025) and the groundwater flow model. These inconsistencies call into question the credibility of the calibrated groundwater model as an accurate representation of the hydrogeologic framework of the basin. In this section, I give some brief background on two important aquifer properties: Sy and HK and their relationship to the water budget in a basin, and then I highlight several significant inconsistencies here both in the representation of the HCF and in the conceptual flow budget.

Hydrogeologic Properties

Four hydrogeologic properties are critical for the calculation of groundwater flow and storage within the IWV groundwater basin: Specific Yield (Sy), Horizontal Hydraulic Conductivity (HK), Specific Storage (Ss) and the ratio of Horizontal to Vertical Hydraulic Conductivity (HKA). Here, I focus on the development of Sy and HK estimates from the HCF to the calibrated groundwater model as described in Ramboll (2025).

The sedimentary deposits of the IWV are porous with a range of pore space sizes between the sediment grains. These pore spaces hold the groundwater in storage and allow the groundwater to flow between connected pore spaces. The porosity of the sediments comprising the aquifer is the ratio of the volume of the pore space to the total volume of the aquifer. In the unconsolidated sedimentary deposits of sands and gravels of the IWV, average porosity can range from 20 to 50 percent (e.g., Manger 1963). Specific Yield (Sy) is the ratio of the volume of water that can be released from the pores in the aquifer by gravity drainage to the total volume of the aquifer. Sy is generally denoted as a fraction or percent, and, by definition, Sy cannot be greater than the porosity of the aquifer. Similar to a sponge sitting in a bucket full of water, when that sponge is pulled out of the bucket, gravity will pull much of the water from the sponge and it will drain back into the bucket. However, not all water is released by gravity drainage from an aquifer or a sponge, as some is held by capillary suction in the smaller pore spaces. **Sy is critical in determining how much water is released from storage when water levels decline and is a key property in determining Safe Yield in a groundwater basin. For the same decrease in water level, an aquifer with a higher Sy will release more water from storage relative to one with a lower Sy value, meaning that a higher Sy will result in a lower Safe Yield.**

A water balance requires the amount of water leaving the basin to be equal to the amount of water entering the basin plus or minus any change in water storage (Discharge = Recharge +/- Change in Storage). In a water table aquifer such as the IWV, Sy plays a critical role in determining the volume of water entering or leaving storage. The change in storage for a water table aquifer is equal to the change in water level (positive or negative), multiplied by the area over which that change applies, multiplied by the Sy (Change in storage = Change in water level * Area * Sy). Changes in storage are a critical component of estimating the Safe Yield.

Hydraulic conductivity, K, is a measure of how easily groundwater can flow through an aquifer. Lower K values require more energy to transmit the same volume of water through the aquifer than would be required for an aquifer with a higher K value. The hydraulic gradient is the change in water pressure per unit of distance between the measurement points. For a constant hydraulic gradient, higher values of K lead to greater volumes of water passing through the aquifer. Groundwater flow is analogous to the flow of electricity in a circuit where the hydraulic gradient is the voltage difference, the groundwater flow through the aquifer is analogous to electrical current and K is the conductance of the electrical circuit. Here, I focus on the horizontal hydraulic conductivity within an aquifer and denote that as HK. While Sy determines how much water can be taken from storage for a given reduction in water levels, HK determines how easily water is transmitted through the aquifer. Like Sy, HK is primarily derived from the properties of the sand or rock in the aquifer. **HK is the controlling factor in how much water can be transmitted through an aquifer from the recharge areas to the discharge areas. HK is important for determining how readily groundwater can be transmitted from sources (e.g., recharge) further away to discharge points (e.g., pumping wells). Higher HK values enable easier transmission of groundwater and thereby alleviate the need to pull water out of storage locally.**

Hydrogeologic Conceptual Framework

In this section, I examine the treatment of hydrogeologic properties in the development of the HCF (Ramboll, 2019, Parker, 2025) and their final representation in the calibrated Ramboll groundwater model as described in Ramboll (2025). I highlight several inconsistencies between the HCF and the calibrated model.

Treatment of Heterogeneous Properties

Parker (2025) and Ramboll (2025) divide the basin sediments into three main hydrogeologic zones (HGZ1, HGZ2 and HGZ3 in top to bottom order), along with an HGZ4 that underlies the bottom of the groundwater flow model. Each of the three main HGZs is further subdivided into two layers. Each HGZ is characterized as “vertically and laterally heterogeneous with interbedded intervals of fine and coarse materials” characteristic of the depositional environment (Ramboll, 2025, Section 3.2). HGZ1 is the uppermost HGZ with sand and gravel as the most common materials. The majority (71%) of the wells used for the transient calibration are screened in HGZ1, and provide the basis for defining the spatial heterogeneity of hydraulic properties.

However, for the vast majority of the main portion of the basin (the basin excluding the El Paso subarea), Layer 1 (top layer of HGZ1) of the Ramboll (2025) model does not represent the “vertically and laterally heterogeneous” material described in the HCF. In the model, this portion of Layer 1 has only three different values for HK (Ramboll, 2025, Figure 5-3) and only two values for Sy (Ramboll, 2025, Figure 5-4). Similarly, this region of Layer 2 has only four different values of HK and the same two values for Sy as in Layer 1. Figure 1 provides a visual comparison showing the stark difference between the material heterogeneity in the HCF and the complete smoothing over of that heterogeneity in the Ramboll model. The image on the left side of Figure 1 is taken from Bedekar (2025) and was created using well logs and AEM survey data. It shows the fraction of coarse sediments at every location in Layer 1 of the Ramboll model. Sediment grain size is often used as a predictor of hydraulic properties with coarser sediments, sand and gravel, correlating with higher values of Sy and HK.

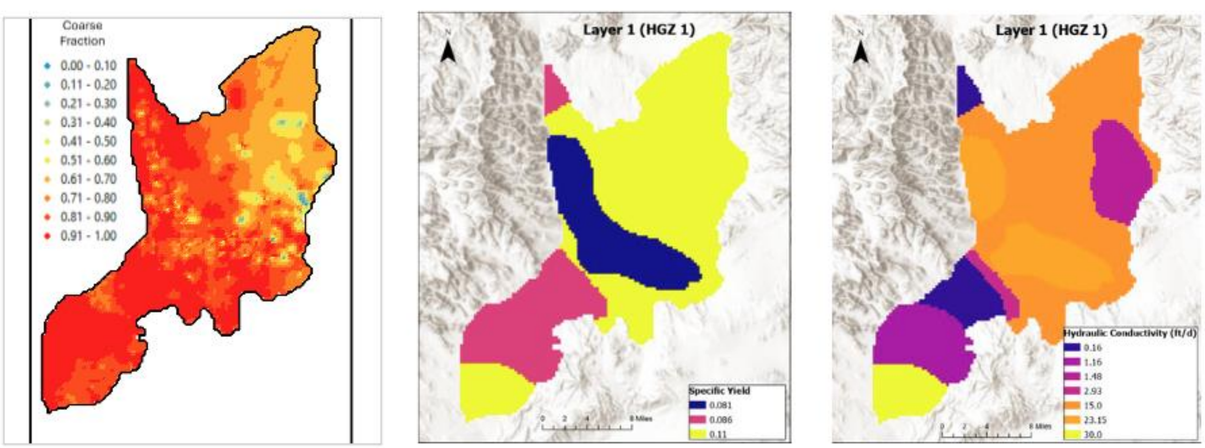

Figure 1. The coarse fraction (sand and gravel) as interpreted by Bedekar (2025) from combining sediment texture in lithologic well logs with the AEM data (left image, from Bedekar, 2025). The final calibrated values of Sy (center image, from Ramboll, 2025) and the final calibrated values of HK (right image, from Ramboll, 2025).

The middle and right images in Figure 1 show the Sy and HK values in Layer 1 of the calibrated groundwater model developed in Ramboll (2025). The strong variation in the amount of coarse material across Layer 1, described by Bedekar (Figure 1, left) is not at all represented in the model's highly simplified representations of Sy and HK. For example, an Sy value of 0.11 is applied to regions with more than 90% coarse material as well as to regions with less than 20% coarse material. The significant loss of geologic detail is also apparent in the calibrated values of HK (Figure 1, right image).

The lowest values of Sy are shown in blue in the center image of Figure 1 and are applied to the "hydrological contact" zone where HGZ2 is missing and HGZ1 and HGZ3 are in direct contact (see Ramboll, 2019, Figure 6-9). This hydrologic contact zone is defined by Ramboll (2019) as being composed of coarse alluvial fan and fluvial sediments containing sand and gravel (see Ramboll 2019, Figure 6-12) surrounded both laterally and below by finer-grained sediments. The groundwater model's assignment of the lowest Sy value (0.081) to the hydrologic contact zone is inconsistent with sand and gravel sediments. Assignment of the lowest Sy values to this zone is also contrary to the Ramboll (2025) report's statement that *"Fine-grained units, like silts and clays, are assigned lower specific yields due to their limited drainage capacity, while coarser units, such as sands and gravels, are assigned higher values to simulate more readily available storage."* **Overall, the Ramboll (2025) groundwater model's assignment of Sy and HK is inconsistent with their HCF and makes a gross simplification of the heterogeneity in the aquifer. These flaws are important because Sy controls the amount of water that is released from storage due to a decline in the water table and change in storage is a critical component of the water balance for the basin.**

Hydrogeologic Conceptual Framework in North-Central Basin

Figure 6-10 in Ramboll (2019), also included within Appendix B of Parker (2025), is a West-East cross section across the northwest portion of the basin containing AEM resistivity values in a color scale, one well log, and interpretations of the depositional environments and the boundaries between HGZ's. That figure is reproduced below as Figure 2. This cross-section was chosen by Ramboll (2019) to emphasize several notable aspects of the basin, including areas where HGZ2 is missing and also a large, nearly 1000 feet thick, high electrical resistivity (~70-100 Ohm·m) sand body identified as a deltaic deposit.

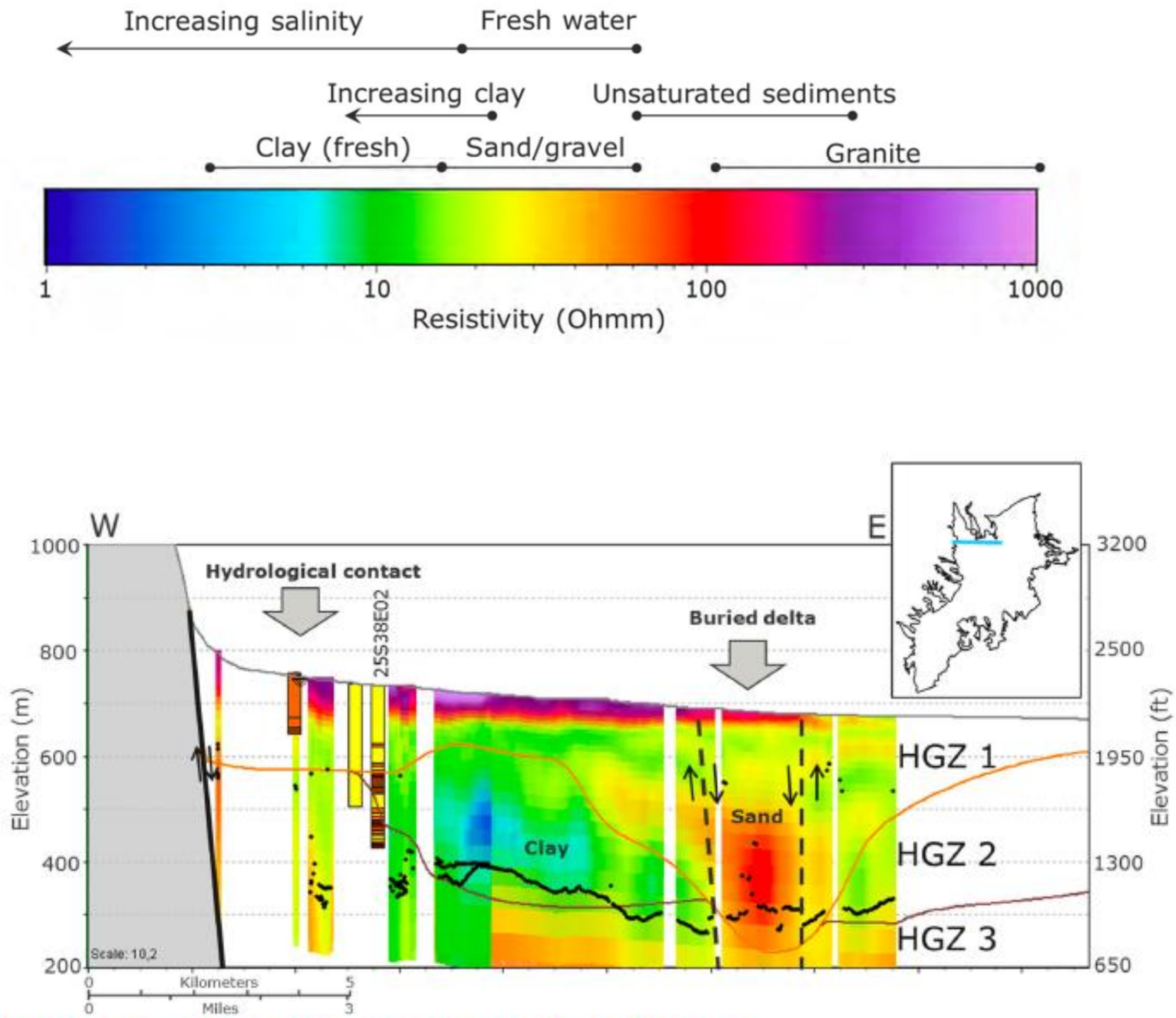

Figure 6-10. Cross-section showing the well lithology and SkyTEM data
In the west, direct hydrological contact between HGZ 1 and HGZ 3 is seen both in the well lithologies and SkyTEM data. In the center of the profile, a structure composed of coarser material, interpreted to be a buried delta deposit. A this location there is also direct hydrological contact between HGZ 1 and HGZ 3. The dashed lines show the interpreted faults bounding the structure. The orange line shows the bottom of HGZ 1, the brown line shows the bottom of HGZ 2 and the small dots show the depth of investigation for the SkyTEM data.

Figure 2. Copy of Figure 6-10 in Ramboll (2019) showing across-section with a high resistivity sand deposit between two faults in the northwest area of the IWV Basin. The absence of HGZ2 between the faults and on the west (left) side of the section are also shown. The annotated color legend for the AEM (SkyTEM) data in Figure 4-4 of Ramboll (2019) and their interpretations of lithology and water quality are also provided.

