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SUPERIOR COURT OF THE STATE OF CALIFORNIA

COUNTY OF ORANGE, CIVIL COMPLEX CENTER

MOJAVE PISTACHIOS, LLC; et al.,

Plaintiffs,

v.

INDIAN WELLS VALLEY WATER DISTRICT; et al.,

Defendants.

Case No. 30-2021-01187275

NOTICE OF INDIAN WELLS VALLEY GROUNDWATER AUTHORITY'S PRODUCTION OF EXPERT REPORT

[Exempt from filing fees pursuant to Govt. Code § 6103]

Pursuant to the First Amended Case Management Order Re: Phase 2 Trial, and the parties' subsequent agreement, the Indian Wells Groundwater Authority hereby produces its expert report and reliance documents. The report and documents can be downloaded: https://app.box.com/s/rdbvqo4mx7tw62xlbvuq6oi2vadizfyr.

A copy of the report is also attached to this notice.

Dated: August 15, 2025

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EXPERT OPINION OF DR. TODD KINCAID, P.G. REGARDING THE SAFE YIELD OF THE PRINCIPAL AQUIFER IN THE INDIAN WELLS VALLEY GROUNDWATER BASIN

Mojave Pistachios, LLC; et. al. v. Indian Wells Valley Water District; et. al.
Case No. 30-2021-01187275

Issued: August 8, 2025

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Attachment 1. Compilation of Reported Pumping and Overdraft - Indian Wells Valley

Attachment 2. Model Water Budget Comparisons – IWVGB

Attachment 3. Review of Published Recharge Rates - Indian Wells Valley

1. Purpose

I was engaged in 2025 by the Richards Watson Gershon law firm (RWG) to:

- Assist RWG staff with the interpretation of hydrogeological concepts related to the Indian Wells Valley Groundwater Basin (IWVGB) in support of their work for Mojave Pistachios, LLC; et. al. v. Indian Wells Valley Water District; et. al. Case No. 30-2021-01187275;
- Review available published literature describing the hydrogeology and specifically estimations of the water budget for the IWVGB;
- Provide an opinion regarding the total magnitude of groundwater inflow to the IWVGB;
- Provide an opinion regarding the safe and sustainable yields for the IWVGB;
- Perform a cursory review of the 2025 version of the GSP groundwater flow model (GSP-GWM-2025) and the groundwater flow model independently developed by the Indian Wells Valley Water District (IWVWD-GWM);
- Provide a preliminary opinion regarding the differences between the two models;
- Provide expert testimony, if needed, regarding my efforts and opinions relating to and derived from the tasks described above.

2. Summary of Opinions

It is my opinion, to a reasonable degree of scientific certainty, and based on the available information, that:

Opinion 1. At present, the safe yield from the IWVGB will necessarily be less than the total natural recharge to the basin and is likely between 6,100 and 8,400 AFY.

Opinion 2. The most reliable method of estimating the safe yield of the principal aquifer in the IWVGB is through the use of the hydrologic equation and estimates of steady-state pre-pumping (circa 1912) total groundwater discharge and recharge in the IWVGB.

Opinion 3. The IWVGB is, for all practicable purposes, a "closed" basin, meaning that all, or very nearly all of the natural inflow to the basin is being consumed internally by some combination of ET and groundwater extraction.

Opinion 4. Total groundwater inflow to the IWVGB is between 7,200 and 9,900 AFY.

Opinion 5. Due to climate change, the present-day total recharge to the IWVGB is likely less than what it was in the early 20th century and it is likely to continue to decline in the future.

Opinion 6. Estimation and designation of safe yield should not rely on leakage from the Los Angeles Department of Water and Power (LADWP) aqueduct, irrigation returns, or discharge from the Ridgecrest / Naval Air Weapons Station (NAWS) wastewater treatment plant.

Opinion 7. The 2025 version of the GSP-GWM is a better tool for groundwater resource management in the IWVGB than the GWM independently developed by the Indian Wells Valley Water District (IWVWD).

3. History of Aquifer Depletion

3.1. Groundwater level declines

Groundwater levels in the IWVGB have been consistently declining since the start of groundwater pumping in the early 20th century (Kunkel and Chase, 1969; Dutcher and Moyle, 1973; Todd Engineers, 2014, Stetson Engineers, 2020). The following summarizes key observations that have been published over time.

- By 1965, groundwater levels in the central part of the IWVGB had declined by more than 20 feet and were dropping at a rate of more than one foot per year in the most impacted area (Kunkel and Chase, 1969).
- By 2010, Todd Engineers (2014) reported the maximum rate of groundwater level decline to be more than 1.8 feet per year spanning an approximately 2.8 square mile area southwest of Ridgecrest between Brown Road and Highway 395.
- Todd Engineers (2014) published a map showing that the 1 foot per year rate of decline had grown to cover an area of approximately 43.5 square miles on the west side of Ridgecrest from near the junction of Brown Road and Highway 395 to north of Inyokern and east into the China Lake Naval Air Weapons Station (NAWS).
- By 2015, Stetson Engineers (2020) reported that the maximum rate of groundwater level decline had increased further to between 2 and 2.5 feet per year in areas southwest of Ridgecrest and northeast of Inyokern.

3.2. Overdraft

The IWVGB was considered to be in a state of overdraft by the early to mid-20th century, Kunkel and Chase (1969) estimated that the IWVGB was over-drafted by 4,000 AFY in 1953. Brown and Caldwell (2009) estimated minor overdraft as far back as 1920. Aside, from researchers that promoted the "open basin" model for the IWVGB (discussed in Section 5.3), there has been a consensus on the facts that the IWVGB is over drafted and that the magnitude of the overdraft has been steadily increasing over time. I've provided a summary of the published estimates of overdraft along with published estimates of pumping occurring in the same years in Table 1 and Figure 1 below.

I used four of the five published overdraft values along with the corresponding pumping rates to develop an estimate of cumulative storage loss from the IWVGB occurring between 1920 and 2025 (Figure 2). My assumptions for that estimate are:

- That overdraft is linearly related to pumping rate;
- That the rate of storage loss changed linearly according to the change in reported pumping for the given period;

- That overdraft in 192o was 0 despite being reported as 301 AFY; and
- That both pumping and overdraft remained constant between 2015 and 2025.

A full accounting of pumping rates by year from 1920 to 2025 along with the estimated overdraft for those years and the estimated cumulative loss of groundwater storage is provided as Attachment 1.

Table 1. History of pumping and overdraft in the IWVGB.

Year	Total Pumping (AFY)	Overdraft (AFY)	Data Sources (Pumping/ Overdraft)	Period (Years)	Cumulative Storage Loss (acre-feet)	Rate of Change in Storage Loss (AFY/year)
1920	1,000	301	3/3	NA	0[a]	NA
1953	8,726	4,000	3/1	33	29,748	112
1985	24,739	16,515	3/2	32	283,247	391
2010	22,300	15,100	4/4	25	384,520	-57
2015	25,285	25,000	5/5	5	101,958	1,980
2025	25,285	25,000	6/6	10	250,000	0
Estimated Storage Loss over 105 Years (1920 to 2025):					*1,049,474*	
Average Rate of Increased Storage Loss (AFY per year):						*485*

Sources:
1) Kunkel and Chase (1969)
2) Average of values reported by Bean (1989) and Berenbrock & Martin (1991)
3) Brown and Caldwell (2009)
4) Todd Engineers (2014)
5) Stetson Engineers (2020)
6) Assume 2015 rate remained constant

Notes:
a) Assume no storage loss despite reported value

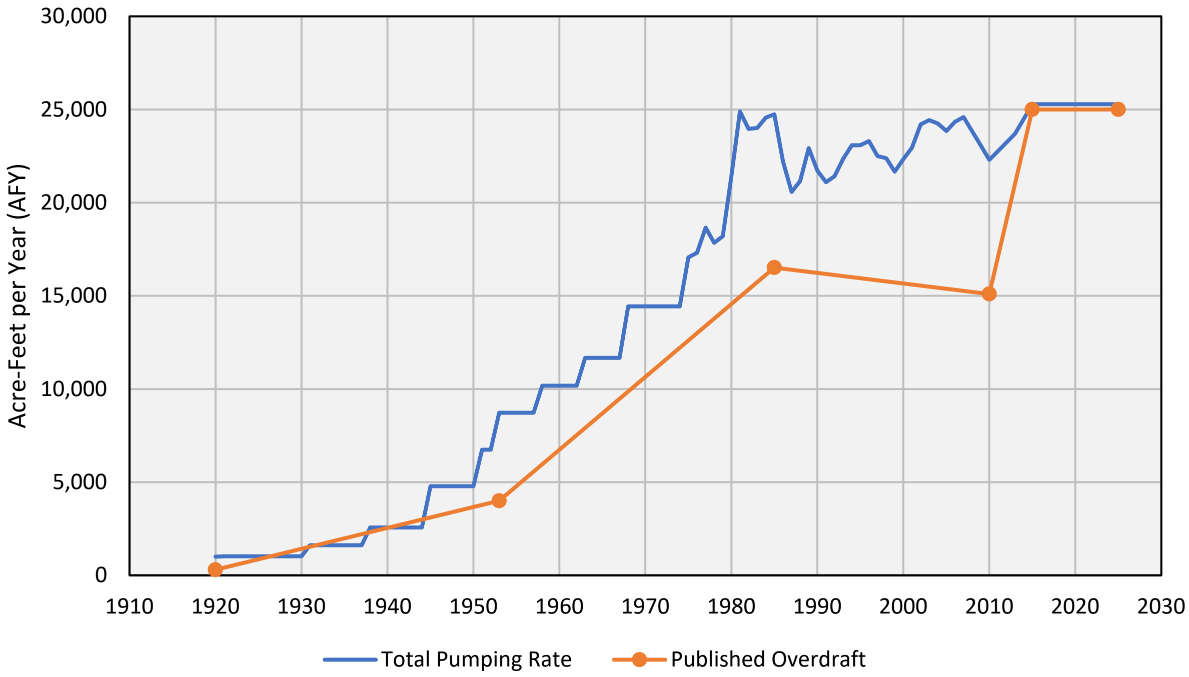

Figure 1. Reported pumping rates and estimated overdraft in a given year for the IWVGB between 1920 and 2025.

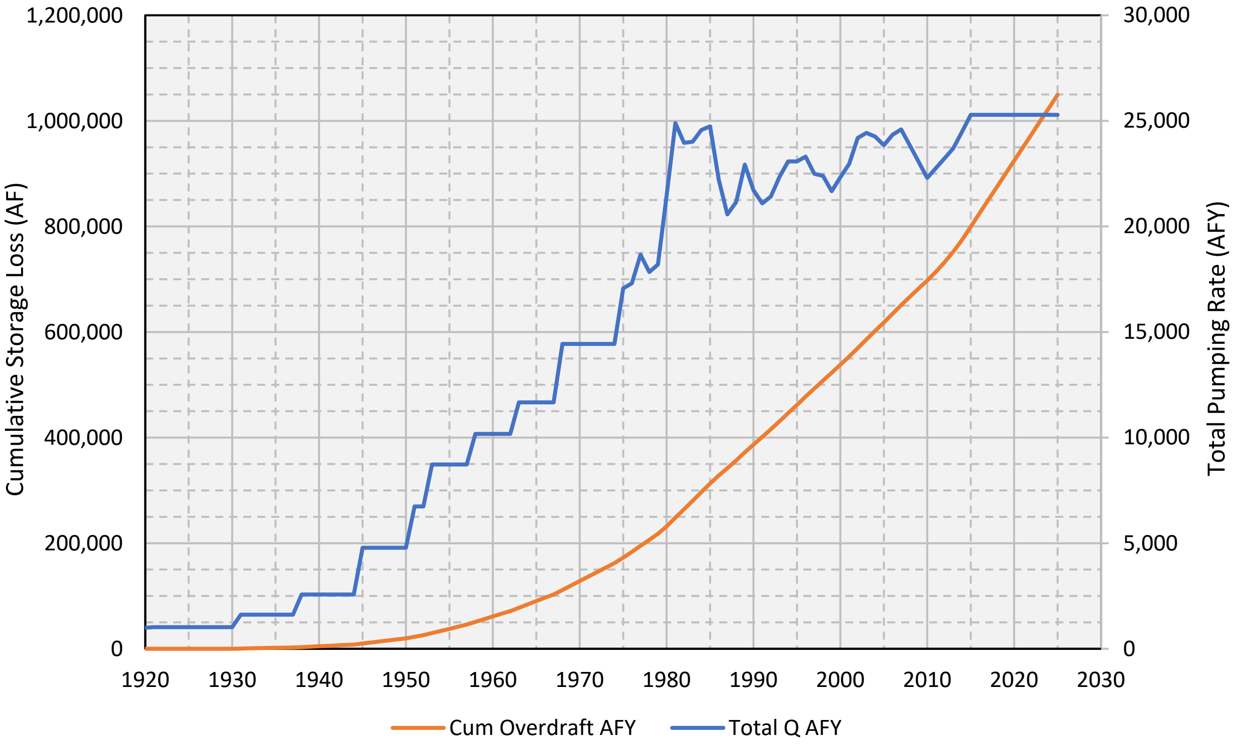

Figure 2. Reported pumping rates and estimated cumulative storage loss from the IWVGB between 1920 and 2025.

4. Explanation of Opinions

4.1. Opinion 1: Safe Yield Must be Less Than Total Recharge

At present, the safe yield from the IWVGB will necessarily be less than the total natural recharge to the basin and is likely between 6,100 and 8,400 AFY.

4.1.1. Safe Yield

"Safe yield" describes the condition of a groundwater basin in which the total average annual groundwater extractions are equal to, or less than, the total average annual groundwater recharge, either naturally or artificially, (CA Water Code § 37900, 2024).

By this definition, it is possible for a basin to achieve safe yield while also being in a state of overdraft. This is because overdraft occurs when total groundwater consumption, which is the sum of natural discharge and groundwater extractions, exceeds total recharge. Safe yield should therefore be set such that it accounts for the portion of recharge that can practicably be intercepted by wells, which in the IWVGB is demonstrably less than total recharge. I estimate that total recharge to the IWVGB is between 7,200 and 9,900 AFY, which I explain below for Opinion-4.

The IWVGB has been in a state of overdraft since 1953 or earlier (Kunkel and Chase, 1969) despite the fact that natural groundwater discharge in the form of upward groundwater flow to the playas and ET has persisted to present. Overdraft in 1953 was estimated to be 4,000 AFY (Kunkel and Chase, 1969) when total pumping from the principal aquifer was only about 8,700 AFY (Brown and Caldwell, 2009; Table 4-1). In 2010, estimated overdraft had risen to be between 14,600 and 15,600 AFY (Todd Engineers, 2014), and in 2015, had risen further to an estimated 25,000 AFY when total groundwater extractions were estimated to be 27,740 AFY (Stetson Engineers, 2020). The continued existence of natural discharge when groundwater extractions have continuously risen and are now likely three or more times higher than total recharge, demonstrates the inability of groundwater users in the IWVGB to design and implement a groundwater extraction program that effectively intercepts natural discharge.

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

Even then, the high end of my estimated range is similar to the reported magnitude of pumping in 1953 when the basin was already deemed to be in overdraft by 4,000 AFY. In order to achieve safe yield at that magnitude of pumping, it is therefore likely that some number of pumping wells within the basin will have to be redistributed such that they are better able to intercept natural groundwater flow to the playas, as was suggested by the early researchers (Kunkel and Chase, 1969; Ducher and Moyle, 1973).

4.1.2. Sustainable Yield

Safe yield is similar to the "sustainable yield" that is defined by the Sustainable Groundwater Management Act (SGMA) as the maximum quantity of water that can be withdrawn annually without causing undesirable results. The IWVGB groundwater sustainability plan (GSP) identifies four types of undesirable results that are expected to occur as a consequence of groundwater extractions in excess of the safe yield.

- Chronic lowering of groundwater levels will reduce the operational life of shallow domestic wells, decrease well yields, increase the cost of pumping for most pumpers, and threaten groundwater dependent ecosystems (GDEs).
- Degradation of water quality will occur as a result of downward flow of poor quality (saline or nearly saline) water from the shallow aquifer zone into the principal aquifer in response to persistent groundwater level decline.
- Continued reduction of groundwater storage has been occurring in the IWVGB since 1920 (Brown and Caldwell, 2009) and increasing at an average rate of approximately 485 AFY per year since that time (Kunkel and Chase, 1969; Bean, 1989; Brown and Caldwell, 2009; Todd Engineers, 2014; Stetson Engineers, 2020).
- Land subsidence will occur due to the inelastic compaction of fine-grained sediments that occurs when those sediments become dewatered, particularly in confined sections of an aquifer.

All but the water quality problem can be mitigated through the stabilization of groundwater levels, which could presumably occur even if extractions were able to capture 100% of the natural discharge. In order to preserve groundwater quality in the principal aquifer, however, some amount of natural discharge to the playas must be preserved such that upward gradients between the principal and shallow aquifers are maintained. Since those gradients have already been reversed in portions of the shallow aquifer (McGraw, et al., 2016), groundwater levels in those areas will likely have to rise in order to stop the migration of poor-quality water into the principal aquifer that is presently occurring. Both Kunkel and Chase (1969) and Dutcher and Moyle (1973) recognized the importance of maintaining upward gradients in their early characterization efforts and recommended preserving 1,000 AFY of ET in the playas.

It is important to recognize, however, that the objective is to preserve and possibly restore upward gradients rather than preserve the ET itself, which means that artificial recharge to the shallow aquifer will not achieve the goal. Some portion of the natural recharge must remain uncaptured and free to move through the basin and upward into the playas. My recommendation that safe yield be less than natural recharge accommodates this need and therefore, at present, my recommendation for sustainable yield equals my recommendation for safe yield.

4.2. Opinion 2: The Hydrologic Equation and Safe Yield

The most reliable method of estimating the safe yield of the principal aquifer in the IWVGB is through the use of the hydrologic equation and estimates of steady-state pre-pumping (circa 1912) total groundwater discharge and recharge in the IWVGB.

Two methods can be used to estimate safe yield. Both focus on identifying a total pumping rate that can be sustained without causing a depletion in groundwater storage. Both methods also rely on the expression of mass balance defined by the hydrologic equation.