The calibrated parameters in the groundwater model (Ramboll, 2025, Figures 5-3 and 5-4) provide no indication that the deltaic deposit exists. There is no explanation for this omission, even though this large sand deposit could significantly impact the amount of storage in the upper layers of the model. The faults that bound the deltaic deposit (see Figure 2) should create sharp, lateral boundaries for the aquifer properties (Sy and HK) assigned to either side of the faults in the HGZs, but those boundaries are not present in the groundwater model (see Ramboll, 2025, Figures 5-3 and 5-4). The hydrologic contact zone described in Ramboll (2019) where HGZ-2 is missing is represented in the Ramboll model as fully continuous. In these areas, the thickness of HGZ2 is set to 10 feet and HK is set to relatively high values of 15-30 ft/day (Ramboll, 2025, Section 5.3.1.2) that creates a connected flow path across the region bounded by faults. **These features of the HCF (faults, contacts and sand zone) are important in determining the flow of water and groundwater storage in the basin and were ignored without explanation when constructing the groundwater model. Ignoring significant features of the HCF when calibrating the groundwater model is not consistent with industry standards.**

Specific Yield (Sy)

Roughly 80% of the Sy values in Layer 1 of the Ramboll model are equal to 0.11. The other 20% of the Sy values are less than 0.11, reaching a minimum value of 0.081 (Ramboll (2025), Table 5.2). These values are not consistent with (1) mapping of sediment types in Ramboll (2025); (2) other Sy values measured and inferred in the IWV and similar depositional settings; and (3) a direct measurement of Sy taken in the basin.

Figure 5-2 of Ramboll (2025) identifies the percentage of coarse materials (i.e. sands and gravels) within each 1x1 mile cell that contains one or more wells with logs. Table 1 below shows the number and percentage of cells containing increasing fractions of coarse material in HGZ1 and HGZ2 as taken from Ramboll (20205, Figure 5-2). More than 74 percent of the cells in HGZ1 have at least 40% coarse material in them (Green, Light Blue and Dark Blue rows in Table 1). Sy values less than or equal to 0.11 are not consistent with this fraction of coarse material.

Table 1. Coarse fraction within the upper two HGZ's provided as both cell counts and percentage of the HGZ (Ramboll, 2025). Coarse fraction refers to sands and gravels.

	HGZ-1		HGZ2	
Coarse Fraction (%)	**Count**	**Percent**	**Count**	**Percent**
0 (Red)	*4*	*2.9*	22	34.9
1-40 (Orange)	*31*	*22.5*	31	49.2
40-60 (Green)	*36*	*26.1*	3	4.8
60-80 (Light Blue)	*40*	*29.0*	2	3.2
80-100 (Dark Blue)	*27*	*19.6*	5	7.9
Total Count	138		63	

Sy is a fundamental property of any water table aquifer and has been measured by hydrogeologists for over 100 years. In a seminal work, Johnson (1967) completed a comprehensive review of work done mainly in California over an approximately 70-year period. The average Sy values of this review for a range of geologic materials are shown in Table 29 of Johnson (1967) and recreated here in Table 2. Sy values reported in Johnson (1967) for the coarse materials identified in Ramboll (2025) range from 21 to 27% (0.21 to 0.27), far higher than the 0.11 used in the Ramboll model.

Table 2. Average specific yields from 17 studies as reported in Table 29 of Johnson (1967).

Material	Average Sy
Clay	0.02
Silt	0.08
Sandy Clay	0.07
Fine Sand	0.21
Medium Sand	0.26
Coarse Sand	0.27
Gravelly Sand	0.25
Fine Gravel	0.25
Medium Gravel	0.23
Coarse Gravel	0.22

Hollett, et al. (1991) reported measurements and estimates of Sy in the heavily studied Owens Valley to the north of the IWV. The alluvial fan, transition zone and fluvial and lacustrine deposits assessed in Hollett, et al (1991) are all similar to depositional settings and ages in the IWV. The Sy values reported for these deposits range from < 0.01 to 0.30, with the higher values (between 0.10 and 0.30) occurring in the sands and gravels. Again, most values are significantly higher than those used in the Ramboll (2025) groundwater model.

Dutcher and Moyle (1973) estimated an average Sy value of 0.155 for the upper 200 feet of the saturated zone in the IWV basin, which generally corresponds to Layer 1 in the Ramboll groundwater model. Hollet et al. (1991) and Dutcher and Moyle (1973) demonstrate that the values of Sy used by Ramboll (2025) are too low. These studies also point out that Sy values vary according to variations in the geologic material. In contrast, the Sy is constant over 80% of the Ramboll model (Figure 3) despite the wide variation of geologic material found by Bedekar (2025). Not only does the Ramboll model fail to capture the heterogeneity of the geologic material, the model is inconsistent with the range of Sy values reported in Ramboll (2025). Table 3-1 of Ramboll (2025) shows that Sy varies between 0.12

and 0.17 in HGZ1 (Layers 1 and 2). All of the Sy values used in the Ramboll model fall below this range.

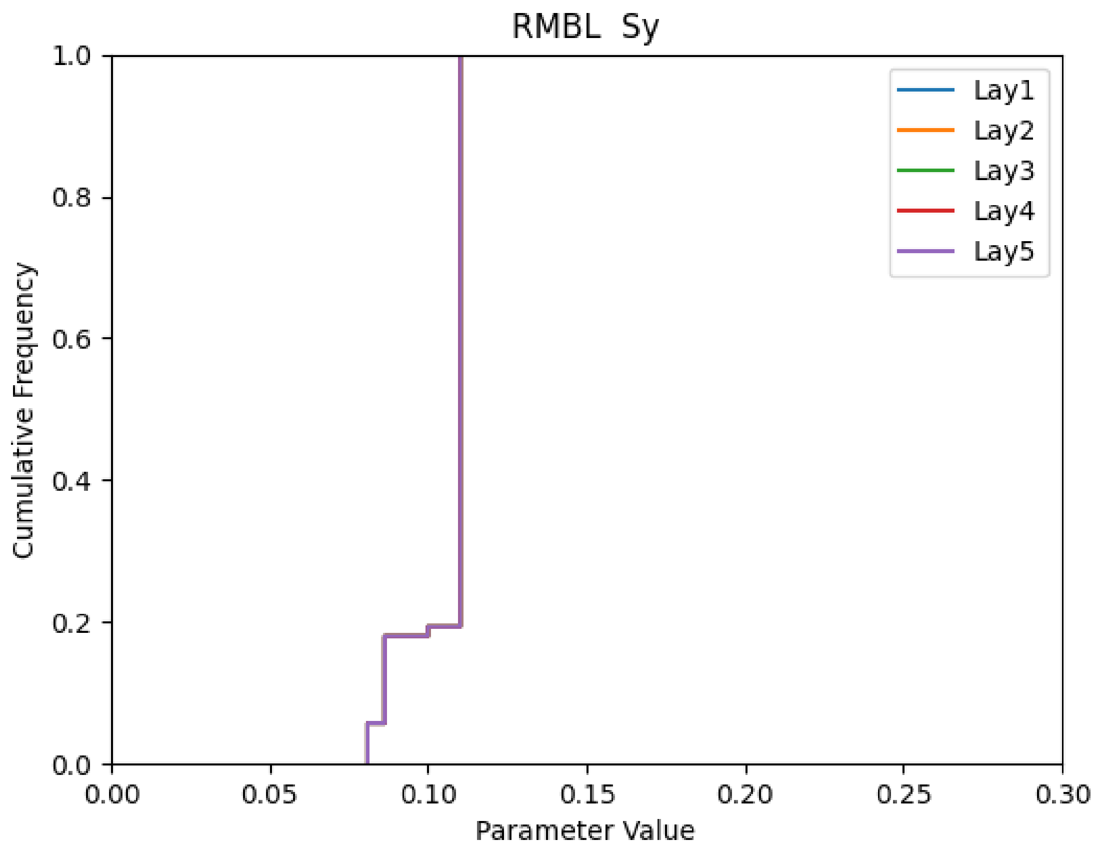

Figure 3. Cumulative distributions of Sy for each layer in the Ramboll (2025) model.

Additionally, the lack of variation in Sy values within and across all layers that I noted above is even less credible given the differences in the fractions of coarse material found between HGZ1 and HGZ2 highlighted in the Ramboll (2025) report (see Figure 5-2, Ramboll, 2025; and Table 1 above). Table 1 shows that while nearly 75% of the measured cells in HGZ1 contain a 40% or greater fraction of coarse material, only 16% of the measured cells in HGZ2 have a 40% or greater fraction of coarse material. Yet, these HGZs are assigned the same Sy values and similar specific storage (Ss) values. The complete lack of variation within and between layers and between HGZs, where both Ramboll (2025) and Bedekar (2025) have identified significant differences in the amount of coarse material, is not hydrogeologically credible.

Finally, the Sy levels used in Ramboll (2025) are inconsistent with a recent direct measurement of Sy presented in Teasdale (2025). Teasdale (2025) reports an April 2025 pumping test in the area of Meadowbrook Dairy which resulted in an Sy value of 0.20 (Teasdale 2025, Section 2.4.5). Teasdale (2025) found this result to be consistent with a mixture of sand and gravel in the area of the test and to also be consistent with values from textbooks. This measured value is not only consistent with the reported studies discussed above, but also nearly twice the value of the highest calibrated value in the Ramboll (2025) model. This data point is not mentioned in Ramboll (2025).

In my opinion, the groundwater model described in Ramboll (2025) resulted in Sy values that are lower than can be supported by available measurements and data. This result appears to be driven by the boundary conditions and the calibration process, which I examine in more detail below. Simple water balance calculations for the basin dictate that for a fixed discharge and water level decline, low Sy estimates result in less water coming from storage and more water having to come from recharge to maintain the observed pumping rates and water level declines. Put differently, lower Sy values facilitate a higher Safe Yield estimate.

Horizontal Hydraulic Conductivity (HK)

The cumulative distributions of HK for the six layers in the Ramboll model are shown in Figure 4. The mean and median HK values for each layer are shown in Table 3. One issue with the HK values in the Ramboll model is the very similar values in HGZ1 and HGZ3. Ramboll (2025) describes the materials of HGZ3 as unconsolidated/semi-consolidated alluvial gravel, sand and clayey sand of the Late Pliocene (3.6 to 2.8 million years old) White Hills sequence. Although previous geologic and geophysical studies in Indian Wells Valley confirm that the depths and material types of Ramboll's (2025) HGZ3 are accurate, these same studies describe the geologic materials as being consolidated (Monastero et al., 2002; Shah and Boyd, 2018). Given the great depths and age of the White Hills sequence, the material types in this sequence are more accurately described as rocks (e.g., conglomerate and sandstone), and therefore their respective HK values should reflect this by being significantly lower. The geologic materials in HGZ3 are significantly older and more consolidated than those in HGZ,1 and I would expect that to be reflected in lower HK values in HGZ3 relative to HGZ1. **The Ramboll (2025) model fails to accurately characterize the deeper hydrogeologic conditions in the basin and assigns unrealistically high HK values to consolidated rocks which allow more water to pass through them than lower HK values would**.

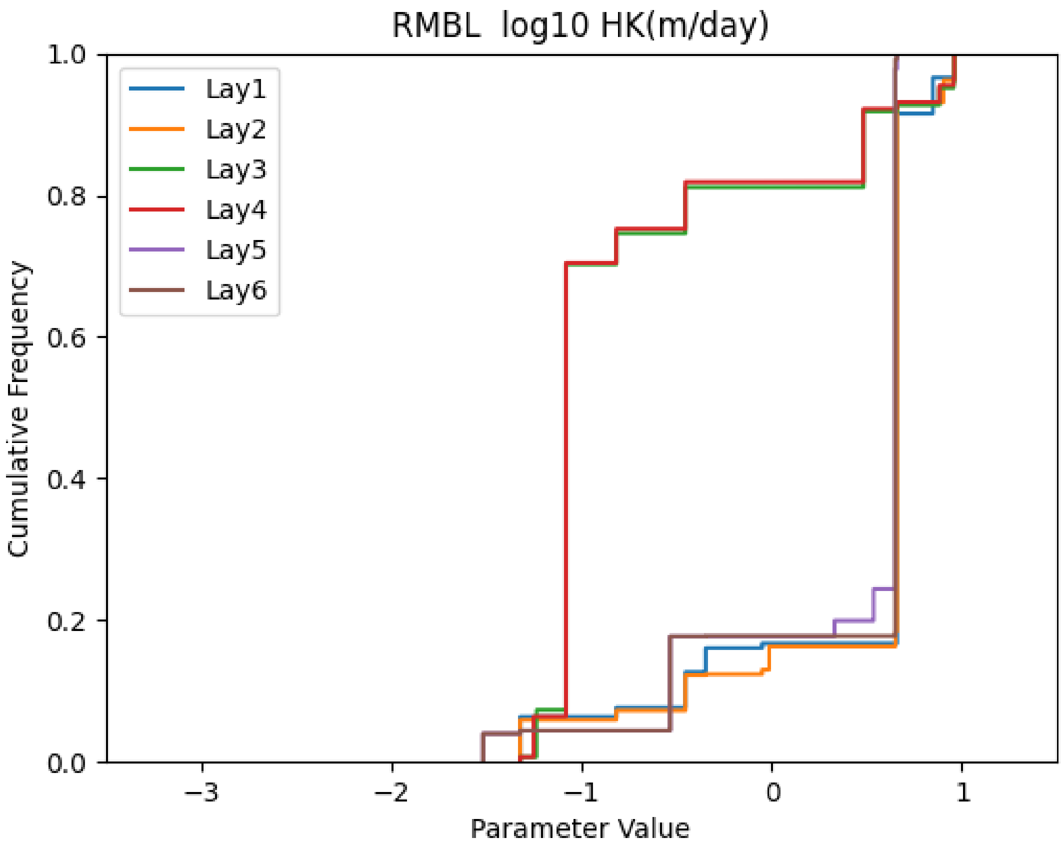

Figure 4. Cumulative distributions of HK for each layer in the Ramboll (2025) model. Units of HK are log10 of m/day.

Table 3 reports the average HK values used in Ramboll (2025). The HK values in layers 1 and 2 of the Ramboll (2025) model are relatively high and fit within the broad range of representative values for fine, medium and coarse sand reported in Domenico and Schwartz (1990, Table 3.2). However, for these same units, the calibrated HK values are not consistent with the calibrated low values of Sy. The low values of Sy assigned to these layers are consistent with reported values for a silt or sandy clay (Johnson, 1967), while the calibrated HK values for the same material are consistent with those of clean sands.