$Inflows_T + Outflows_T = \delta Storage$; where: *eq.1*

$Inflows_T =$ total inflows to an aquifer basin [L^3/T], typically including:

- recharge from precipitation on the land surface,
- recharge from losing streams,
- groundwater flow into the aquifer basin from adjacent basins, and sometimes
- direct injection of water through wells or infiltration basins;

$Outflows_T =$ total outflows to an aquifer basin [L^3/T], typically including:

- groundwater discharge to springs and/or gaining rivers,
- evapotranspiration from the water table surface,
- extractions from wells, and
- groundwater flow out of the aquifer basin into adjacent basins; and

$\delta Storage =$ change in groundwater storage.

One method, which I will call the "recharge method," relies on estimating the long-term average natural recharge to an aquifer basin and defining safe yield as some percentage of that value. The other method, which I will call the "storage method," relies on estimating the change in groundwater storage and the total pumping occurring over a given period of time in which the change in storage can be reasonably assumed to be due solely to pumping. The safe yield for the respective period can then be assigned as the fraction of the respective pumping that would result in no net change in storage.

I generally prefer the recharge method because it involves fewer variables, particularly when, as is the case for the IWVGB, the basin is a closed hydrologic system meaning that all, or the significant majority of recharge to the basin discharges internally, and it is possible to estimate the natural recharge to the basin before the onset of significant pumping.

4.2.1. The Recharge Method

Under steady-state conditions (long term average in the absence of climate change) and in the absence of anthropocentric forces, e.g. groundwater extraction from wells, an aquifer basin can be reasonably assumed to be in equilibrium with respect to aquifer storage. That is the change in aquifer storage can reasonably be assumed to be zero such that:

$Inflows_T = Outflows_T$; when $\delta Storage = 0$. *eq. 2*

It is reasonable to assume that in the early 20th century, specifically prior to 1920, the IWVGB was in a relatively steady-state condition wherein total inflow to the basin was equal to total outflow. Significant groundwater pumping had yet to begin (Moyle, 1963; Kunkel and Chase, 1969; Bloyd and Robson, 1971). For that early time period, understanding the groundwater budget for the IWVGB comes down to estimating either total recharge or total discharge.

The majority of research that I have reviewed is in general agreement that:

- All, or the significant majority of natural recharge to the IWVGB is derived from precipitation falling on the mountain slopes flanking the basin on nearly all sides (described as mountain front recharge); and
- All, or the significant majority of total discharge from the principal aquifer in the IWVGB occurs as ET to the playas and adjacent areas.

Multiple researchers have developed independent estimates for both the total recharge and the total ET from groundwater discharge within the IWVGB (Lee, 1913; Kunkel and Chase, 1969; Bloyd and Robson, 1971; Brown and Caldwell, 2009; McGraw, et al., 2016) that have, to varying extents been used by most of the other researchers that have worked on characterizing the hydrogeology of the IWVGB in their analyses.

In some cases, researchers have used the previous estimations of one of these quantities (total recharge or total ET from groundwater discharge) to help them constrain their estimation of the other. They've been able to do so because there is consensus that estimations of either quantity for the pre-pumping period, generally identified as prior to 1920, is reflective of a steady-state condition in which total outflows from the IWVGB were equal to total inflows.

4.2.1.1. Estimating Recharge

Nearly all of the previous researchers generally agree that the majority of recharge, if not all of it, originates as precipitation at elevations generally above 4,500 feet in the mountain ranges that border the IWVGB; the Sierra Nevada to the west, the Coso and Argus ranges to the north and northeast, and the El Paso Mountains to the south. The variables associated with these estimates include:

- the magnitude and distribution of precipitation; and
- the magnitude of evapotranspiration that depletes precipitation before it infiltrates the ground surface to become recharge.

Though there is uncertainty associated with estimating these variables, researchers have been able to capitalize on a clear and well-accepted relationship between recharge from precipitation and the elevation at which it falls that has been developed and tested in multiple arid mountain settings similar to the IWV. Estimating mountain front recharge to the IWVGB has focused on understanding and applying these relationships and then testing the assignments through numerical groundwater modeling.

In addition to mountain front recharge, some researchers contend that groundwater inflow to the northern part of the IWVGB likely comes from the Rose Valley basin. Here too, the magnitude of such inflow has not been measured directly. Its existence is indicated by geologic logs that show continuity of water bearing sediments between the southern end of the Rose Valley basin near Little Lake and the northwestern corner of the IWVGB, as well as groundwater elevations measured in wells that indicate a generally southward hydraulic gradient between the two basins (Kunkel and Chase, 1969; Bean, 1989; Todd Engineers, 2014; McGraw, et al., 2016). Whether performed analytically or with a numerical model, estimation of this flow involves the use of Dary's Law, which states:

$$Q = k \times {}^{dh}/_{l} \times A; where: \qquad \textit{eq. 3}$$

Q = the magnitude of groundwater flow [L^3/T];

k = the hydraulic conductivity of the aquifer material [L/T], which is a measure of the aquifer's capacity to transmit water through a unit thickness;

$\delta h/l$ = the hydraulic gradient = the change in hydraulic head (dh) over a length of flow path (l) [-]; and

A = the cross-sectional area through which the flow occurs [L^2].

The variables associated with these estimates therefore include:

- the hydraulic conductivity, or distribution of hydraulic conductivities, characteristics of the saturated sediments between the Rose Valley basin and the IWVGB through which groundwater can flow;
- the hydraulic gradient between the Rose Valley basin and the IWVGB; and
- the cross-sectional area of the section of the aquifer between the Rose Valley basin and the IWVGB.

Neither *k*, or the distribution of *k*-values if the aquifer is heterogeneous, or *A* can be measured directly; they must be estimated using a combination of sparse data and professional judgement. Only $\delta h/l$ can be measured, through water level monitoring in wells. Even then however, there remains uncertainty.

Some researchers have contended that the apparent hydraulic gradient between the two basins may be a consequence of faulting or an otherwise low-permeable barrier, which would render estimates derived from the application of Darcy's Law and over-estimation, perhaps significant over-estimation of the interflow. In most cases, where it is assumed to occur, inflow from the Rose Valley basin has been considered small relative to mountain front recharge.

4.2.1.2. Estimating ET

Nearly all of the previous researchers also generally agree that all or nearly all of the pre-pumping discharge from the IWVGB occurred as ET from the playas and adjacent sparsely vegetated areas. The variables associated with these estimates include:

- the type, spatial distribution, and density of vegetation that is known to rely on shallow groundwater (phreatophytes);
- the related distribution of soil types;
- the relationship between plant type and ET rate; and
- the associated relationships between ET rate, ambient temperature, and depth to water.

The first two of these variables were sufficiently delineated by early researchers (Kunkel and Chase, 1969) to be relied upon to varying degrees for many of the ensuing studies including the 2020 GSP. The magnitude of total ET from basin has been consistently revised, predominantly downward, since the early work, on the basis of evolving and improving understanding of the latter two variables. Once defined for the pre-pumping period, equation-1 dictates that the estimate of total ET equals the total pre-pumping recharge to the basin.

4.2.1.3. Defining Safe Yield

Once either total recharge or ET has been estimated, safe yield can be defined as a value less than or equal to the estimated total recharge the basin. For the reasons I described in Opinion-1, I've recommended setting the safe yield value to be 15% less than the estimate for total basin groundwater inflow.

4.2.2. The Storage Method

In the presence of groundwater pumping, a groundwater basin can be assumed to be in a steady-state condition when either:

- Total outflows, including pumping, equals total inflows and groundwater levels in the basin are reasonably stable, which is to say that they have equilibrated to the magnitude of pumping; or
- Total outflows exceed total inflows, which is defined as overdraft, but the rate of change in groundwater levels is relatively constant and can be reasonably and solely attributed to groundwater pumping.

Either of these two conditions is referred to as a "stable base period" from which the estimation of safe yield can be rendered. The latter would be the expectation for the IWVGB because the basin is in overdraft. The definition of a stable base period for the IWVGB therefore requires:

- Sufficiently long period of time to be reasonably considered demonstrative of average hydrologic conditions in the basin, i.e. balanced precipitation relative to long-term average;
- Reasonably stable pumping; and
- A record of groundwater levels that can be reasonably assumed to be equilibrated to the magnitude of pumping, i.e. the rate of decline is not changing.

When those conditions are met, the magnitude of pumping that would result in no further reduction in groundwater storage could be considered the safe yield and defined as:

$$Safe\ Yield = Qp \pm \partial Storage; where: \qquad eq.\ 4$$

Qp = the magnitude of total groundwater pumping [L^3/T] from the aquifer for which the safe yield is to be estimated that occurred during the estimation period;

$\partial Storage$ = the change (decline) in groundwater storage within the aquifer [L^3/T] for which the safe yield is to be estimated that occurred during the estimation period;

Neither quantity can typically be measured directly. While some pumping is metered, most including pumping to support agricultural irrigation, which is typically the largest or second largest use of groundwater in a basin, is not metered and must be estimated.

Change in aquifer storage cannot be measured directly and must be estimated through calculations involving measured groundwater level changes and the amount of water that will drain from the pore spaces in the aquifer material to wells, which itself must be estimated. A typical calculation of storage change follows:

$$\delta Storage = \delta GWE \times A \times S; where: \qquad eq.\ 5$$

δGWE = the change in the elevation of the groundwater surface over the estimation period [L];

A = area of the aquifer in which the change in storage is being estimated [L^2]; and

S = storativity of the aquifer, which is a is the volume of water released from storage per unit decline in groundwater elevation, per unit area of the aquifer, or part of the aquifer being estimated [-].

Groundwater elevations can be measured in wells and at water bodies in equilibrium with the groundwater surface. That said, there is considerable uncertainty associated with converting typically sparse datapoints defining groundwater surface elevations measured at different times into maps that describe the surface across the aerial extent of an aquifer being characterized for a desired estimation period. This is particularly true when the aquifer, or part of the aquifer being characterized is heterogeneous and/or broken up into variably connected zones by geologic structures such as faults or intrusives such as is the case in the IWVGB.

S cannot be measured directly. It can be estimated from aquifer performance tests involving at least two wells, one being stressed through either pumping or injection, and the other used to observe the change in groundwater surface elevation caused by the applied stress. S can also be estimated through transient numerical groundwater modeling by matching the model-simulated change in groundwater surface to changes observed in wells during the model simulation period. Alternatively, S can be assigned on the basis of observed sediment types and values that have been identified through laboratory and controlled field testing as indicative of the respective materials.

All three methods of estimation carry considerable uncertainty, particularly with respect to the assignment of values estimated from specific tests or for sediment types observed in specific locations to the areas in between. Values derived through numerical modeling carry uncertainty associated with the modeling effort, which is reflected by the degree to which the model simulation matches the totality of observed hydrologic conditions relevant to the modeling effort. Regardless of the estimation method, the magnitude of S is very different in unconfined and confined aquifers or unconfined and confined parts of an aquifer.

4.2.2.1. Unconfined Conditions

Unconfined conditions in an aquifer exist when the groundwater surface, also called the water table surface, is at atmospheric pressure. Changes in the elevation of the groundwater surface correspond to changes in saturation of the aquifer material. As the groundwater surface falls, the capacity of wells pumping from the aquifer becomes diminished because the saturated thickness decreases. Within the IWVGB, unconfined conditions in the principal aquifer exist in the western portion of the basin but transition to confined conditions to the east where the principal aquifer is covered by lower permeability sediments and the shallow aquifer.

In unconfined conditions, S is described as the specific yield (S_y) and defines the volume of water that drain will from the aquifer material to a pumping well due to gravity as the water table surface is lowered. S_y can be conceptualized as the drainable porosity. It is a ratio between 0 and 1 and is less than the porosity. It is only a valid characterization of aquifer storage capacity for portions of an aquifer that are unconfined, that is where the groundwater surface is at atmospheric pressure. Typical values of S_y range from <0.05 for clayey sediments, to <0.01 for silty sediments, to 0.25 to 0.30 for sands and gravels (Johnson, 1967).

4.2.2.2. Confined Conditions

Confined conditions in an aquifer exist when the groundwater surface, also called the potentiometric surface, is at a pressure higher than atmospheric pressure and therefore above the top of the aquifer. Confined aquifers or confined parts of an aquifer are usually bounded on top and bottom by lower permeable material, typically described as confining layers. Changes in the elevation of the groundwater surface correspond to changes in the upward pressure exerted on the surface wherein the body of the aquifer remains saturated. Pumping from a confined aquifer causes local reductions in the pressure on the potentiometric surface resulting in flow to the well.

Reductions in pressure sufficient to draw the groundwater surface below the top of the aquifer are to be avoided because doing so will typically result in subsidence as the dewatered pore spaces, particularly in fine-grained sediments, collapse due to the weight of the overlying materials. Water contained within the pore spaces of the aquifer material itself is therefore essentially inaccessible to pumping and certainly inaccessible with respect to the estimation of sustainable yield.

In unconfined conditions, S is described as the specific storage times the aquifer thickness ($S_s b$). S_s is similar to S_y in that it defines the volume of water released from one unit volume of the aquifer under one unit decline in groundwater surface elevation. It differs from S_y in that:

- It is related to both the compressibility of the aquifer and the water; and most importantly
- It is very much smaller, i.e. $S_s \ll S_y$.

Typical values of S_s range from around $3\text{x}10^{-4}$ to $6\text{x}10^{-3}$ for clayey sediments, from around $6\text{x}10^{-5}$ to $1\text{x}10^{-4}$ for sands, and around $1\text{x}10^{-5}$ to $3\text{x}10^{-5}$ for sandy gravels (Domenico and Mifflin, 1965).

4.2.2.3. Problem with the Storage Method

Application of the storage method will likely result in an over-estimation of safe yield because the uncertainties associated with the estimation of S (S_y in unconfined conditions and S_s in confined conditions) tend to favor higher values. This is because field tests are typically performed on production wells that are intentionally located in the more productive parts of an aquifer, and, in heterogeneous settings, the tests themselves tend to measure the more productive zones. Extrapolation of those values across the parts of an aquifer that are not directly tested can result in significant over-estimations of the aquifer storage capacity.

Alternatively, S_y and S_s values derived from numerical modeling are subject to modeling bias imposed on most projects due to time and money constraints. Numerical models are non-unique meaning that a number, likely a large number, of possible combinations of aquifer properties, e.g. hydraulic conductivity and S_y or S_s combined with boundary condition values will result in acceptable (acceptably calibrated) simulations. The bias arises because, for most efforts, only a small number of such configurations can be tested. Instead, the first configuration that achieves acceptable calibration often becomes the singular configuration reported, the result being a false sense of certainty in the model-defined properties.

Here too, model-defined properties are extrapolated across the model domain, in most cases to areas of the aquifer where calibration data is lacking. The extrapolated values therefore have little effect on the degree of model acceptability (i.e. calibration) yet have significant effect on estimations of total aquifer storage that get carried into the estimation of safe yield. Models also tend not to calibrate equally well across the model domain. The expectation should therefore be higher levels of uncertainty in model-defined parameters in the regions that calibrate more poorly.

There are two examples where aquifer properties were likely poorly estimated in the IWVGB resulting in over-estimation of total available groundwater flow. The first was done by Kunkel and Chase (1969) to provide an alternative to their estimate of total inflow to the aquifer on the basis of their estimates of ET. They calculated the magnitude of groundwater flow under the mid-valley using the analytical model described by equation 6 (variant of equation 3), and an estimate of the aquifer's capacity to transmit water.

$$Q = T \times {}^{dh}\!/_{l} \times d; where: \qquad \text{eq. 6}$$

Q = the magnitude of groundwater flow through a cross-sectional area of the aquifer [L^3/t];

T = the transmissivity of the aquifer [L/T], which is a measure of the aquifer's capacity to transmit water through its full thickness;

$\delta h/l$ = the hydraulic gradient = the change in hydraulic head (δh) over a length of flow path (l) [-]; and

d = length of the 2,200-foot water level contour [L] that formed the width of the cross-sectional area of the aquifer for which the calculation was performed.

Results of their analytical model indicated that the total flow through the aquifer at mid-valley was 15,000 AFY, which on the basis of mass balance, they contended must be equal to the total inflow to the basin. That estimate was 36% higher than the value of 11,000 AFY that they estimated from ET. At the time, they saw no reason to believe that one would be more reliable than the other so they reported total inflows to the IWVGB to be somewhere between the two; 11,000 to 15,000 AFY.

Another example comes from the work performed by Gillespie and Thyne (1996) wherein the researchers used the same analytical modeling technique as did Kunkel and Chase to estimate total inflows to the IWVGB across the western and northwestern boundaries of the basin at 41,500 AFY as compared to just over 9,000 AFY that they calculated from direct estimates of mountain front recharge occurring along the Sierra Nevada front and inflow from Rose Valley. In this case, the researchers believed more strongly in the higher value.

Though in both examples, both methods of estimation carried some degree of uncertainty, time and the subsequent work done by other researchers has provided considerably more support for the direct estimates of discharge or recharge than for the estimates derived from analytical modeling and its associated uncertainties. In both cases, subsequent research has indicated that to different degrees and for different reasons, both sets of authors likely over-estimated one or more of the key aquifer parameters used in the respective analytical modeling studies including the continuity of aquifer properties across buried faults in the basin.

The third example is at hand where the IWVWD has used a form of the storage method to estimate and propose a safe yield for the IWVGB of 14,300 AFY, which is the minimum of four estimates using S_y values derived two different numerical groundwater models and two different spatial assignment methods that ranged from 14,300 to 17,000 AFY. As with the modeling efforts described above, it is likely that some combination of pumping and S_y are over-estimated, particularly considering that there was no effort to discriminate between S_y in the unconfined section of the aquifer and S_s in the confined section. In this case, however one need only look to the historical data to see that the proposed safe yield values are likely close to double that which is actually safe given that the basin was deemed in overdraft by 4,000 AFY as early as 1953 when the total pumping rate was only around 8,700 AFY.

The storage method for estimating safe yield may be the only option in cases where the pre-pumping water budget cannot be reasonably estimated or where natural hydrologic conditions are believed to be significantly different at present than during the pre-pumping period, e.g. loss of recharge due to climate change. Neither of these are the case in the IWVGB where the direct approximation of total inflows and/or total outflows have proven to be reasonable and relatively consistent estimates of the groundwater budget.

4.3. Opinion 3: The IWVGB is a “Closed” Basin

The IWVGB is, for all practicable purposes, a “closed” basin, meaning that all, or very nearly all of the natural inflow to the basin is being consumed internally by some combination of ET and groundwater extraction.