Layers 3 and 4 of the Ramboll (2025) model are comprised of fine-grained material (clay and silt) with interbeds of coarser sediments. This material is identified as an aquitard in the Ramboll HCF (Ramboll 2025, Section 3.2). The mean and median calibrated HK values shown in Table 3 are much higher than the representative values of clay in Domenico and Schwartz (1990). The calibrated Layer 3 and 4 HK values in Ramboll (2025) are in line with a fine to coarse sand deposit, not a clay deposit. Expected HK values in a clay deposit would be roughly four orders of magnitude (10,000 times) lower than the calibrated values in

Ramboll (2025). The elevated values in the model allow for much more water to pass through than would be expected from a clay layer.

Table 3. Mean and Median HK values in m/day for each layer in the Ramboll (2025) model.

	Mean	**Median**
HGZ1		
Layer 1	4.136	4.572
Layer 2	4.167	4.572
HGZ2		
Layer 3	1.086	0.083
Layer 4	1.042	0.083
HGZ3		
Layer 5	3.631	4.468
Layer 6	3.716	4.468

The importance of HK and its relationship to recharge rates, water levels and groundwater flows are demonstrated in Figure 5. Figure 5 shows four possible combinations of recharge rate and HK where each quantity is simply high or low. If a high rate of recharge is applied to a low HK aquifer (Figure 5, Example B), water levels will rise. Conversely, Figure 5 (Example C) shows that low recharge combined with high HK, allows the lower volume of water to move through the aquifer without backing up and raising water levels. Examples A and D (Figure 5) show that the same water levels are achievable from a combination of high recharge and high HK (Figure 5, A) as well as from a combination of low recharge and low HK (Figure 5, D). In case A, the high recharge can keep the water levels high even though the high HK allows considerable volumes of water to pass through the aquifer. In case D, the low HK impedes the groundwater flow, creating higher water levels even though the recharge rate is small. These identical results from two different situations highlight the non-uniqueness inherent in calibrating a groundwater model. Figure 5 (A and D) are of particular interest because they show that reasonable groundwater model calibration results can be achieved with very different recharge rates by using different HK values.

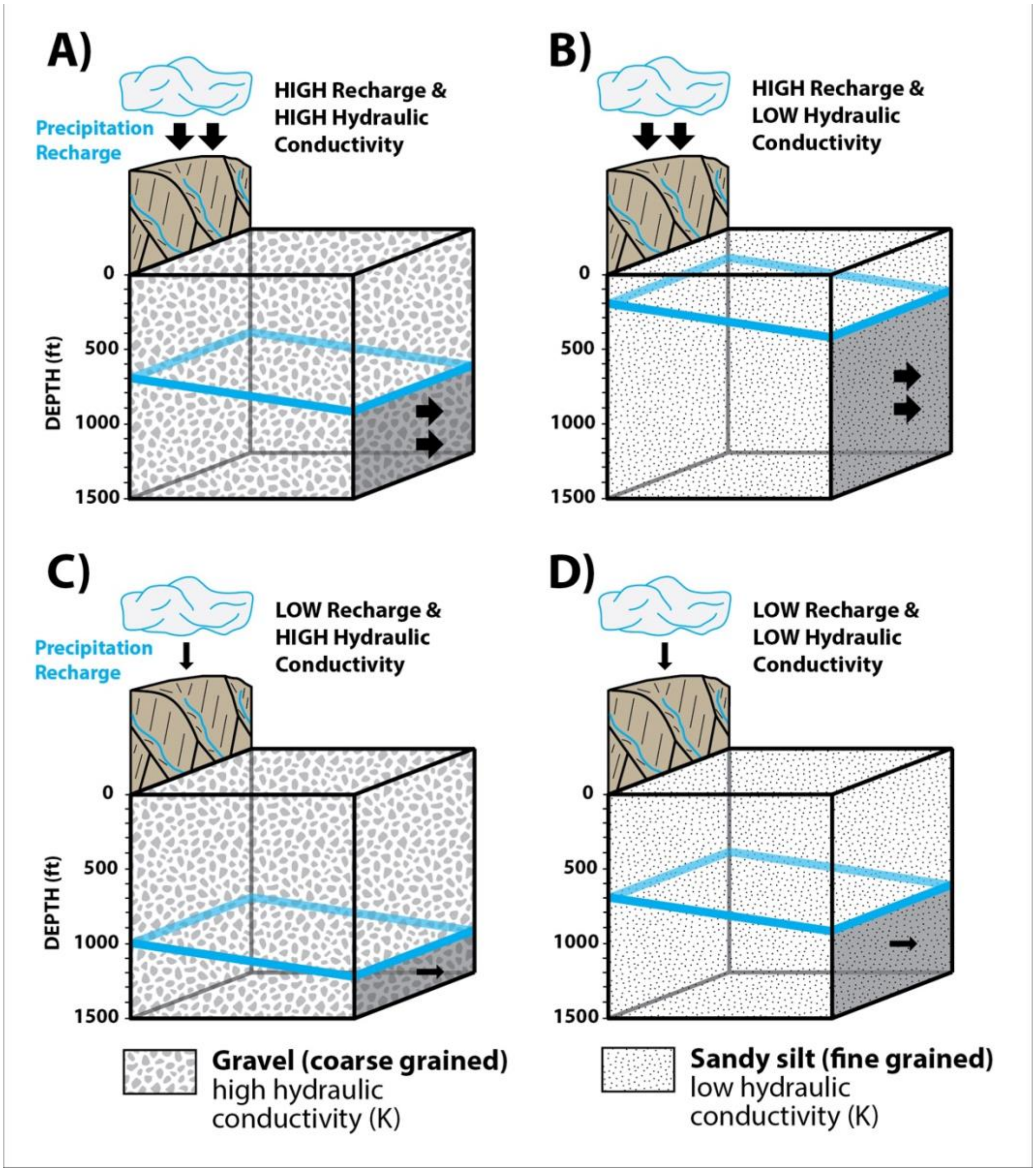

Figure 5. A simplified view of different combinations of recharge and HK and their impact on water levels and groundwater flow volumes through an aquifer.

The calibrated aquifer properties in the Ramboll (2025) model display a number of inconsistencies. Inappropriately low Sy values for these types of geologic deposits lead to less water being removed from storage for a given decline in the water level relative to higher Sy values. Similarly, the HK values assigned to Layers 3 and 4 are much higher than expected for a clay unit, and the HK values assigned to Layers 5 and 6 are much higher than expected for consolidated rock. **Assignment of relatively higher HK values allow a larger amount of water to be transmitted horizontally through the aquifer from a recharge location to a discharge location for a given hydraulic gradient. Consequently, it is then**

possible to pump more water from the aquifer before reducing storage. In effect, the high recharge increases the Safe Yield.

Faults

The IWV is one of the most seismically active basins in the United States. As an example, the 2019 earthquakes in IWV had measured vertical ground displacements of up to two meters. This type of vertical displacement tends to offset geologic layers that were laterally continuous when deposited. Those offsets occur along faults and the offset layers can then interrupt groundwater flow by juxtaposing layers of different materials against each other. Faults themselves can also act as barriers to groundwater flow by having lower hydraulic conductivities than the aquifer materials on either side of the fault.

Ramboll (2019, 2025) developed a detailed HCF using well data, geophysical data including seismic profiles, AEM data and other information. A significant component of any HCF is the presence and location of faults. The HCF discusses many faults and provides maps and cross-sections identifying the location, dip angle and direction of offset (see Sections 5 and 6, Ramboll, 2019). However, there is not a single location in the model where an HGZ ends abruptly or is raised or lowered relative to other layers. Not using the faults identified in the Ramboll (2019) HCF to inform the structure of the groundwater flow model enables higher connectivity along units and is inconsistent with best practices.

Ramboll (2025) does add faults as flow barriers to the groundwater model, rather than as discrete features that accommodate geologic offsets. Ramboll (2025) includes three faults: El Paso (aka: Freeman) Fault, Little Lake Fault and an additional northern strand of the Little Lake Fault that is to the east of the main fault. The conductance values assigned to the different segments of the Little Lake Fault are reasonable. However, the conductance assigned to the El Paso fault is anomalous at 1.0E-15 ft/day, more than 9 orders of magnitude (1 billion times) less than the conductance assigned to any segment of the Little Lake Fault. Assuming a fault zone thickness of 1000 feet, this would be equivalent to a hydraulic conductivity of 1.0E-12 ft/day – 5 orders of magnitude lower than unfractured igneous and metamorphic rocks, such as granite (Domenico and Schwartz, 1990). Neither Ramboll (2025) nor Ramboll (2019) explains why the El Paso Fault would have such a low conductance.

Conceptual Flow Budget

The behavior of groundwater systems is fundamentally governed by the principle of mass balance: inflow equals outflow plus any change in storage. A conceptual flow budget for a groundwater basin describes the rates and locations of inflows and outflows to and from the aquifer or aquifers within the basin. Inflows to the groundwater system include natural recharge from precipitation and surface water infiltration, while outflows occur via evapotranspiration (ET), discharge to streams and springs, and groundwater extraction through pumping. When outflows exceed inflows over time, groundwater levels decline, reflecting a reduction in stored volume of groundwater. In an undisturbed (i.e., predevelopment) groundwater basin, the long-term average inflows are equal to the long-term average outflows, meaning that on average, groundwater levels are stable and there is no change in storage. Development of a balanced conceptual flow budget is a critical first step to understanding a groundwater system.

It is best practice to develop a steady-state model to represent a period when the flow system is at equilibrium (Reilly and Harbaugh, 2004), and steady-state models are therefore commonly designed to represent a time prior to significant development of the basin. It is generally accepted that under predevelopment conditions, groundwater entered IWV as mountain block and mountain front recharge, and discharged primarily as phreatophyte and bare soil ET in the China Lake area (Brown and Caldwell, 2009; Tonkin, 2025). Given the principle of mass balance, this outflow must be equal to the inflow derived from natural recharge that Ramboll (2025) asserts is 10,740 AFY – the average natural recharge rate from 1986-2023, based on application of the United States Geological Survey's (USGS) Basin Characterization Model version 8 (BCMv8). While the Ramboll model does simulate ET in the China Lake area, the model does not close the natural water balance. The maximum possible natural outflow that can be simulated using the Ramboll model is 2,980 AFY, leaving an unaccounted-for balance of 7,760 AFY. Ramboll (2025) makes no effort to explain the mechanism of natural discharge in IWV prior to development. **The total lack of a predevelopment flow budget in Ramboll (2025) is a fundamental flaw of the analysis of the groundwater system in IWV, the consequences of which propagate through the development of the Ramboll numerical model and any subsequent estimates of Safe Yield.** A critical evaluation of all sources of recharge and natural discharge utilized in Ramboll (2025) is presented in the following sections.

Natural Recharge

Application of the Basin Characterization Model (BCMv8) to Estimate Recharge

The Ramboll (2025) model relies on estimates of natural recharge derived from the USGS Basin Characterization Model (BCMv8; Flint et al., 2021). The BCMv8 model includes mountain block and mountain front recharge from the northern Sierra Nevada, southern Sierra Nevada, Volcanics, Coso Range, Argus Range, and El Paso as well as interbasin groundwater flow from Rose Valley (Figure 6). Ramboll (2025) correctly treats flow from the Rose Valley as interbasin flow, but improperly **fails to apply the same treatment to the**

Coso Range and Argus Range recharge areas. This approach leads to the groundwater model overestimating recharge in these areas.

Typically, the rate of groundwater leaving a basin as interbasin flow is expected to be smaller than the rate of recharge entering that basin. This is because some fraction of the inflows to the basin are expected to be discharged through other mechanisms, such as pumping or ET. The Ramboll groundwater model uses a value of 2,567 AFY to represent interbasin flow from the Rose Valley, which is 41% of the average annual recharge for Rose Valley of 6,230 AFY estimated by the BCMv8 for the period 1986–2023.

The Ramboll model incorrectly treats the BCMv8 recharge from the Coso and Argus Ranges as mountain-front recharge directly into the IWV basin instead of interbasin flow. The entire Coso Range recharge area (i.e., watershed) directly drains into Airport Lake basin, a terminal playa basin that does not have an outlet (Figure 6). The Argus Range recharge area also shares a drainage divide between Airport Lake and IWV basins, such that half of the surface runoff and associated recharge from the Argus Range also drains into Airport Lake basin (Figure 6). As a result, no runoff or runoff-derived recharge, and no groundwater that discharges (e.g., evaporates) from the playa of Airport Lake contributes to the IWV groundwater basin as mountain-front recharge. Most of the recharge to the IWV from these areas is more accurately described as interbasin flow from the Airport Lake Basin and should have been treated in the same way as Rose Valley is treated in the Ramboll model.

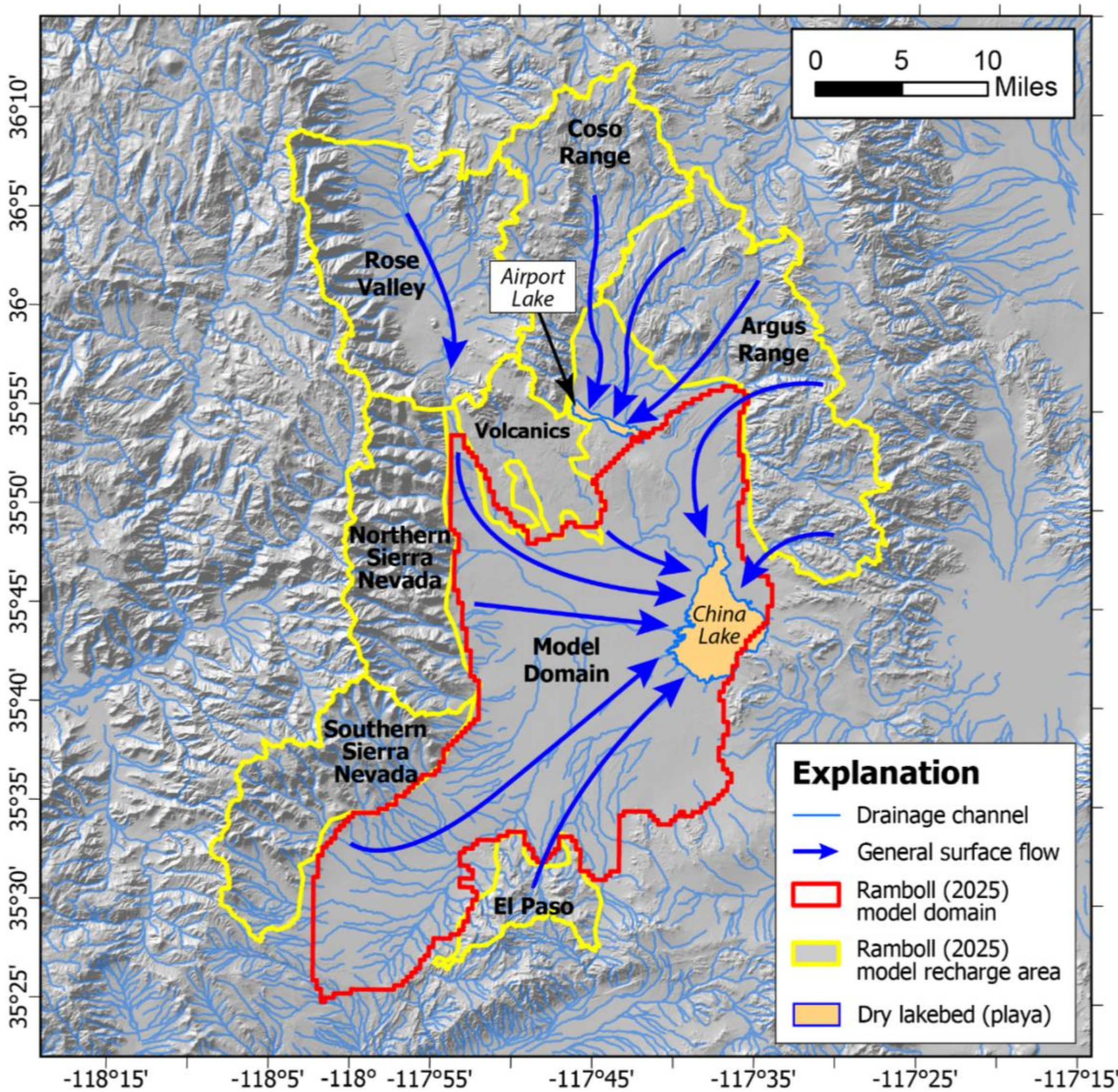

Figure 6. Map showing the Ramboll (2025) model domain and recharge areas. The drainage channel patterns and general surface flow directions within the model domain and recharge areas are also shown. The general surface flow directions show the Coso Range recharge area drains directly into the playa basin of Airport Lake. The general flow directions also show that the Argus Range recharge area shares a drainage divide between the Airport Lake and China Lake playa basins.