A closed groundwater basin is one in which all of the inflows discharge within the basin such that there are no outflows to adjacent basins. The IWVGB is essentially a closed basin wherein somewhere between 97.5% and 100% of inflow to the groundwater system in the basin either discharges to the playas as ET or is intercepted and extracted by pumping wells. Some researchers contend that there is likely some amount of groundwater flow leaving the basin on the east side to either the Salt Wells or Searles Lake Valley basins (Kunkel and Chase, 1969; Austin, 1988; Bean, 1989; Todd Engineers, 2014; Garner et al., 2017). Other researchers content that there is none (Bloyd and Robson, 1971; Berenbrock and Martin, 1991; Brown and Caldwell, 2009).

Argument for the existence of outflow to the Salt Wells Valley stems from:

- Observations that groundwater elevations are higher on the IWV side of the buried bedrock ridge that separates the IWV from the Salt Wells Valley groundwater basins (Tetra Tech EM, 2003; TriEcoTt, 2012);
- The existence of saturated conditions in part of the now sand-filled channel that formerly connected China Lake to the Salt Wells Valley (Kunkel and Chase, 1969);
- Recognition of eastward groundwater flow through the Salt Wells Valley that could, in part, originate as fracture flow through the bedrock on the west side of the basin (TriEcoTt, 2012);
- Similarities in groundwater quality between the China Lake area of the IWV and the western side of the Salt Wells Valley (Tetra Tech EM, 2003; TriEcoTt, 2012); and
- Absence of salt build up in the principal aquifer which would be expected in the absence of some groundwater outflow from the basin (Kunkel and Chase, 1969).

Amongst the researchers who contend that there is outflow, most contend that it is very small relative to the magnitude of total groundwater inflow, ranging between 20 AFY (Kunkel and Chase, 1969), 50 AFY (Todd Engineers, 2014), 100 AFY (Garner et al., 2017), and 200 AFY (Bean, 1989) and is to the Salt Wells Valley.

I concur with those who contend that there is outflow to the Salt Wells Valley but see no evidence from any of the published data or arguments I've reviewed to suggest that the outflow is significant, not more than 1% or 2% of total inflows, and well within the margin of error associated with the estimation of internal outflows (ET and pumping).

The reason this issue remains significant is because advocates for a larger safe yield from the IWVGB continue to argue, either directly or indirectly, that there is more outflow from the basin than what can be accounted for by ET from playas and adjacent areas and pumping. This position is essentially a resurgence of the "open basin" conceptual model of groundwater flow through the IWVGB that was studied and discounted by the Indian Wells Valley Cooperative Groundwater Management Group (GTC, 2008). Their conclusion and mine is that groundwater management in the IWVGB should be based on the reasonably verifiable inflows largely originating as mountain front recharge along the perimeter of the basin that are being consumed internally by a combination of ET and groundwater pumping.

4.4. Opinion 4: Total Groundwater Inflow is between 7,200 and 9,900 AFY

Total groundwater inflow to the IWVGB is between 7,200 and 9,900 AFY.

Total groundwater inflow to the IWVGB has been estimated three different ways over the past fifty years:

- Estimation of ET from the playas and adjacent sparsely vegetated areas occurring in 1912 (Kunkel and Chase, 1969; McGraw, et al., 2016);

- Estimation of mountain front recharge on the basin of the relationship between precipitation-driven recharge and elevation (Brown and Caldwell, 2009; McGraw, et al., 2016); and
- The adjustment of the magnitude and distribution of the previously estimated inflows using numerical groundwater flow models (Bloyd and Robson, 1971; Berenbrock and Martin, 1991; Brown and Caldwell, 2009; McGraw, et al., 2016; Garner, et al., 2017).

All of those researchers made the following assumptions with which I concur:

- The IWVGB was in a state of equilibrium prior to 1920 wherein inflows to the basin equaled outflows;
- Total groundwater outflow from the IWVGB prior to 1912 occurred as ET from the playas and adjacent sparsely vegetated areas; and
- The primary source of inflow to the groundwater system occurred in the form of recharge from precipitation occurring in the mountains that surround the basin.

4.4.1. Evapotranspiration

4.4.1.1. Kunkel and Chase, 1969

Arguably the most comprehensive study of ET in the IWVGB was performed by Kunkel and Chase (1969) for 1953. Their work built onto the previous work of Lee (1913) who had estimated ET for 1912 based on mapping of soil types and moisture levels around China Lake and the use of a linear model of ET rates versus the depth of the water table surface. The Kunkel and Chase effort included:

- revising Lee's maps through the use of aerial photography to include 15 units characterized by different combinations of soil type, vegetation type and density, and depth to water;
- application of a non-linear model for ET rate versus depth to water (Blaney and Criddle, 1949; Blaney, 1951) to estimate the average ET rate for each of the 15 units;
- calculating total ET for 1953 from the average ET rates and areas of the respective units;
- estimating the change in depth to water that occurred between 1912 and 1953 based on depth to water beneath the China Lake playa that they measured at eight piezometers distributed across the playa, and depth to water measured by Lee (1913) in 1912 at one location in the playa;
- adjusting the ET rates in the 15 mapped units to account for the estimated change in depth to water that occurred between 1912 and 1953; and
- calculating total ET for 1912 from the average ET rates and areas of the respective units.

Kunkel and Chase concluded that total ET from the basin was 8,000 AFY in 1953 and 11,000 AFY in 1912. Assuming that the 1912 value is representative of total discharge from the basin, which I believe is reasonable, total steady-state inflows to the groundwater system would have equaled total discharge and were therefore equal to 11,000 AFY.

Their estimated value, which was subsequently used by several researchers as measure of total pre-pumping steady-state groundwater inflows to the IWVGB, either directly or as a starting point for their own estimations. It is important to note, that Kunkel and Chase's estimate is about 65% lower than the value estimated by Lee in 1912, which Kunkel and Chase, as well as subsequent researchers (Berenbrock and Martin, 1991; McGraw, et al., 2016), attributed mostly to the use of a more appropriate model of ET rate versus depth to water.

4.4.1.2. Bloyd and Robson, 1971

In advance of their modeling effort, Bloyd and Robson (1971) reviewed the work on ET done by Kunkel and Chase, specifically their effort to estimate 1912 ET on the bases of change in depth to water beneath China Lake between 1912 and 1953. Bloyd and Robson determined that the magnitude of the change in depth to water was suspect because measurements were available from only one location in 1912 and it was within the range of values measured at eight locations in 1953. On that basis, Bloyd and Robson concluded that the pre-pumping total inflow to the IWVGB is likely less than 11,000 AFY as estimated by Kunkel and Chase but more than the 8,000 AFY that they estimated for 1953.

In their modeling effort, Bloyd and Robson adjusted recharge to the IWVGB downward to facilitate calibration ultimately arriving at a value of 9,850 AFY, which became their estimate for total mountain front recharge and, by mass balance, total ET from the basin prior to the onset of pumping.

4.4.1.3. McGraw, et al., 2016

In their modeling work for the U.S. Navy, McGraw and others (2016) conducted a review of the ET estimation work performed by Kunkel and Chase. They concluded that the ET rates assigned by Kunkel and Chase to the respective soil/vegetation/depth-to-water units were generalized values provided by the U.S. Department of Agriculture and not site specific (Kunkel and Chase, 1969; McGraw, et al., 2016).

McGraw and others proceeded to develop site-specific values following a methodology used by Tyler and others (1997) to estimate ET rates for Owens Lake, California, located about 60 miles to the north of the IWVGB and also under artesian conditions. Tyler's group used instrumentation to directly measure ET rates for the bare playa surface of between 0.29 and 0.34 feet per year (ft/yr), which by comparison to the rates Kunkel and Chase used (0.3 to 0.7 ft/yr) led McGraw's grouup to conclude that Kunkel and Chase may have over-estimated total ET in the IWVGB by between 33% and 66% (McGraw, et al., 2016). Apply the potential range in over-estimation, total ET from the basin could be between 3,740 and 7,370 AFY.

McGraw's group developed their own estimation of ET rates using an eddy covariance station (same type of instrumentation used by Tyler's group at Owens Lake), that was installed at the south end of China Lake. From the data collected at that station, they estimated ET rates for the bare playa at China Lake to range between 0.2 and 0.4 ft/yr for depth to water down to 7.5 feet, which are comparable to those reported by Tyler's group at Owens Lake.

4.4.2. Mountain Front Recharge

The magnitude of groundwater inflows has been independently estimated by at least two sets of researchers while the distribution of a previously estimated magnitude of inflows has been estimated by several others.

4.4.2.1. Brown and Caldwell, 2009

Brown and Caldwell developed a partially independent estimate of total groundwater inflow to the IWVGB. They focused on estimating mountain front recharge occurring in the Sierra Nevada, Coso and Argus mountains that border the IWVGB to the west north and northeast. Their work was based on a study of Owens Valley conducted by Danskin (1998) who produced an empirical relationship between precipitation rate from more than 50 years of precipitation and snow records collected routinely at 20 survey stations. Adjusting Daskin's precipitation/elevation relationship for an observation that precipitation decreases moving south along the Sierra Nevada, Brown and Caldwell assumed precipitation rates on the mountains flanking the IWVGB of:

- 8 inches per year (in/yr) @ elevations between 4,500 and 6,500 feet, and
- 10 in/yr above 6,000 feet.

They checked and found that their estimates generally agreed with information obtained from the Western Region Climate Center and the California Climate Data Archive. They then calculated total precipitation for sub-watershed areas between elevations 4,500 and 6,000 feet and for the part of those sub-watersheds above 6,000 feet. They then assumed that 15% of their calculated total precipitation values resulted in recharge to the principal aquifer in the IWVGB such that their final estimated total fell within the range of 9,000 to 11,000 AFY as determined by Bloyd and Robson (1971) and Kunkel and Chase (1969). Brown and Caldwell's initial estimate of total mountain front recharge was 9,400 AFY.

Recognizing the uncertainty associated with their estimate as well as the estimates developed by previous researchers, Brown and Caldwell varied both their estimate of total mountain front recharge and their estimated distribution during the calibration of their steady-state model. Their final model-simulated value was 7,521 AFY and their final model-simulated value for total inflow to the groundwater system was 8,821 AFY of which 1,300 AFY was from groundwater subflow into the IWVGB from the Rose Valley basin.

4.4.2.2. McGraw, et al., 2016

McGraw and others (2016) also developed an estimate for mountain front recharge that was more independent than the one preformed by Brown and Caldwell (2009) because they didn't report constraining their estimate by previously estimated values. McGraw's approach leveraged an empirical model known as the bootstrap brute-force recharge model (BBRM; Epstein, et al., 2010), that was derived from a relationship between precipitation and natural groundwater recharge originally developed for Nevada basins by Maxey and Eakin (1949).

The BBRM relates recharge to annual zonal precipitation through the use of dimensionless coefficients calibrated to ninety Nevada hydrographic areas with independently derived recharge estimates. McGraw's group assumed that transference of the empirically derived coefficients was appropriate for the IWVGB based on the close proximity of eastern California and southwestern Nevada basins. McGraw's group used the BBRM in conjunction with the PRISM precipitation map (PRISM Climate Group, 2012) to estimate recharge to the IWVGB from the sub-watersheds in the mountains surrounding the IWVGB for zones of increasing precipitation above 8 in/yr. Using this method, they estimated total mountain front recharge to the IWVGB to be 9,265 AFY and that the value could vary downward to as low as 5,800 AFY while remaining within the 95% confidence interval for the BBRM.

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

McGraw's final estimate of mountain front recharge was 5,250 AFY to which they added an additional 2,400 AFY of subflow into the IWVGB from the Rose Valley basin such that their estimate for total inflow to the to the groundwater system was 7,650 AFY.

4.4.3. Summary of Reported Values

As described above, at least three sets of researchers have developed independent estimates of total inflow to the principal aquifer in the IWVGB. They and numerous others have reported that they considered and sometimes adjusted previously reported values to best conform to their conceptual and/or numerical models. Nearly all have stated that, given the uncertainties associated with estimating and simulating the water budget components, additional data should be collected to better constrain the estimation of recharge and discharge in the IWVGB, which to date has not been forthcoming.

For this reason, it is my opinion that the best available science is represented, not by any one particular estimate, but rather by an evaluation of the range and trajectory of published values through time. Doing so recognizes that each value represents the best efforts of the respective researchers to address the uncertainties while capitalizing on improved data and understanding of hydrologic conditions and processes relevant to the IWVGB.

A summary of published values for mountain front recharge and total groundwater inflow to the IWVGB is provided as Attachment 2.

In my summary, I have intentionally omitted exceptionally high values that were derived from analytical models (i.e. equations 3 and 6) and an assumption that the IWVGB is an open basin. I consider all the values presented to be equally defensible. The average value of estimated total groundwater inflow is 9,089 AFY. The values range from 5,976 AFY, the most recent, to 11,000, the earliest. When considering the few that also reported ranges for their estimates, the estimates of total inflow expand to between 5,800 AFY and 15,000 AFY.

The average value for mountain front recharge is 8,314 AFY. The values range from 5,250, published in 2019, to 11,000, published in 1969. The average value for subflow (mostly from the Rose Valley basin) is 933 AFY and ranged from 45 AFY to 2,400 AFY.

When ordered by date of publication, it is apparent that estimates of both mountain front recharge and total groundwater inflow have been declining since 1989 (Figure 3). Considering just the 10 values published since then, the range of estimates for total groundwater inflow remains similar but the average drops by more than 500 AFY to 8,548 AFY. It is my opinion that the apparent decline in estimated recharge and total groundwater inflow reflects a progressive scientific understanding of the hydrologic processes relevant to the IWVGB and a non-bias consensus that there is less groundwater inflow to the IWVGB that was estimated by the earlier researchers.

In order to account for the uncertainty in the estimates, I have bounded the post-1989 average by one standard deviation and rounded the resulting value to the nearest 100 AFY such that, in my opinion, total groundwater inflow to the IWVGB is between 7,200 AFY and 9,900 AFY. Within this range and based solely on my observation of declining trend, I favor the lower value.

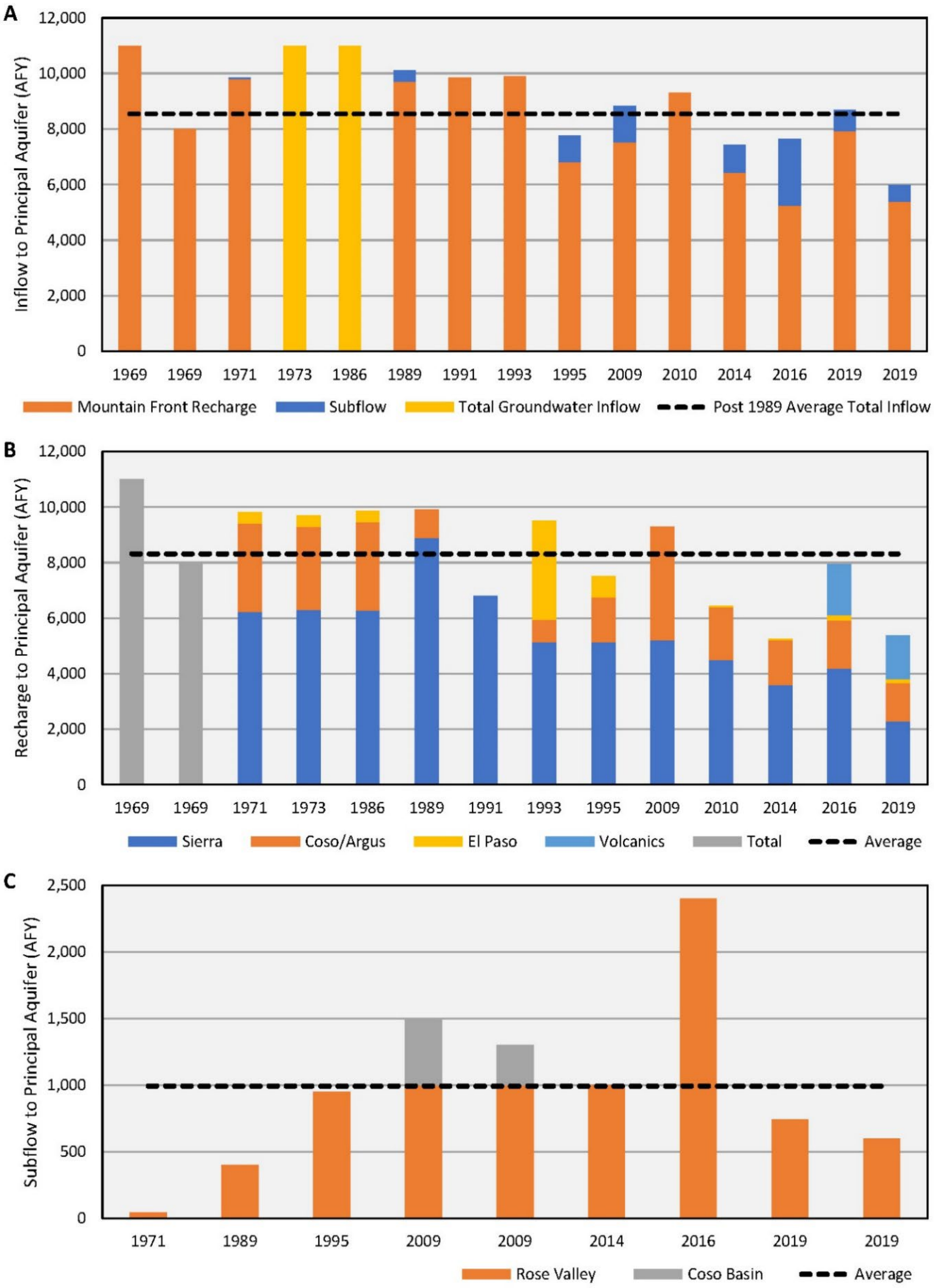

Figure 3. Range in reported inflows to the principal aquifer in the IWVGB by type and date of publication (A) total groundwater inflows; (B) mountain front recharge; (C) subflow.

4.5. Opinion 5: Recharge to the IWVGB is Likely Declining

Due to climate change, the present-day total recharge to the IWVGB is likely less than what it was in the early 20th century and it is likely to continue to decline in the future.