Table 4 below corrects that error by adjusting the BCMv8 values to more accurately depict the physiography and hydrology of the groundwater basin by differentiating between shallow mountain-front recharge and interbasin flow. I considered the 41% ratio used by Ramboll (2025) for Rose Valley interbasin flow to be representative and applied it to characterize the relationship between how much interbasin flow is derived from watershed-scale recharge in the Coso Range and Argus Range recharge areas.

Table 4. Average California BCMv8 recharge between 1986 and 2023 within recharge areas of the Ramboll (2025) groundwater model.

Ramboll recharge area	BCMv8 recharge (AFY)	BCMv8 recharge with assigned Rose Valley interbasin flow (AFY)	Total recharge modified to account for interbasin flow (AFY)
Northern Sierra	3626	3626	3626
Southern Sierra	2516	2516	2516
Rose Valley	6230	2567	2567*
Coso Range	1032	1032	425*
Argus Range	339	339	240*
Volcanics	492	492	492
El Paso Mtns	170	170	170
Total	**14,406**	**10,743**	**10,037**

Note: *recharge adjusted using an interbasin flow/recharge fraction of 0.412 based on assigned Rose Valley interbasin flow value used in the Ramboll (2025) model. See text for explanation.

Inappropriate use of BCMv8 Recharge Estimates from Runoff

The Ramboll model assumes 15% of simulated runoff will become recharge. It is generally accepted in the hydrologic research community that a fraction of runoff from the mountains becomes groundwater recharge from infiltration losses along streams that cross alluvial fan slopes or valley floors. These losses generally range from 10–15% of the runoff for parts of the Mojave Desert similar to the Indian Wells Valley (e.g., Flint and Flint, 2004; 2007). **However, Ramboll (2025) and Parker (2025) were wrong to assume 15% of the BCMv8's simulated runoff would become recharge. The 15% assumption is a vestige of prior versions of the BCM model** (e.g., Flint and Flint, 2004; 2007). Version 8 of the BCM explicitly calculates natural recharge directly from a water-balance accounting structure and therefore no longer applies a flat 15% of the runoff to recharge. This means that a modeler must have data to support treating 15% of the runoff as recharge, especially for an ephemeral surface hydrologic system, such as in Indian Wells Valley. No such data is presented in Ramboll (2025) or Parker (2025).

Uncertainties with the California BCMv8 Recharge Estimates for Indian Wells Valley

Hydrologic models simulating complex physical processes commonly present a range of model results (i.e., uncertainties) following scientific and industry standards. Only the average recharge values from BCMv8 model were used in the Ramboll model. However, the BCMv8 model also produces a range of potential results within 95% confidence intervals for the model recharge areas. That range is very broad. When Rose Valley, the Coso Range and half of the Argus Range are properly treated as interbasin flow, the range of total recharge values spans from 5,900 to 13,173 AFY (Tables 5 and 6).

The large range in total recharge values raises the question of how well the BCMv8 model, which was developed for statewide conditions, can accurately represent recharge and runoff in the specific case of the ephemeral and arid hydroclimate of Indian Wells Valley. Recharge is one of the most difficult hydrogeologic processes to estimate, and recharge rates cannot be measured directly. Surface runoff, however, can be measured from stream gages and compared to modeled BCMv8 runoff to provide confidence in model performance and/or aid in calibrating the BCMv8 model to site-specific geologic and hydrologic conditions (Flint et al., 2021).

The BCMv8 model was calibrated using observed data from across California spanning multiple contrasting hydroclimates. **The BCMv8 model was not specifically calibrated to measured streamflows in Indian Wells Valley. As a result, whatever errors the BCMv8 model has in simulating both recharge and runoff are propagated in the Ramboll model.** For example, in 2017, the year the Ramboll model has the highest recharge (roughly 60,000 acre-feet), the BCMv8 model overestimated the observed runoff by nearly 300 percent (Figure 7).

Table 5. Maximum California BCMv8 recharge between 1986 and 2023 within recharge areas of the Ramboll (2025) groundwater model.

Ramboll recharge area	BCMv8 recharge (AFY)	BCMv8 recharge with Ramboll (2025) assigned Rose Valley interbasin flow (AFY)	Total recharge modified to account for interbasin flow (AFY)
Northern Sierra	5000	5000	5000
Southern Sierra	3800	3800	3800
Rose Valley	9130	2560	2560*
Coso Range	1300	1300	536*
Argus Range	450	450	318*
Volcanics	810	810	810
El Paso Mtns	150	150	150
Surface Runoff**	770	770	770
Total	**21,410**	**14,070**	**13,173**

Note: *recharge adjusted using an interbasin flow/recharge fraction of 0.412 based on mean recharge values reported in the Ramboll (2025) model. See text for explanation. **recharge from surface runoff represents assumed 15% loss.

Table 6. Minimum California BCMv8 recharge between 1986 and 2023 within recharge areas of the Ramboll (2025) groundwater model.

Ramboll recharge area	BCMv8 recharge (AFY)	BCMv8 recharge with Ramboll (2025) assigned Rose Valley interbasin flow (AFY)	Total recharge modified to account for interbasin flow (AFY)
Northern Sierra	1800	1800	1800
Southern Sierra	1000	1000	1000
Rose Valley	3330	2560	2560*
Coso Range	470	470	194*
Argus Range	150	150	106*
Volcanics	190	190	190
El Paso Mtns	50	50	50
Surface Runoff**	230	230	230
Total	**7,220**	**6,220**	**5,900**

Note: *recharge adjusted using an interbasin flow/recharge fraction of 0.412 based on mean recharge values reported in the Ramboll (2025) model. See text for explanation. **recharge from surface runoff represents assumed 15% loss.

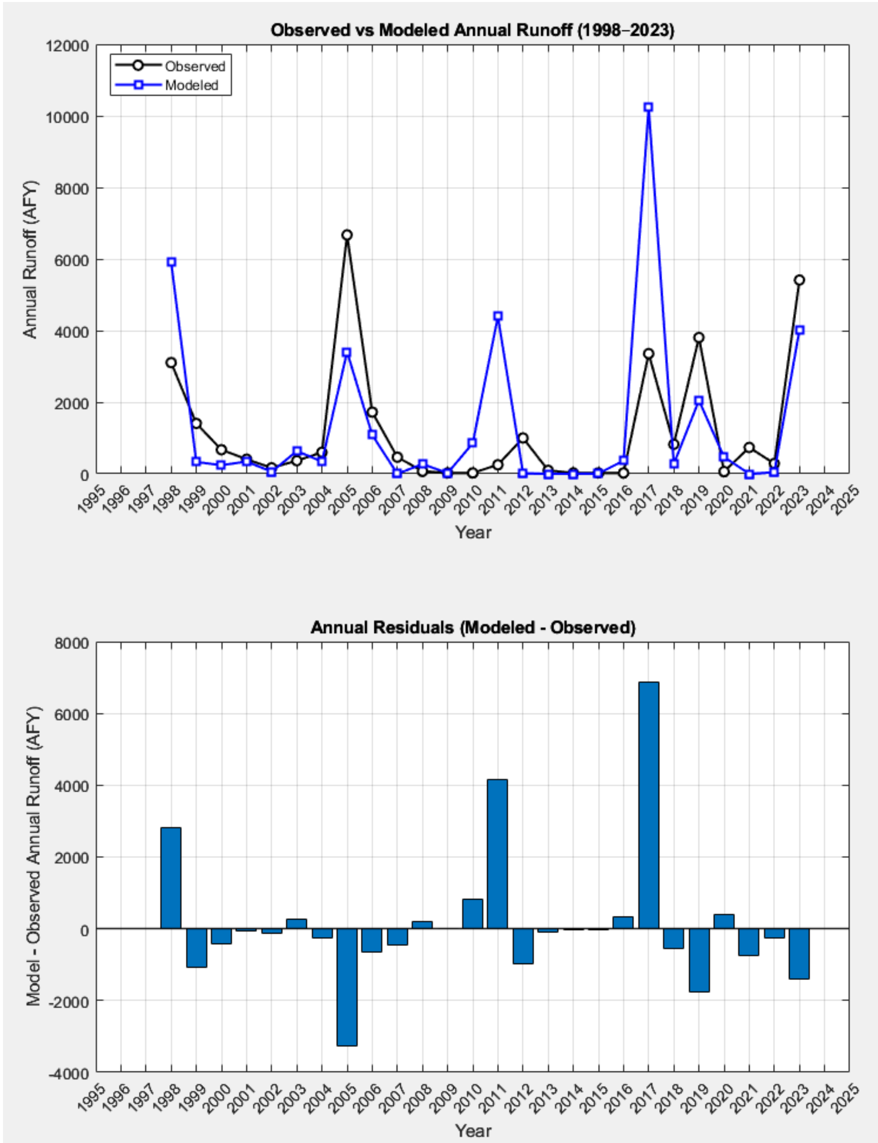

Figure 7. Plots of annual BCMv8 model runoff (modeled) and USGS gage stream discharge (observed) from tributary streams in the Northern Sierra Nevada recharge area of the Ramboll (2025) groundwater model. A) Upper plot shows time-series of modeled and observed runoff for the period 1998–2023 from Tonkin (2025); B) Lower plot shows time series of differences (residuals) between modeled annual runoff and observed. Values above the zero line represent years where the BCMv8 model over-estimated runoff and values below the zero line represent years where the model under-estimated runoff.

Anthropogenic Recharge

The Ramboll (2025) model applies incidental recharge resulting from anthropogenic sources including: water distribution leakage, irrigation return flow, leakage from the Los Angeles Aqueduct, periodic releases from the Los Angeles Aqueduct and percolation from wastewater treatment ponds. My previous report (McKenna, 2025) demonstrated that most of those sources should not be used in calculating a water budget. Below I address the sources not previously addressed.

Releases from the LA Aqueduct

Although I addressed leakage from the LA Aqueduct, I did not address the rare intentional releases from the Aqueduct included in Ramboll (2025). It is unknown whether future releases will occur or how large they may be. Moreover, if the released water is able to infiltrate below the root zone of vegetation, it may take decades to reach the water table.

Percolation from wastewater treatment ponds

The length of time for any leakage from wastewater treatment ponds to infiltrate to the deep aquifers is expected to be similar, or even longer in the case of a thick confining layer, to that of the irrigation return flow infiltration discussed in my prior report and likewise should not be included in present-day water budget accounting. Furthermore, Ramboll (2025) includes the percolation from wastewater treatment ponds because Todd (2014) estimated that 630 AFY from the ponds "was *available* for recharge" (emphasis added). However, in the same paragraph Todd (2014) emphasizes that the water available for recharge does not become recharge: "*Because of the thick clay layers separating the shallow aquifer from the principal aquifer between the WWTP and China Lake playa, essentially none of the percolated water contributes to the yield of the principal aquifer.*" (Todd, 2014). **There is no basis to include contribution from the wastewater treatment plant ponds in the IWV's water budget.**

Natural Discharge

The principle of mass balance dictates that under predevelopment conditions (i.e., before pumping), the natural discharge in IWV must have been equal to the long-term natural recharge. Ramboll (2025) estimates this rate of long-term natural recharge to be 10,740 AFY, based on BCM outputs from 1986-2023. For the long-term natural recharge rate to have been 10,740 AFY, there must have also been a natural mechanism in place to allow for groundwater discharge of 10,740 AFY. There is wide agreement that the vast majority of natural discharge in IWV occurs through ET by phreatophytic plants and bare soil in the area of China Lake (Brown and Caldwell, 2009; Tonkin, 2025), although a small portion of the natural recharge may leave the basin as interbasin flow into the adjoining Salt Wells Valley (Kunkel and Chase, 1969; Rybarski and Bacon, 2025). Ramboll (2025) generally agrees that natural discharge occurs in the area of the playa.

Ramboll (2025) acknowledges that the shallow water table in the China Lake area enables a high rate of ET, because groundwater is readily accessible to the local vegetation. This is consistent with numerous studies that demonstrate phreatophyte zones act as a significant mechanism for groundwater discharge in arid environments and are commonly simulated as such in groundwater models (Brown and Caldwell, 2009; Halford and Jackson, 2020; Huntington et al., 2022).

Ramboll (2025) attempts to assess present day ET rates from the China Lake area using the OpenET (https://etdata.org) dataset for the January 2019 to July 2024 time period. OpenET is most appropriately used to estimate ET over cropland, and shows the highest variability and error over natural ecosystems, such as shrublands and grasslands in desert and semi-arid steppe climates (Volk et al., 2024). Additionally, the results presented in Figure 4-7 (Ramboll, 2025) appear to be results for a single point within the phreatophyte ET zone. It is not apparent why this point was selected, or whether it could be considered representative of an average value within the ET zone. Ramboll's analysis produced ET rates that varied on an annual basis between 800 and 7,000 AFY, based on a range of OpenET derived rates of 0.04 to 1.32 inches per month. These ET rates appear unsupported because even assuming the minimum observed ET rate (0.04 inches per month) is applied every month to the entire ET area defined in the Ramboll model (26,520 acres), the minimum annual ET rate would be 1,060 AFY, not 800 AFY. **In short, Ramboll (2025) applies an inappropriate data source to estimate ET, and then appears to misinterpret the results.**

Finally, Ramboll (2025) and Parker (2025) fail to make any attempt to describe the nature of groundwater discharge prior to development of the IWV basin. If the total long-term average natural recharge entering the basin is equal to 10,740 AFY, then the total discharge under natural conditions must also be equal to 10,740 AFY. The Ramboll model has a maximum natural discharge rate of 2,980 AFY but does not include a mechanism for natural discharge of the remaining 7,760 AFY. This shows the model **has either grossly underestimated and misrepresented the potential for phreatophyte and bare soil ET, or the estimate of natural recharge from the BCM is an overestimate – or both.**

Tonkin (2025) suggests that the groundwater discharge through phreatophyte ET in the China Lake area may originate from a perched shallow hydrogeologic zone, disconnected from and overlying the regional aquifer. This conceptual model relies on the presence of a lacustrine clay layer impeding flow between the deep and shallow aquifer zones. In this scenario, Tonkin (2025) suggests that ET may not need to be accounted for in a present-day water budget as this shallow aquifer zone water would be derived largely from precipitation, wastewater discharges, and runoff. However, Tonkin (2025) also recognizes that under predevelopment conditions, deep groundwater must have discharged into the China Lake area. These assessments are contradictory. If regional deep groundwater discharged as ET in the China Lake playa area under predevelopment conditions, then there must have been a pathway for this water to reach the surface. **The conceptual model of a shallow aquifer zone that is completely disconnected from deeper regional groundwater in the area of phreatophyte and bare soil ET is incompatible with predevelopment discharge from the basin.**

RAMBOLL 2025 NUMERICAL MODEL

The Ramboll 2025 Model is critically flawed in two ways: 1) the steady-state period used to define the initial condition of the model is not representative of long-term conditions; and 2) the boundary conditions allowing for natural points of discharge are inappropriately defined. Both of these flaws act to artificially store groundwater within the model domain than would otherwise be possible given the assigned recharge and discharge rates and aquifer properties assigned to the model. **As a consequence, the Ramboll 2025 Model, including the applied recharge rates and calibrated storage properties of the aquifer used to estimate Safe Yield, is not reliable.** The specific implications of each of these flaws and rationale behind this conclusion are described in the remainder of this section.

Best practice in groundwater modeling is to address two periods: a steady-state period followed by a transient period. The steady-state period represents equilibrium conditions where inflow equals outflow and there is no change in storage. Standard practice is to use the output of the steady-state model as the initial conditions (i.e., the starting water levels) for the transient period (e.g., Anderson, et al., 2015). The transient period simulates changes to that equilibrium caused by change in the applied inflows (e.g., recharge) or outflows (e.g., pumping).

Groundwater models, like real-life aquifers, follow the principle of mass balance, which states that inflows must be equal to outflows, plus or minus any change in storage. Best practices call for defining the boundary conditions, mainly recharge and discharge, for the steady-state model based on long-term average, predevelopment conditions (i.e., prior to the beginning of pumping). Bredehoeft (2002) states this very succinctly: "*The initial head [water level] is a solution to an initial boundary value problem that includes the recharge and discharge*". In other words, the observed water levels in a basin in an equilibrium state are due to the recharge and discharge rates defining that equilibrium. To be able to calibrate a steady-state model to the initial head values, those heads need to be stationary (constant) and representative of the long-term basin recharge and discharge as they will be in a basin prior to any development.

Using predevelopment conditions best allows for a reasonable approximation of true equilibrium conditions. If the available data describing water levels or flows prior to development are not sufficient to allow model calibration, the preferred approach is for the modeler to use historical water level data that most closely represent predevelopment conditions to calibrate the steady-state model. As Reilly and Harbaugh (2004) states: "if the system is not at a period of equilibrium or approximate equilibrium during the periods of interest, then a transient analysis is required." In other words, if a groundwater basin is not at equilibrium for a given period of time, then that period is not an appropriate steady-state period.

The initial conditions of the Ramboll model are defined by a steady-state model intended to represent the average conditions over the 1980-1985 period. This steady-state period is flawed for three reasons:

First, it is very short. Longer observation periods allow a more reliable calibration because they are able to better smooth out perturbations in the measurements caused by any transient recharge or discharge (e.g., pumping events) during the period of intended steady-state conditions.

Second, the timeframe represents one of the wettest periods on record in Indian Wells Valley, the result of which can be seen in the anomalously high natural recharge rate applied to the steady-state stress period (17,891 AFY) in the Ramboll model compared to the average annual recharge rate applied to the transient period of the model for the years 1986-2023 (10,740 AFY).

The period 1980-1985 includes four of the seven highest precipitation volumes in the 120-year record. Figure 8 shows the annual volume of precipitation received in IWV Basin and Rose Valley Basin over a 120-year period (PRISM group, 2017). These volumes are calculated for the areas of the basins that receive more than 8 inches of precipitation each water year. Precipitation data was applied to those areas to calculate total precipitation volume in the combined Rose and IWV basins (Figure 8). The long-term average precipitation volume for the combined basin is 225,740 AFY. The average precipitation volume during the 1980-1985 steady-state period used in the Ramboll (2025) model is approximately 360,000 AFY – 60% higher than the long-term average.

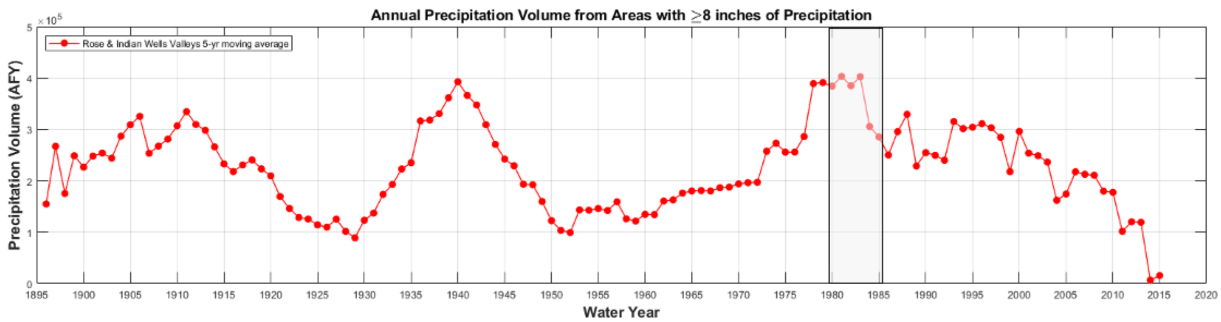

Figure 8. 120-year record of precipitation volume for areas receiving greater than 8 inches of precipitation in each year. The 1980-1985 simulation period for the Ramboll steady-state model is highlighted in grey. Data are shown as a five-year moving average.

Third, it was a period of unusually heavy pumping. The period 1980-1985 includes several years where nearly 30,000 AFY or more were pumped out of the basin, the years with the highest recorded pumping on record (see Figure 4-5, Rybarski and Bacon, 2025; Figure 4-5, Ramboll, 2025). Because inflows and outflows in a steady-state model must be equal, Ramboll (2025) had to cut the recorded total pumping volume by approximately 40 percent (28,000 to 20,000 AFY) "*to achieve a better steady-state water balance*" (Section 5.4.3, Ramboll, 2025). In other words, the modelers were forced to reduce the simulated pumping rate by 40% relative to what had been recorded in the IWV basin to be able to run the model.

Discharge Boundary Condition

The principle of mass balance dictates that because Ramboll (2025) estimated the long-term average recharge in the IWV to be 10,740 AFY, the total discharge under natural conditions must also be equal to 10,740 AFY. The Ramboll model artificially caps the rate of natural discharge at 2,980 AFY. As a result, it is not possible to run the model under predevelopment conditions. This is because without the simulated pumping, it is not possible for the simulated outflows to equal the simulated inflows.

Ramboll (2025) has accounted for a maximum simulated natural discharge rate of 2,980 AFY in the development of the steady-state model. The Ramboll model simulates this discharge via ET using a head-dependent boundary where the rate of outflow is determined by the simulated water levels of the model in areas where ET discharge is allowed. When water levels increase, the outflow increases up to the defined maximum rate, and when water levels decrease, outflow decreases and eventually stops.

It is standard practice to calibrate a groundwater model both to observed water levels *and* to observed or estimated flows through head-dependent boundaries. In a properly configured model, the boundary conditions simulating natural discharge should be capable of simulating the predevelopment discharge rate.

The limit on discharge to a maximum of 2,980 AFY in the Ramboll model creates a situation where simulated groundwater levels are higher than the land surface in the ET zone for the duration (1980-2023) of the Ramboll model. This would create flowing springs in many parts of the basin. Ramboll (2025) does not address this issue. The locations and amount of water that would be flowing out of the ground can be simulated by modifying the Ramboll model to add drains. The result of adding drains is that that the Ramboll model shows significant 'flooding' in the China Lake area for the entire simulated period (1980-2023), meaning that simulated water levels are above land surface elevation. The flooded cells for the steady-state period are shown in Figure 9. Within the context of the Ramboll model, this flooded area is essentially simulated as a pressurized section of the aquifer that has the consequence of raising water levels in the flooded areas of Figure 9 by approximately 20 feet. In reality, and in a model employing appropriate boundary conditions, this water would be expected to discharge to the surface through ET.

In summary, the boundary conditions simulating natural discharge in the Ramboll model are not consistent with best practices or observed processes. The limited ability for the model to discharge water along with the assigned recharge rates and aquifer properties artificially raise simulated water levels. These areas of increased water levels are retaining groundwater within the IWV basin in the model that should be discharged as ET in the China Lake playa area.

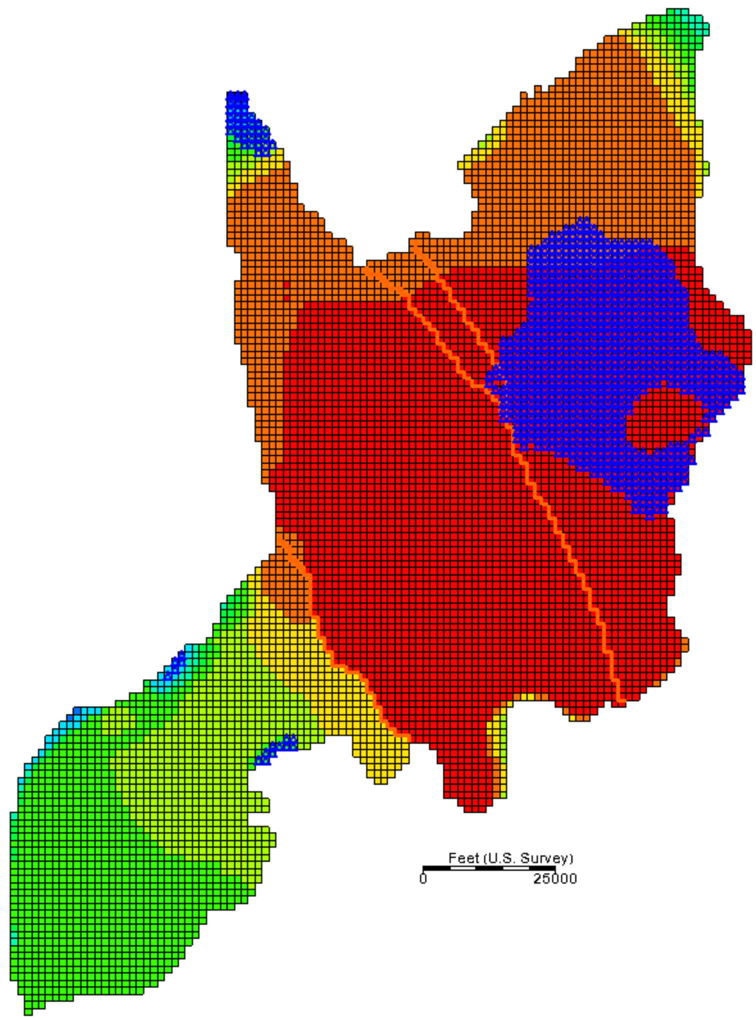

Figure 9. Ramboll 2025 Model showing flooded cells (blue) at the end of the steady-state period.

Modeling scenarios using Ramboll Model

In order to examine the impacts of the inappropriate choice of steady-state period, and the inappropriate simulation of natural discharge from the basin, three tests were performed using the Ramboll model with certain modifications explained below. The results of these tests demonstrate that:

1) Under predevelopment conditions (i.e., before pumping), the Ramboll 2025 Model produces a large perennial lake in the China Lake area. A perennial lake was never

observed in this area. **This result shows that either Ramboll's estimated long-term average recharge is too high, the Ramboll simulated ET is too low, or both.**

2) The inappropriate use of an anomalous wet-period recharge rate in the steady-state model results in simulated water levels several hundred feet higher than what would be simulated if the steady-state model were correctly designed using long-term average recharge rates. **This result shows that the calibrated hydraulic conductivity values in the Ramboll 2025 model are too high.**
3) Correction of hydraulic conductivity values will require changes in specific yield values in order to simulate observed water levels in the basin. **This means that any estimates of Safe Yield supported by the Ramboll 2025 model results are unreliable.**

An explanation of the development of the models used in these tests, and the interpretation of the results, is presented in the following sections. The three models are referred to as:

1) The <u>China Lake Water-Balance Simulation</u> – this simulation represents predevelopment (i.e. before pumping) conditions using the Ramboll model to the extent possible and investigates the volume of water discharging to the surface in the China Lake area.
2) The <u>Transient Wet Period Simulation</u> – this simulation compares the results from two modified versions of the Ramboll model – one using the original Ramboll model, but with drains applied to ET zone, and one simulating the 1921-1985 period as transient, using the Ramboll model domain. The results demonstrate the impact of using an abnormally wet period for the steady-state model.
3) The <u>Equilibrium Time Simulation</u> – this simulation was run for 3,000 years to test the length of time required for water levels in the IWV basin to reach equilibrium using the recharge applied in the Ramboll steady-state model.