Climate change is expected to impact the southern part of the Sierra Nevada in several ways, all of which will likely result in reduced snowpack and thus reduced recharge to the IWVGB because rainfall runoff will be more likely to reach the playa surface before infiltrating resulting in higher ET and lower recharge. Because of this, safe yield set, as I am recommending, on the basis of estimates of steady-state natural inflows, will likely become inappropriately high in the future.

Specific expected changes are published by several entities. The UCLA Center for Climate Science reports that:

- 30% to 64% reduction in springtime snowpack by 2100;
- 25 to 50 days earlier runoff of snowmelt to streams;
- Less snowpack and more rainfall runoff; and
- That the most vulnerable zone within the southern Sierra Nevada is the zone between 5,000 and 8,000 feet of elevation (UCLA-CCS, 2018).

The U.S. Forst Service predicts that:

- Higher temperatures will likely lead to drier atmospheric conditions;
- As precipitation regimes will transition from snow dominated to rain dominated; and
- Future declines in precipitation falling as snow and rapid melt rates may lead to higher soil moisture deficits later in the summer (Halofsky, 2021).

4.6. Opinion 6: Do Not Rely on Aqueduct Leakage, Irrigation Returns, or WWTP Discharge

Estimation and designation of safe yield should not rely on leakage from the Los Angeles Department of Water and Power (LADWP) aqueduct, irrigation returns, or discharge from the Ridgecrest / Naval Air Weapons Station (NAWS) wastewater treatment plant.

It is not appropriate to account for indirect forms of artificial recharge in the calculation of safe yield. By “indirect,” I mean forms of artificial recharge that are not specifically engineered to replenish the principal aquifer, e.g. injection wells or recharge basins. Indirect forms of artificial recharge are speculative by nature and therefore should not be relied upon in efforts to quantify groundwater resource availability. Pipeline leakage, wastewater outflows to the land surface, and agricultural return flows, if they indeed result in recharge to the principal aquifer, would be forms of indirect artificial recharge.

4.6.1. Aqueduct leakage

Incorporating estimated leakage from the Los Angeles Power and Water Department (LAPWD) aqueduct into calculations of safe yield from the principal aquifer in the IWVGB implies a water right that does not exist. If there is significant leakage, Los Angeles could at their discretion repair it and thus eliminate the source from the IWVGB water budget. According to the LAPWD, and as I would expect, they diligently work to maintain their pipelines specifically to reduce the probability of leakage and repair leaks that are found to exist (LAPWD, 2025).

Even if water managers were to decide to gamble on the source, neither the magnitude and spatial distribution of leakage within the IWVGB, nor the percentage of that leakage that results in recharge is known. Incorporating this as a source of recharge into groundwater management planning or the estimation of safe yield s therefore, in my opinion, not scientifically reasonable.

4.6.2. Wastewater Discharge

The Ridgecrest/NAWS wastewater treatment facility (WWTF) is located on the upper clay that overlies the principal aquifer and inhibits downward flow into the underlying principal aquifer (Figure 4). Recharge stemming from WWTF discharge will therefore occur to the shallow aquifer not the principal aquifer (Todd Engineers, 2014).

At present, upward gradients between the principal and shallow aquifer are thought to exist across much of the spatial extent of the clay layer other than in the south and southwestern corners due to pumping in the Ridgecrest area (TriEcoTt Joint Venture, 2012; Todd Engineers, 2014). The southern side of the WWTF is approximately 1.5 miles north of the margin of the clay layer and the eastern side is about 0.75 miles from the eastern margin. It is therefore unlikely that discharge will seep off of the clay layer.

Moreover, since a goal of the sustainable yield is to prevent contamination of the principal aquifer resulting from downward flow of higher TDS water in the shallow aquifer, it is not reasonable to believe that appreciable recharge to the principal aquifer will be derived from WWTF discharge.

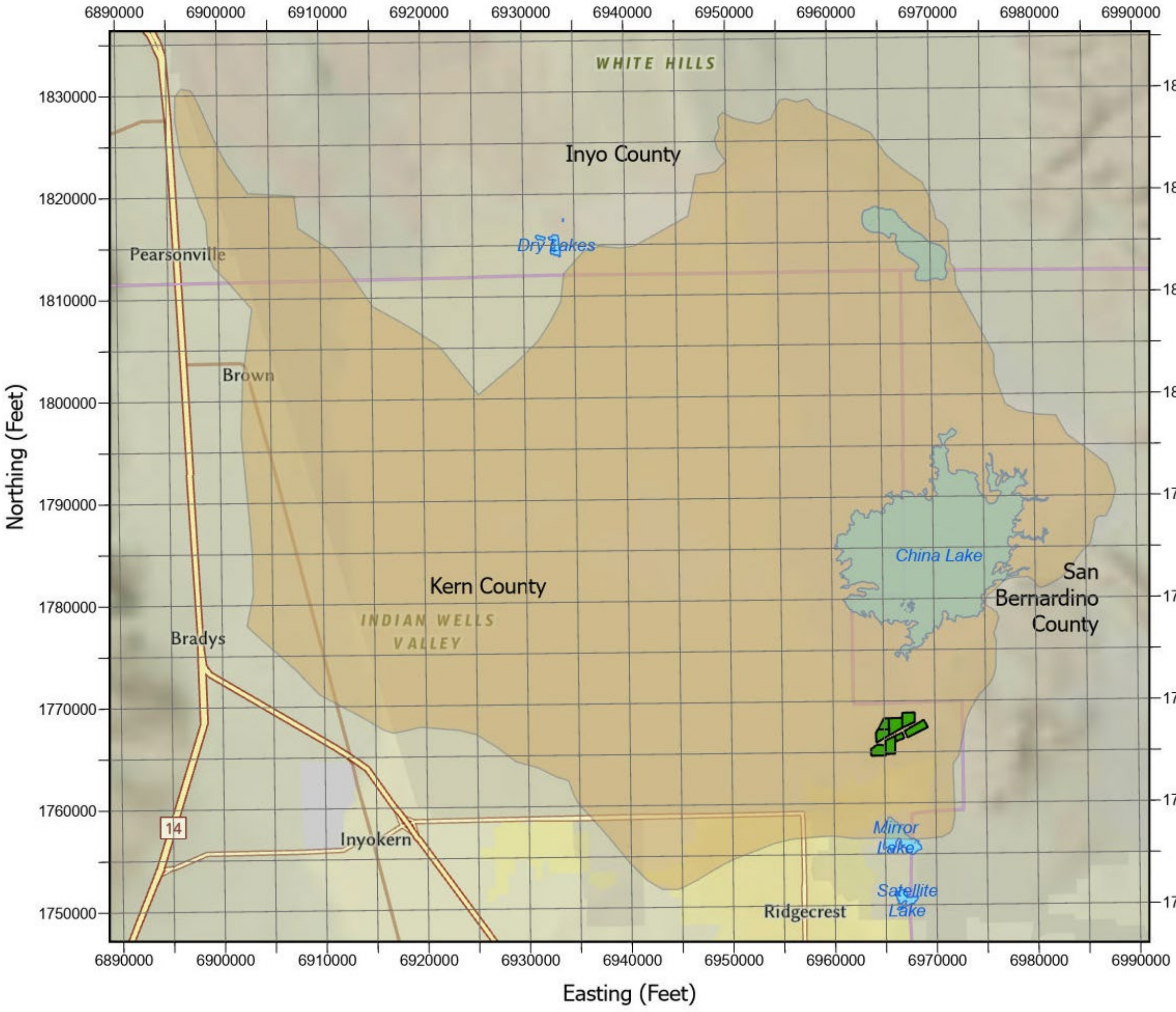
WHITE HILLS
Inyo County
Dry Lakes
Pearsonville
Brown
China Lake
San Bernardino County
Kern County
INDIAN WELLS VALLEY
Bradys
14
Inyokern
Mirror Lake
Satellite Lake
Ridgecrest
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Figure 4. Map showing the extent of the low permeability sediments that separate the deep, principal aquifer from the shallow aquifer and the playas relative to the location of the Ridgecrest/NAWS wastewater treatment facility.

4.6.3. Agricultural Return Flow

Agricultural return flows are, by their nature speculative. In my experience, estimates of magnitude vary considerably and not necessarily reasonably depending on location and desired outcome. My review of literature describing pumping in the IWVGB revealed a general consensus that agricultural return flow would be on the order of 10% of applied water as calculated for specific crops (Todd Engineers, 2014) but no estimation for domestic irrigation.

Kunkel and Chase (1969) pointed out, and with whom I concur, however that some evaporation below the ET extinction depth in the unsaturated zone is to be expected so the magnitude of water that may be reaching the groundwater surface is certainly lees that what escapes consumption by crops (and plants for domestic use). This is likely particularly true in the IWVGB due to the significant depth to water and the aridity. Kunkel and Chase also pointed out that some amount of over-irrigation can be assumed to occur if there is no salt buildup in the irrigated zone but also that if over-irrigation is sufficient enough to recharge the aquifer, some degree of salt buildup is to be expected there. The data doesn't appear to show significant salt accumulation in either zone that can be attributed to irrigation.

Based on this reasoning, if agricultural returns are occurring in the IWVGB, in my opinion, they must be significantly less that 10% of the calculated applied water on agricultural lands and would likely be even less on domestic properties.