China Lake Water-Balance Simulation

This test involved the use of a numerical model derived from the Ramboll steady-state model, and an analytical model used to interpret the results. First, a steady-state model was generated to represent long-term average predevelopment conditions according to the Ramboll (2025) conceptual flow budget. The intent of this model, which will be referred to as the <u>China Lake Water-Balance Simulation,</u> was to assess the amount of simulated groundwater discharge in the China Lake area that is not able to be discharged by the ET zone in the Ramboll model. The model domain and aquifer properties were identical to those used in the Ramboll model. The model was assigned a total recharge rate of 10,740

AFY based on the long-term average recharge rate used in the Ramboll model (Ramboll, 2025; Table 4-1), using the inflow boundaries defined in Ramboll (2025) such that the long-term spatial distribution of recharge defined by the original Ramboll model was retained. Because the ET zone in the Ramboll 2025 Model is not capable of discharging 10,740 AFY, it was necessary to apply an additional discharge zone in order to run the model, as discussed in Tonkin (2025, page 4-12). To perform a similar assessment, both Tonkin (2025) and Bedekar (2025) applied drains to every cell in the top layer of the Ramboll model. These drains allow for water to discharge from the basin anywhere the simulated water level exceeds the land surface elevation. Essentially, the drains simulate groundwater outflow to the surface through springs or seeps. For the China Lake Water-Balance Simulation, the drains used in Tonkin (2025) were only applied to the model east of the Little Lake Fault Zone (Figure 10), because this is conceptually where groundwater is expected to discharge. This model resulted in 9104.67 AFY of discharge through the drains for the predevelopment period.

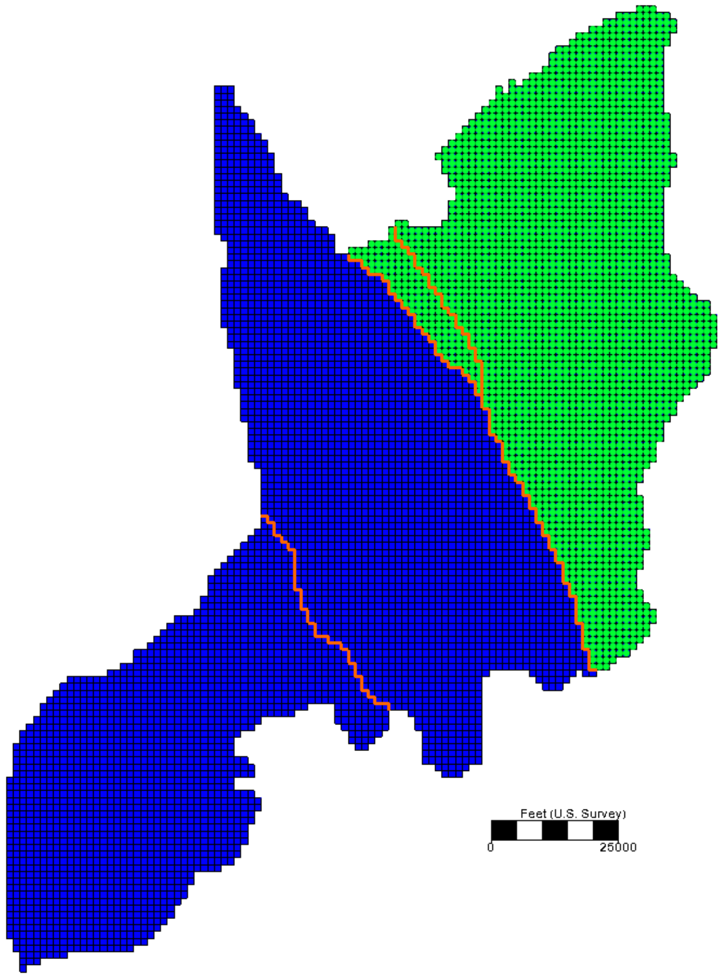

Figure 10. Location of drains applied to the Ramboll 2025 Model for use in three modeling assessments. Drains are shown in green, and simulated faults are shown as orange lines.

The water leaving the model through the drains arrives at the ground surface essentially as a modeled "desert spring." This amount of discharge from the drains has the potential to create a lake in the playa area. Therefore, a monthly lake water-balance analysis that accounts for open-water evaporation was also needed to assess the reasonableness of the volume of groundwater drain discharge ("spring discharge") from the Ramboll model. The goal of the analysis is to determine if the amount of drain discharge is sufficient to support a perennial China Lake, which has not been historically observed.

The standard approach of calculating the water budget of a water body was used, where Inflow = Outflow + Change in Storage (e.g., LaBaugh et al., 1997). This approach excludes precipitation falling on the water body itself and thus produces lower lake levels than one would expect to see in the real world. The datasets used to calculate the water budget for simulated lake level and depth included:

1. **Inflow to China Lake from Drains:** The China Lake Water Balance Simulation (described above) that simulates average long-term natural recharge based on the Ramboll groundwater model results in drains discharging 9,104.67 AFY. This discharge volume is used as annual inflow to the China Lake area. Annual values were evenly distributed as monthly values of 758.7225 AF.

2. **Inflow to China Lake from Runoff:** Mean monthly runoff from BCMv8, reduced by 15%, because this fraction was already applied as recharge in the groundwater model, is a second source of water. The Ramboll model recharge areas that drain directly into the China Lake playa were used, including: northern Sierra Nevada, southern Sierra Nevada, Volcanics, Argus Range, and El Paso. Runoff from Rose Valley was not included because Ramboll (2025) did not use BCMv8 derived recharge for Rose Valley. Runoff from all of the Coso Range and half of the Argus Range was not included because both of those recharge areas directly drain into the Airport Lake basin, and therefore are hydrologically disconnected from the China Lake basin (Figure 6).

3. **Outflow from Evaporation:** Mean monthly open-water evaporation was calculated based on the Priestly-Taylor (1972) analytical solution. A simple method used to derive extraterrestrial solar radiation on a water body is from Allen et al. (1998). Coordinates of 35.7144°N, 117.6319°W and elevation of 2155.5 ft (657 m) were used for the centroid of China Lake playa. PRISM 800-meter historical climate data of mean monthly temperature for the period WY1986-2023 was applied based on the coordinates. The hypsometry of the basin was defined based on 10-meter digital elevation model (DEM). Hypsometry describes how a lake basin's surface area changes with elevation, which is essential for translating water-level changes into corresponding changes in lake area and volume in lake water-balance modeling. An average annual open-water evaporation rate of 8.9 ft/yr (2.7 m/yr) for China Lake was calculated for the period WY1986-2023. This is a reasonable result given the arid climate, as well as shallow depths and warm water temperatures for a simulated lake in Indian Wells Valley. For comparison, the much deeper and cooler water temperatures of Lake Mead in an arid climate on the Colorado River typically has a measured average annual open-water evaporation rate of 6.2 ft/yr (1.9 m/yr) (Earp and Moreo, 2021).

The lake water-balance analysis shows that under predevelopment conditions, the groundwater drains ("spring discharge") from the Ramboll model supports a perennial China Lake with a steady-state maximum yearly depth of around 2.1 feet (Figure 11) and corresponding area of 2.5-square miles. However, if BCMv8 runoff is also included in the water-balance analysis, a yearly maximum depth of around 3.2 feet is achieved (Figure 11). The inclusion of runoff produces an extreme upper bound (i.e., maximum) water level because most runoff in Indian Wells Valley is lost to evaporation within dry channels and rarely makes it to the playa. The relatively high evaporation rate used in the China Lake simulation produced a minimum annual lake depth of 1 ft (Figure 11), prior to the development of the basin.

Having a sustained lake present under steady-state conditions is not consistent with reality. There has not been documentation of a sustained lake in Indian Wells Valley over the past 1,000 years (e.g., Lee, 1913; Rosenthal et al., 2017). Instead, there have only been ephemeral (short lived) playa lakes in the valley during the past 125 years that have formed following extremely wet years (St. Amand, 1986) or rare flooding events associated with remnants of landfalling hurricanes. These ephemeral lakes, rare in occurrence, typically form during the winter/spring months and completely dry up and disappear during the summer months when evaporation is the highest.

The water-balance analysis shows the Ramboll (2025) model does not produce an accurate representation of predevelopment conditions in Indian Wells Valley. The groundwater model grossly overestimates groundwater conditions to the point that the model supports the existence of a perennial lake covering 2.5 square miles. For reference, this lake is roughly three times larger than the entire area of Disneyland Resort in southern California. The primary reason the Ramboll (2025) model sustains a perennial China Lake are because there is either too little evapotranspiration (ET) occurring in the model due to poor representation of ET processes (e.g., spatial extent, rates), too much recharge being applied to the model, or both. While the lake simulation represents the predevelopment period, the errors also apply to the transient modeling period from 1986 to 2023.

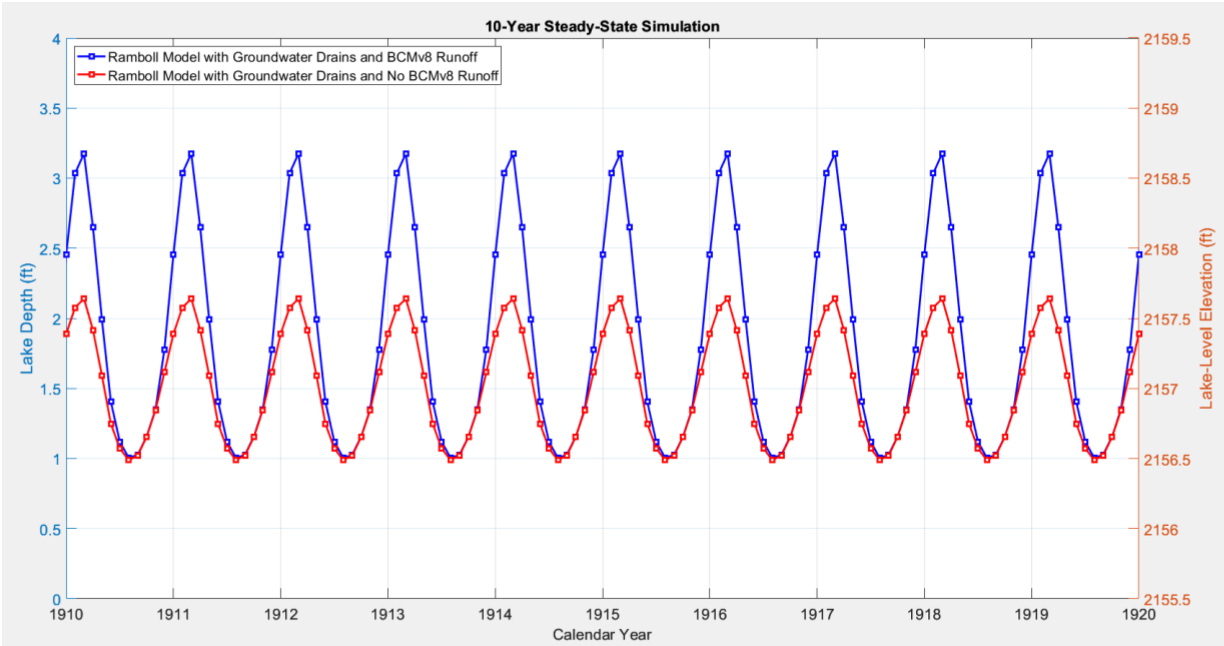

Figure 11. Plot of simulated China Lake depth and water-level elevation from 1910–1920 at monthly time steps (dots on lines). Lake-level oscillations represent a 10-year steady-state simulation under predevelopment conditions using the Ramboll (2025) groundwater model with no groundwater pumping. Two lake-levels are shown that are based on the amount of water collected in the lake bottom from either drain discharge ("springs") and BCMv8 model runoff or only drain discharge.

Transient Wet Period Simulation

The steady-state period in the Ramboll model inappropriately uses recharge rates from an abnormally wet period (1980-1985). These high recharge rates required estimated pumping for this period to be reduced by 40% during model calibration, because estimated pumping rates during this period greatly exceeded this abnormally large, estimated recharge. Ramboll (2025) asserts that the steady-state model design is acceptable given its ability to reasonably match observed water levels measured between 1980-1985. Bedekar (2025) agrees that this configuration is acceptable, because the purpose of the steady-state period is to establish initial water levels. However, both Ramboll (2025) and Bedekar (2025) fail to consider the implications of assigning above-average recharge rates to a steady-state model, both in terms of the impact it will have on water levels in the model and on the resultant calibrated aquifer properties.

Steady-state water levels represent a basin in equilibrium conditions, where there are no fluctuations in water levels, outflows equal inflows, and there is no change in storage. Effectively, simulated water levels derived from a steady-state model represent basin conditions after infinite time. Recharge rates for the Ramboll steady-state period were derived from the average of the years 1980-1985 – a six-year period with abnormally high precipitation. In reality, and in groundwater modeling, applying an increased recharge rate will result in a gradual increase in water levels. Water levels will continue to increase as long as the recharge rate is elevated, until a new equilibrium water level is reached. In a steady-state model, there is no time dimension and the equilibrium water level is defined immediately. However, the very wet period in IWV lasted only six years. Therefore, the use of the steady-state period, defined by the average of six wet years, can only be considered appropriate if water levels in the basin would be able to equilibrate to the elevated recharge rate after six years. Otherwise, the initial conditions for the transient model taken from the steady-state model will be a misrepresentation of the expected water levels given the long-term applied average recharge and the assigned aquifer properties (i.e., hydraulic conductivity and storage properties).

The Transient Wet Period Simulation tests this idea by initializing the Ramboll transient model with the long-term average recharge rate (10,740 AFY) rather than the elevated wet period recharge rate used in Ramboll's steady-state model. The model begins prior to 1921 and is then allowed to run into the future through 1985 and represents the 1980-1985 wet period as an actual six-year period with increased recharge.

For this model, the results of the China Lake Water-Balance Simulation were assumed to represent basin conditions prior to 1920. Because Ramboll (2025) did not estimate pumping rates prior to 1980, it was necessary to use pumping rates derived for the 2025 GSP Model (Rybarski and Bacon, 2025). For the WY 1921-1980 time period, natural recharge rates were simulated using a long-term natural recharge rate of 10,740 AFY from Ramboll (2025, Table 4-1). Natural recharge includes both mountain front recharge and recharge from runoff. Beginning in 1980, natural recharge rates were assigned according to those used in the Ramboll model (Figure 12, top). Anthropogenic recharge was applied at the rates defined in the steady-state (1980-1985) Ramboll model, and was extrapolated backwards where appropriate to cover the time prior to the beginning of the Ramboll 2025 Model (Figure 12, bottom).

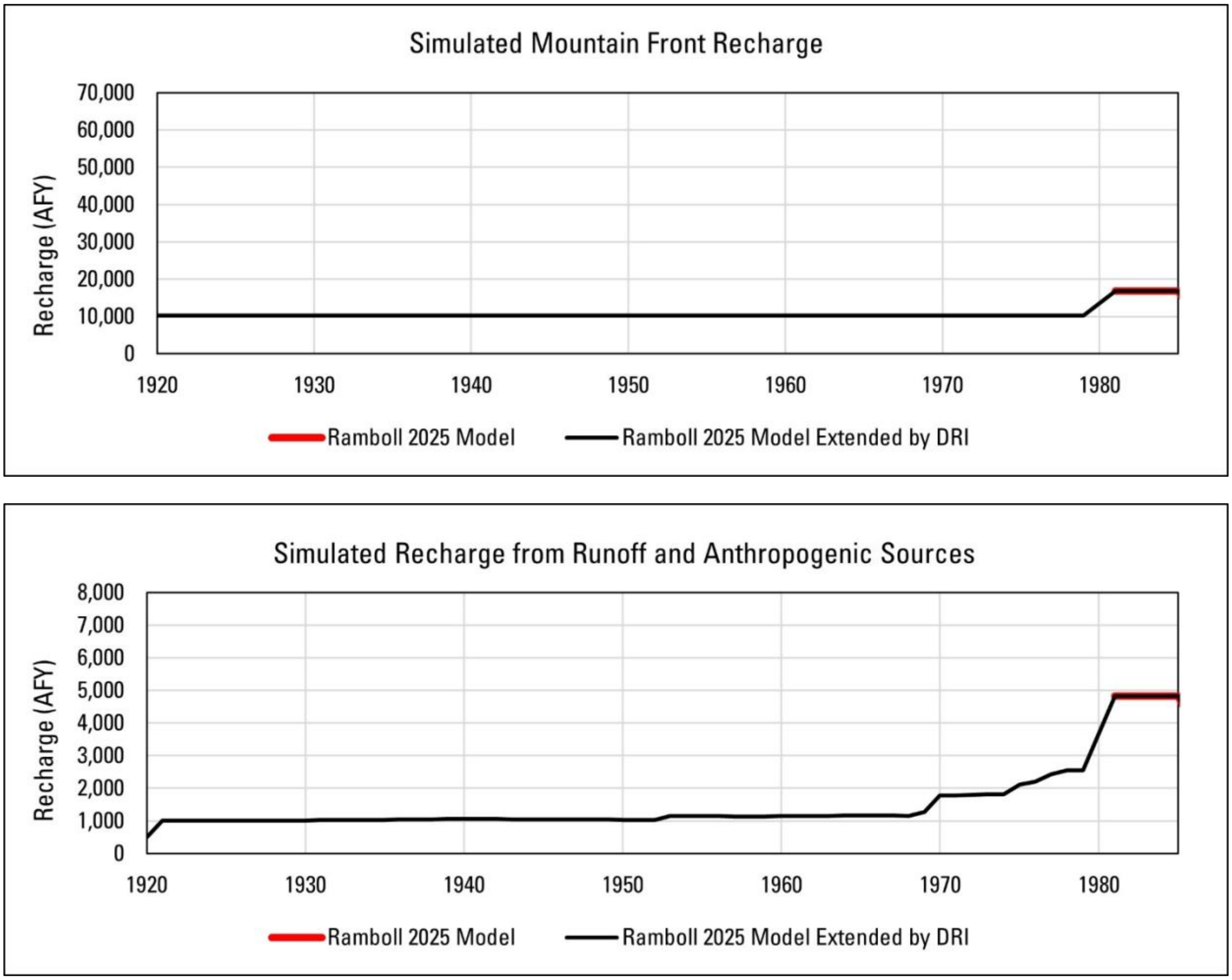

Figure 12. Simulated rates of mountain front recharge (top) and recharge from runoff and anthropogenic sources (bottom) in the Transient Wet Period Simulation compared to the Ramboll Model.

A second version of the Ramboll model was created for comparison with the Transient Wet Period Simulation. Since the Transient Wet Period Simulation began with a steady-state stress period representing predevelopment conditions, it was necessary to apply drains to the area east of the Little Lake Fault to close the water balance as was also done in the China Lake Water Balance Simulation. Therefore, to create a fair comparison, the original Ramboll 2025 model was also run with drains applied east of the Little Lake Fault. In this way, any differences in water levels between the two models at the end of 1985 would be attributable to the inappropriate steady-state period only.

If the wet period (1980-1985) recharge rate presented in Ramboll (2025) were appropriate, by the end of 1985 in the Transient Wet Period Simulation I would expect to see simulated water levels near or equal to the level of the steady-state period in the original steady-state Ramboll model. Simulated water levels at the end of 1985 from the original Ramboll model were subtracted from simulated water levels at the end of 1985 from the Transient Wet Period Simulation. The results are shown in Figure 13.

Results show that water levels in the IWV main basin (i.e., excluding the El Paso subarea) are generally higher in the Transient Wet Period Simulation at the end of 1985 than they are in the Ramboll steady-state model. This occurs because the Ramboll model steady-state period also includes a large amount of pumping, even though it is reduced to be only 60% of what Ramboll (2025) estimated for pumping in this period. This pumping, like the recharge, is effectively simulated for infinite time. In contrast, the Transient Wet Period Simulation simulates pumping using the full estimated pumping rates for each of the years 1980-1985. The biggest difference between the two simulations occurs in the El Paso subarea, where water levels are between 200 and 300 feet lower in the Transient Wet Period Simulation than in the Ramboll steady state model at the end of 1985. Effectively, through the use of an inappropriate steady-state recharge rate, the Ramboll 2025 Model is producing a large reservoir of water in the El Paso subarea that otherwise would not be possible given the long-term average recharge rate and the assigned aquifer properties. **This result demonstrates that the calibrated hydraulic conductivity values in the Ramboll model, especially in the El Paso subarea, are inappropriate. Furthermore, it seems likely that through the use of an inappropriate steady-state recharge rate, the Ramboll model is producing a large reservoir of water in the El Paso subarea that otherwise would not be possible given the long-term average recharge rate and the assigned aquifer properties. This reservoir serves as an additional source of inflow to the IWV main basin in the steady state and transient Ramboll models.**

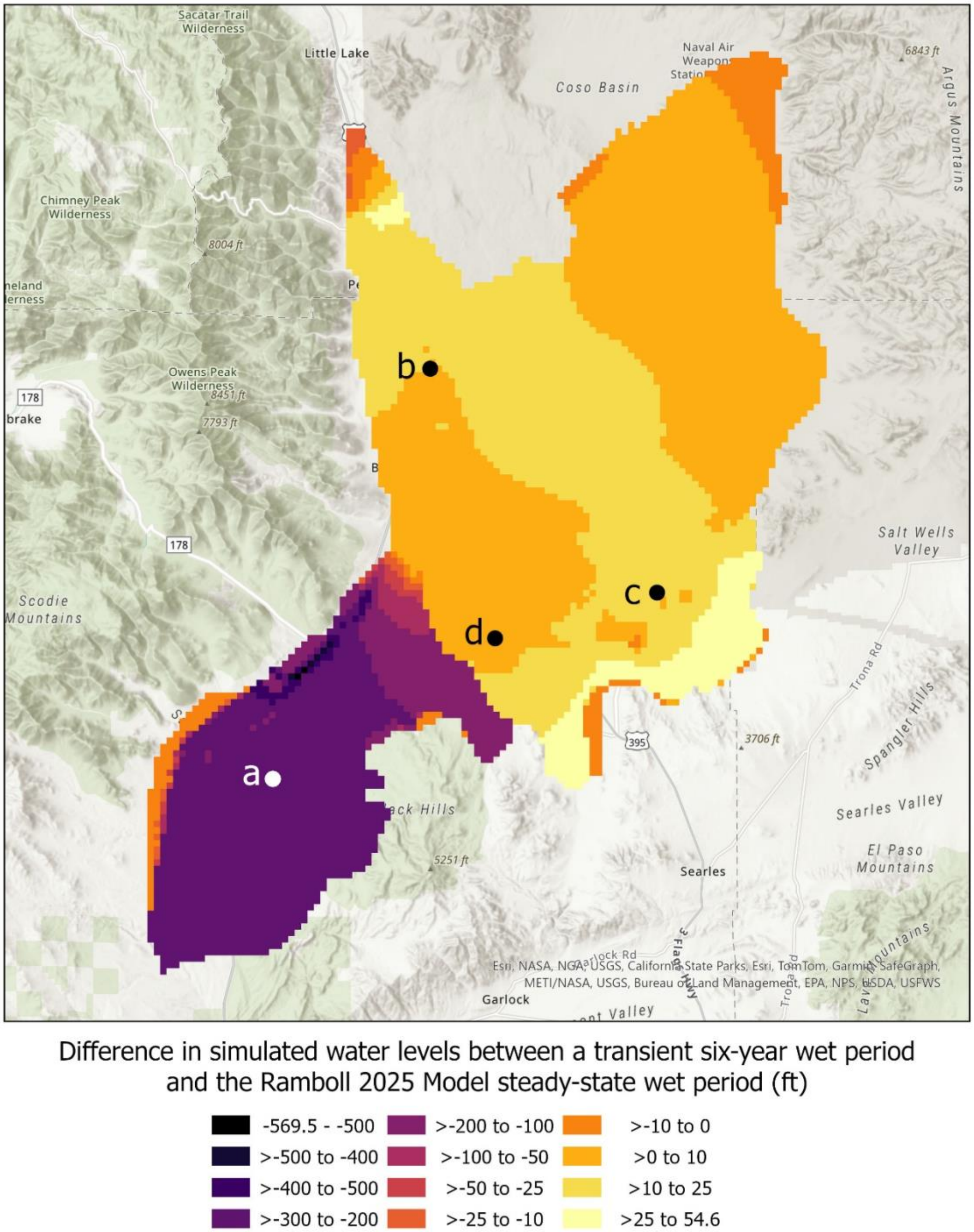

Figure 13. Difference in simulated water levels between the Transient Wet Period Simulation and the Ramboll 2025 Model, at the end of 1985. Differences are calculated as Transient Wet Period minus Steady State. Results show that the use of a wet period for the steady-state model produces several hundred feet of groundwater in the El Paso subarea that otherwise would not be possible given the simulated aquifer properties.

Equilibrium Time Simulation

To better understand the results of the Transient Wet Period Simulation, a third model was developed to assess the length of time required for water levels in the IWV basin to equilibrate to those resulting from the elevated recharge simulated in the steady-state period of the Ramboll model. This model will be referred to as the Equilibrium Time Model. Again, this model used the steady-state results of the China Lake Water-Balance Simulation (see above) as the initial condition, with a long-term average recharge rate of 10,740 AFY. The recharge rate was then set to the Ramboll-defined wet period (1980-1985) natural recharge rate of 17,891 AFY, 167% of the long-term Ramboll model average recharge, and the model was run forward for 3,000 years. To assess the time required for basin water levels to equilibrate solely to the elevated recharge, no pumping or anthropogenic sources of recharge were simulated.

The Equilibrium Time Model is initialized with a long-term steady-state recharge rate of 10,740 AFY, as used in the Ramboll transient period model. First, the model solves for the steady-state equilibrium water levels given that recharge rate. Then, the recharge rate is increased to 17,891 AFY, the value used in the Ramboll steady-state model. The results of the model show the gradual increase in water levels over time caused by the increased recharge rate (Figure 14). Different locations in the model domain respond at different rates (Figure 14), but in general, there is very little change in water levels after six years of increased recharge. Although water levels continue to increase over time, they still have not reached equilibrium after hundreds of years and in the case of the El Paso sub-area they have still not reached equilibrium after thousands of years. These results are consistent with previous work in large basins, that showed the time to reach a new equilibrium after a large change can be thousands of years (Bredehoeft and Durbin, 2009).

This shows that, while the Ramboll model is able to reasonably match observed water levels in the steady-state period, it is only able to do so by simulating a condition that did not happen – that is, the model simulates a long-term recharge rate of 17,891 AFY at an assumed equilibrium state for effectively infinite time, even though the wet period it is based on lasted only 6 years. **This means that the aquifer properties in the model were calibrated to an unrealistic condition, the steady state model does not provide representative initial conditions for the steady state model, and the model is therefore not representative of conditions in the basin. As a consequence, it cannot be used to support an assessment of Safe Yield.**

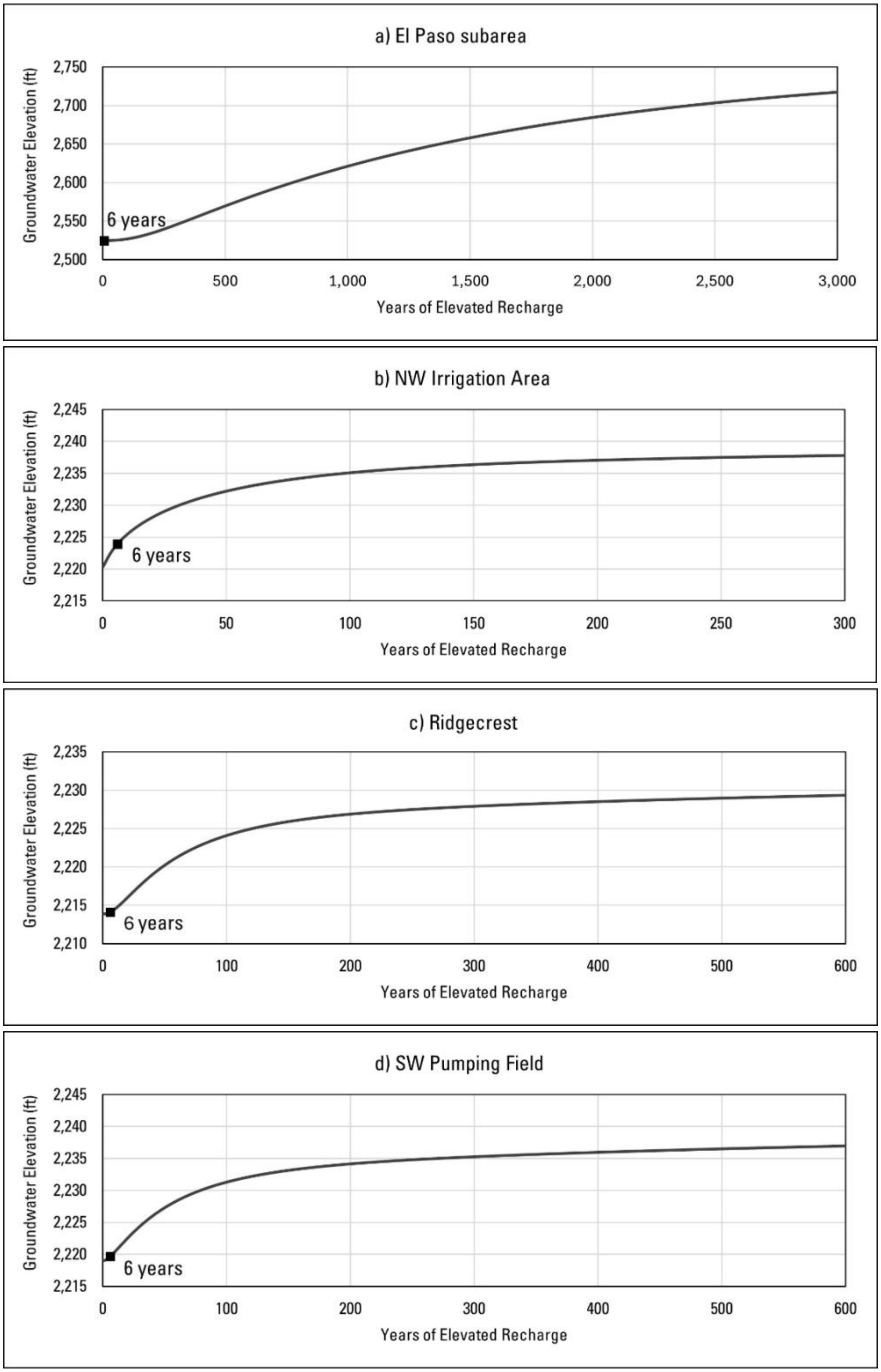

Figure 14. Hydrographs of four locations in the Equilibrium Time Model. Results show that water levels would take decades to over thousands of years to equilibrate to the wet period recharge rates used in the Ramboll 2025 model steady-state period.

ESTIMATES OF SAFE YIELD & TOTAL BASIN STORAGE

For the purposes of adjudication, Safe Yield has been defined as "*the maximum quantity of water which can be withdrawn annually via pumping from a groundwater basin as a whole based on long-term conditions in the basin without causing an undesirable result. Undesirable result is the gradual lowering of the groundwater level resulting eventually in depletion of a supply intended to last perpetually*" (Highberger, 2024). **By definition, Safe Yield cannot be larger than the total amount of recharge that a basin receives from all sources, because discharging more water than is recharged will result in declining water levels.**

Estimates of Safe Yield

Recent estimates of Safe Yield in the IWV are presented in Table 7. These estimates of Safe Yield were calculated as the difference between annual pumping and the annual change in storage. This method works on the principle of mass balance, where inflows must be equal to outflows, plus or minus any change in storage. Therefore, if pumping is greater than the change in storage, the difference must be equal to the recharge. For each of the estimates in Table 7, change in storage was calculated using the Thiessen polygon method. The source of the Sy values used in each study is also given in Table 7. The Theissen polygon method calculates change in storage for a given period based on observed change in water levels and estimated Sy (Parker, 2025; Tonkin, 2025; Bedeker, 2025; Teasdale, 2025). **This means that the estimated change in storage, and therefore the estimated Safe Yield, is very sensitive to the estimated value of Sy.**

Table 7. Summary of Safe Yield estimates for the Indian Wells Valley groundwater basin.

	Safe Yield Estimate (AFY)			
Sy Source	Brown & Caldwell (2009)	Ramboll (2019)	Ramboll (2024)	Ramboll (2025)
Type of study	Numerical groundwater model	Hydrologic conceptual framework	Preliminary groundwater model	Numerical groundwater model
Parker (2025)	15,200 - 18,900	15,800	14,300	18,200
Teasdale (2025)	14,200 - 14,900	–	–	15,100 - 15,700
Tonkin (2025)	–	–	–	14,300 - 17,000

The majority of the estimates of Safe Yield in Parker (2025, Table 8-2) (summarized in Table 7) rely on estimates of Sy that are taken from calibrated groundwater models. The use of calibrated Sy values to calculate Safe Yield is problematic because the two are strongly coupled in a water balance calculation: an increase in Sy leads to a decrease in recharge if the discharge and water level change are both held constant. Given that the recharge rates are defined by the modeler, the Sy values in the model are calibrated to a pre-determined rate of recharge, meaning that the Safe Yield is also effectively pre-determined. **As a consequence, estimates of Safe Yield based on calibrated Sy values have little meaning if the rate of recharge applied to the model is unsupported.**

The estimates of Safe Yield based on Sy values from the Brown and Caldwell (2009) model, presented in Parker (2025) and Teasdale (2025), are not consistent with the Brown and Caldwell model flow budget. Brown and Caldwell, then the Water District's groundwater modelers, attempted to apply a recharge rate of 11,000 AFY but were unable to achieve a reasonable model calibration, and ultimately used a recharge rate of only 8,821 AFY, including both natural and anthropogenic sources. Parker's estimates of Safe Yield (16,200-17,000 AFY) based on the Brown and Caldwell (2009) Sy values are nearly double this amount (Table 7). These estimates of Safe Yield cannot be squared with a recharge rate of 8,821 AFY, since by definition Safe Yield cannot exceed recharge. This provides an example of the errors that can be expected when using Sy values in the Theissen polygon method to estimate change in storage. In particular, this error likely occurs because the Brown and Caldwell model appears to simulate a large amount of water stored under confined conditions. In contrast, the estimation method used in Parker (2025) and Teasdale (2025) is only appropriate for unconfined (water table) aquifers, because it relies on specific yield (CADWR, 2020), and will only provide an estimate for change in storage from the unconfined areas of IWV.

Teasdale (2025) partially addresses the problem of using model-calibrated values of Sy to calculate Safe Yield by including the higher measured values of Sy in the area of the Meadowbrook wells. However, based on Figure 2-6 in Teasdale (2025), it appears that he has misinterpreted depth-to-groundwater measurements to be groundwater elevations. This has the effect of showing measured declines in groundwater levels as increases. If these incorrect interpretations of groundwater level change were incorporated into the Teasdale (2025) estimates of Safe Yield, it would result in an overestimate of Safe Yield. It does appear that this is the case, but it is difficult to ascertain based on the limited data accompanying the Teasdale (2025) report. Nevertheless, Teasdale's estimates would still be subject to the circular logic inherent in estimating Safe Yield based on Sy values calibrated to assumed recharge, since the majority of the Sy values used in his analysis were derived from calibrated values.

Estimates of Total Basin Storage

Several estimates of the total volume of groundwater in the IWV have been made in the past year (Parker, 2025; Tonkin, 2025). These estimates vary depending on the exact calculation methods used, and on whether the estimator discounted very deep or poor-quality groundwater, which may make the water unrecoverable or unusable. All of these estimates are based on calibrated storage properties taken from groundwater models. As a result, these estimates are subject to the same deficiencies discussed above that are inherent in estimating Safe Yield from calibrated storage properties. **Therefore, the groundwater volume estimates are unreliable. However, when considering the question of Safe Yield, the total volume of groundwater held in storage is irrelevant.** If water is removed at a faster rate than it is replenished, water levels will decline regardless of the quantity of water in storage.

REFERENCES

Allen, R.G., L.S. Pereira, D. Raes, M. Smith, 1998, Crop evapotranspiration – Guidelines for computing crop water requirements, Irrigation and Drainage Paper 56, FAO – Food and Agriculture Organization of the United Nations, Rome, Italy.

Anderson, M.P., W.W. Woessner and R.J. Hunt, 2015, *Applied Groundwater Modeling: Simulation of Flow and Advective Transport, Second Edition*, Elsevier, Accessed online at: https://agualabs.edublogs.org/files/2022/02/Applied-Groundwater-Modeling-Second-Edition-Simulation-of-Flow-and-Advective-Transport-by-Mary-P.-Anderson-William-W.-Woessner-Randall-J.-Hunt-z-lib.org_.pdf

Bedekar, V., 2025, Review of the Numerical Groundwater Model Developed by Ramboll for the Indian Wells Valley (IWV) Groundwater Basin, California, SS Papadopulos & Associates.

Bredehoeft, J., 2002, The Water Budget Myth Revisited: Why Hydrogeologists Model, Ground Water, 40 (4), pp. 340-345.

Bredehoeft, J. and T. Durbin, 2009, Ground Water Development, the Time to Full Capture Problem, *Ground Water*, 47 (4), pp. 506-514.

Brown and Caldwell, 2009. Final Report: Indian Wells Valley Basin Groundwater Flow Model and Hydrogeologic Study. Prepared for Indian Wells Valley Water District, Ridgecrest, California,

CADWR, 2020, Draft Handbook for Water Budget Development, with or without Models. https://data.ca.gov/dataset/water-budget-handbook/resource/c67003b5-53b2-4f30-8772-a721ac5efbd9.

Domenico, P.A. and F.W. Schwartz, 1990, *Physical and Chemical Hydrogeology*, John Wiley and Sons, 824 pp.

Dutcher, L.C. and Moyle, W. R., 1973, Geologic and Hydrologic Features of Indian Wells Valley, California, US Geological Survey Water Supply Paper 2007.

Earp, K.J., and M.T. Moreo, 2021, Water Evaporation from Lake Mead and Lake Mohave, Nevada and Arizona, 2010–2019, US Geological Survey Open-File Report, 2021–1022, 36 p.

Flint, A.L., L.E., Flint, J.A., Hevesi, and J.B., Blainey, 2004, Fundamental concepts of recharge in the Desert Southwest—A regional modeling perspective in Hogan, J.F., Phillips, F.M., and Scanlon, B.R., eds., Groundwater recharge in a desert environment—The southwestern United States: Water Science and Appications, v. 9, p. 159–184.

Flint, L.E., and A.L., Flint, 2007, Regional analysis of ground-water recharge, chap. B *of* Stonestrom, D.A., Constantz, J., Ferré, T.P.A., and Leake, S.A., eds., Ground-water recharge in the arid and semiarid southwestern United States. US Geological Professional Paper 1703–B, p. 29–60.

Flint, L.E., A.L. Flint and M.A. Stern, 2021, The Basin Characterization Model—A Regional Water Balance Software Package, US Geological Survey Techniques and Methods 6-H1, 85 p.

Halford, K. and Jackson, T., 2020. Groundwater Characterization and Effects of Pumping in the Death Valley Regional Groundwater Flow System, Nevada and California, with Special Reference to Devil's Hole, US Geological Survey Professional Paper 1863.

Hollett, K.J, W.R. Danskin, W.F. McCaffrey and C.L. Walti, 1991, Chapter B: Geology and Water Resources of Owens Valley, California, US Geological Survey Water-Supply Paper 2370, 77 pp.

Huntington, J., Bromley, M., Minor, B., Morton, C., and Smith, G., 2022. Groundwater Discharge from Phreatophyte Vegetation, Humboldt River Basin, Nevada. DRI Publication No. 41288.

Johnson, A.I., 1967, Specific Yield – Compilation of Specific Yields for Various Materials, US Geological Survey Water Supply Paper, 1662-D.

Kunkel, F., and G.H. Chase, 1969. Geology and ground water in Indian Wells Valley, California, U.S. Geological Survey Open-File Report, 84 p.

LaBaugh, J.W., T.C. Winter, D.O. Rosenberry, P.F. Schuster, M.M., Reddy, and G.R. Aiken, 1997, Hydrological and chemical estimates of the water balance of a closed-basin lake in north central Minnesota. Water Resources Research, vol. 33, 2799–2812.

Lee, C.H., 1912, Ground Water Resources of Indian Wells Valley, California. California State Conservation Commission Report, p. 403–429.

Manger, G.E., 1963, Porosity and Bulk Density of Sedimentary Rocks, U.S. Geological Survey, Bulletin 1144-E, 55 pp.

McKenna, S.A., 2025, Expert Report in the matter of Mojave Pistachios, LLC et al., vs. Indian Wells Valley Water District, et al, 35 pp.

Monastero, F.C., J.D., Walker, A.M., Katzenstein, and A.E., Sabin, 2002, Neogene evolution of the Indian Wells Valley, east-central California. In: Glazner, A.F., Walker, J.D., Bartley, J.M. (Eds.), Geologic Evolution of the Mojave Desert and Southwestern Basin and Range: Geological Society of America Memoir 195, 199–228.

Parker, T.K., 2025, Phase 2 Report: Hydrogeological conceptual model, storage, and safe yield evaluation, Indian Wells Valley Basin, California. Intended for: McMurtrey, Hartsock, Worth & St. Lawrence, 451 pp.

Priestly, C.H.B., and R.J. Taylor, 1972, On the assessment of surface heat flux and evaporation using large-scale parameters. Monthly Weather Review 100, 81–92.

PRISM Group, 2017, Parameter-elevation Regressions on Independent Slopes Model (PRISM) 800-meter historical climate data. Oregon State University, https://prism.oregonstate.edu, purchased 1 January 2017.

Ramboll, 2019. Hydrogeologic Conceptual Framework – Indian Wells Valley, dated June. 113 pp including appendices

Ramboll, 2025, Indian Wells Valley Groundwater Flow Model Report, Intended for: McMurtrey, Hartsock, Worth & St. Lawrence, 2166 pp.

Reilly, T., and Harbaugh, A., 2004, Guidelines for Evaluating Ground-Water Flow Models, US Geological Survey Scientific Investigations Report 2004-5038, 30 p.

Rosenthal, J.S., J. Meyer, M.R. Palacios-Fest, D.C. Young, A. Ugan, B.F. Byrd, K. Goblet and J. Giacomo, 2017, Paleohydrology of China Lake basin and the context of early human occupation in the northwestern Mojave Desert, USA. Quaternary Science Reviews 176, 112–139.

Rybarski, S., and S. Bacon, 2025, Documentation of the Indian Wells Valley 2025 Basin Groundwater Model Update, prepared by Division of Hydrological Sciences, Desert Research Institute, Reno, NV, February 2025.

Shah, A.K, and O.S., Boyd, 2018, Depth to basement and thickness of unconsolidated sediments for the western United States—Initial estimates for layers of the U.S. Geological Survey National Crustal Model: U.S. Geological Survey Open-File Report 2018–1115, 13 p.

St. Amand, P., 1986, Water Supply of Indian Wells Valley, California. Naval Weapons Center Technical Publication 6404, Ridgecrest, CA.

Teasdale, E., 2025, Expert report on safe yield for Indian Wells Valley Groundwater Basin: Final Report | August 2025, Prepared by Luhdorff and Scalamini Consulting Engineers, Prepared for Fennemore, 114 pp.

Todd Engineers, 2014. Indian Wells Valley Resource Opportunity Plan – Water Availability and Conservation Report, Submitted to Kern County Planning and Community Development Department, 89p.

Tonkin, M.J., 2025, Expert Opinion Phase II Report: Evaluation of the safe yield and storage properties of the Indian Wells Valley (IWV) basin, California. Report prepared by S.S. Papadopulos & Associates, Inc.

Volk, J.M., Huntington, J.L., Melton, F.S. *et al, 2024,* Assessing the accuracy of OpenET satellite-based evapotranspiration data to support water resource and land management applications. *Nat Water* **2**, 193–205. https://doi.org/10.1038/s44221-023-00181-7