Overall, unless the irrigation return is applied to a different aquifer or to an area distant from the extraction, I concur with McGraw and others (2016) that irrigation returns are better handled through reasoned and negotiated reductions to pumping magnitudes rather than the application of surface recharge.

4.7. Opinion 7: The GSP-GWMv5 vs the IWVWD Groundwater Model

The 2025 version of the GSP-GWM is a better tool for groundwater resource management in the IWVGB than the GWM independently developed by the Indian Wells Valley Water District.

In order to perform the requested reviews of the GSP-GWM-2025 and the IWVWD-GWM, I asked Stetson Engineers for the following outputs from each model:

- Water budget inflows and outflows by year for the years 1980-2021;
- Maps showing the representation of boundary conditions and internal flow barriers;
- Maps showing the distribution of simulated ET;
- Maps showing the distribution of dry and flooded cells; and
- Calibration residuals for a select set of wells common to both models.

4.7.1. Water Budgets

The simulated distribution of inflows and outflows can be exported from the model in the form of a water budget. Evaluation of the model water budget will therefore reveal a great deal about the degree to which model-simulated flow patterns are consistent with the conceptual model of a basin. There are steady-state and transient versions of both the GSP-GWM-2025 and the IWVWD-GWM. The steady-state model provides an interpretation of long-term average conditions in the basin and they are typically developed to set the initial conditions for a transient simulation of groundwater flow fluctuations over a desired time period. If that period is balanced with respect to inflows and outflows, the average inflows and outflows for the transient period should be similar to those depicted by the respective steady-state version of the model.

4.7.1.1. Steady-state Inflows

Table 2. Comparison of model-simulated water budgets: GSP-GWM-2025 and IWVWD-GWM.

IWVWD-GWM	GSP-GWM-2025
Simulates 21,755 AFY of recharge distributed approximately 12% as under flow from the Rose Valley basin, 66% as mountain front recharge, and 23% as pipeline leakage and return flows, presumably from agricultural and domestic irrigation.	Simulates 7,660 AFY of recharge distributed approximately 25% as underflow from the Rose Valley basin and 75% as mountain front recharge. No simulated recharge from anthropogenic sources.
Total Simulated Inflow	
Relative to what I consider to be the maximum reasonable published estimate of the total groundwater inflow to the IWVGB:	
198%	70%
Relative to my estimate of the maximum probable total groundwater inflow to the IWVGB:	
220%	77%
Relative to my estimate of the minimum probable total groundwater inflow to the IWVGB:	
302%	106%
Component of Total Simulated Inflow Representing Mountain Front Recharge	
Relative to what I consider to be the maximum reasonable published estimate of mountain front recharge to the IWVGB:	
130%	52%
Total Simulated Inflow Minus Simulated Recharge from Pipeline Leakage & Return Flows	
Relative to my estimate of the maximum probable total groundwater inflow to the IWVGB:	
170%	77%
Relative to my estimate of the minimum probable total groundwater inflow to the IWVGB:	
234%	106%

The steady-state version of the IWVWD-GWM appears to unreasonably represent the total available groundwater flow moving through the IWVGB. Total inflow minus return flows (16,822 AFY) is more than 50% higher than the maximum reasonable published estimate of the total groundwater inflow to the IWVGB (11,000 AFY). Unless there is a defensible reason for assuming that total inflows have increased by more than 50% since 1912, ET would have had to have been more than 50% higher than what was estimated by Kunkel and Chase (1969), which according to later researchers was likely, itself, an overestimation of what was actually occurring.

Total simulated inflows in the GSP-GWM-2025 is within the range of values that I believe reasonably characterize total groundwater inflow to the IWVGB. The values have apparently not changed, or changed very little since those estimated for DRI's 2016 model (McGraw, et al., 2016).

4.7.1.2. Transient Inflows

Detailed comparisons of the water budgets exported from both models and condensed to show yearly values from 1980 to 2021 are provided as Attachment 3. A plot comparing assigned recharge per year is provided below as Figure 5.

With respect to the IWVWD-GWM, mountain front recharge ranged from 939 to 55,966 AFY driving total assigned recharge to between 3,238 to 62,234 AFY. These values reflect an assumption that 100% of runoff from periodic floods results in recharge to the principal aquifer, which is unique to the IWVWD-GWM relative to the published values.

Conceptually, the IWVWD-GWM assignments of mountain front recharge equate to flood flows infiltrating before any losses to ET can occur. I would expect that, if such spikes in recharge occur, there would be evidence of mounding in the monitoring well data, particularly at wells close to the mountain front recharge boundaries, but the data I've reviewed doesn't reflect any such mounding.

Though the average value for mountain front recharge is within the range of reported values, 10,289 AFY, it is near the maximum of the published estimates (Attachment 2). The median is significantly less, 6,317 AFY, indicating that a small number of very high values has a significant effect on the assigned average. The average total assigned recharge is a little more than half of the total recharge assigned in the steady-state model. I would have expected the two to match or at least be similar.

Return flows, which include some percentage of estimated pipeline leakage, equates to between about 9 and 26% of the assigned pumping values. That percentage seems high given that the literature describes 10% of applied water as a general estimate for irrigation returns and agricultural irrigation should account for half or less than half of pumping.

With respect to the GSP-GWM-2025, total assigned recharge ranges from 3,863 to 15,682 AFY. There is no recharge from return flow or pipeline leakage. The average value is 8,180 and the median is similar at 7,978. The average value is within about 7% of the recharge assigned in the corresponding steady-state model. The small difference between average and median indicates that the values are close to normally distributed and therefore neither highs or lows are favored in the simulation period.

The GSP-GWM-2025 version of recharge is more in keeping with my expectations relative to published estimates for total groundwater inflows. Though recharge fluctuates yearly, there are no significant spikes indicating that only a fraction of the period floods is conceptualized as resulting in recharge. Presumably, the remainder would flow out to the lower elevations of the playa and be lost to ET.

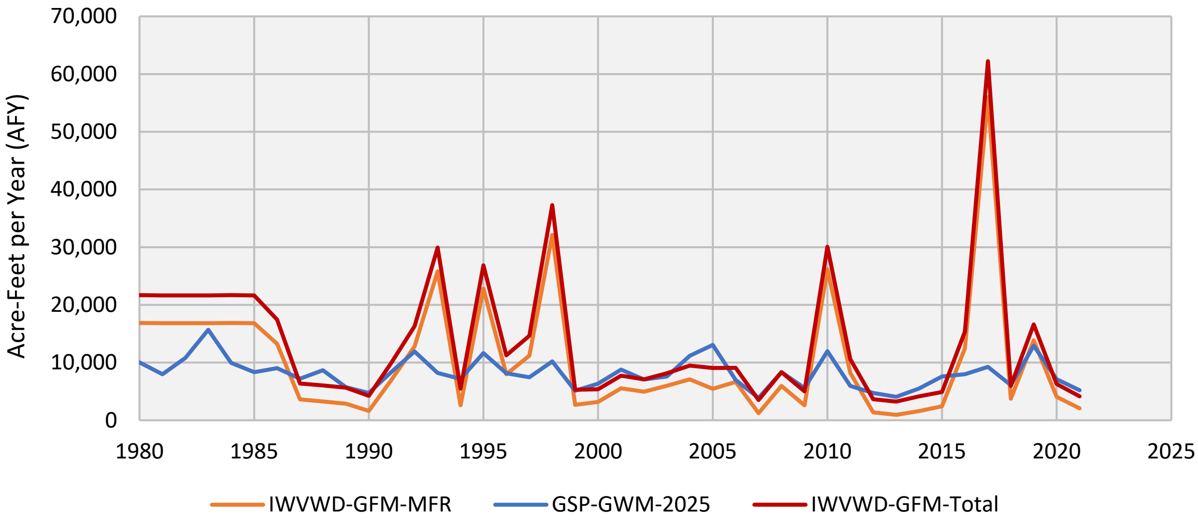


Figure 5. Comparison of transient total recharge assigned in the GSP-GWM-2025 and IWVWD-GWM relative to the portion of total inflows assigned as mountain front recharge in the IWVWD-GWM.

4.7.1.3. Transient ET

In the GSP-GWM-2025, ET was assigned to 12 zones (Figure 6) with rates associated with specific soil and vegetation types more closely aligned with previous field investigations and mapping (Kunkel and Chase, 1969; McGraw, et al., 2016). ET was simulated using the MODFLOW-ETS package, which uses a non-linear model of assignment based on simulated depth to water.

In the IWVWD-GWM, ET was assigned to two homogeneous zones (Figure 6), one representing the bare playa surface and the other the surrounding vegetation. ET was simulated in the model using the MODFLOW-EVT package, which uses a liner model of assignment based on simulated depth to water.

Figure 7 compares ET as simulated by the GSP-GWM-2025 and IWVWD-GWM. The GSP-GWM-2025 simulates a larger magnitude of ET and a larger decline in ET across the simulation period. Simulated ET in the IWVWD-GWM ranges between 1,651 AFY to 2,314 AFY, which represents between about 3 and 57% of the total assigned inflows. Simulated flow to pumping wells in the IWVWD-GWM therefore constitutes between 43 and 97% of the total inflows. The spikes in recharge apparent on Figure 5 are not reflected in the plot of simulated ET indicating that the model-simulated upward flow to the playas is insensitive to the magnitude of inflow assigned on the boundaries.

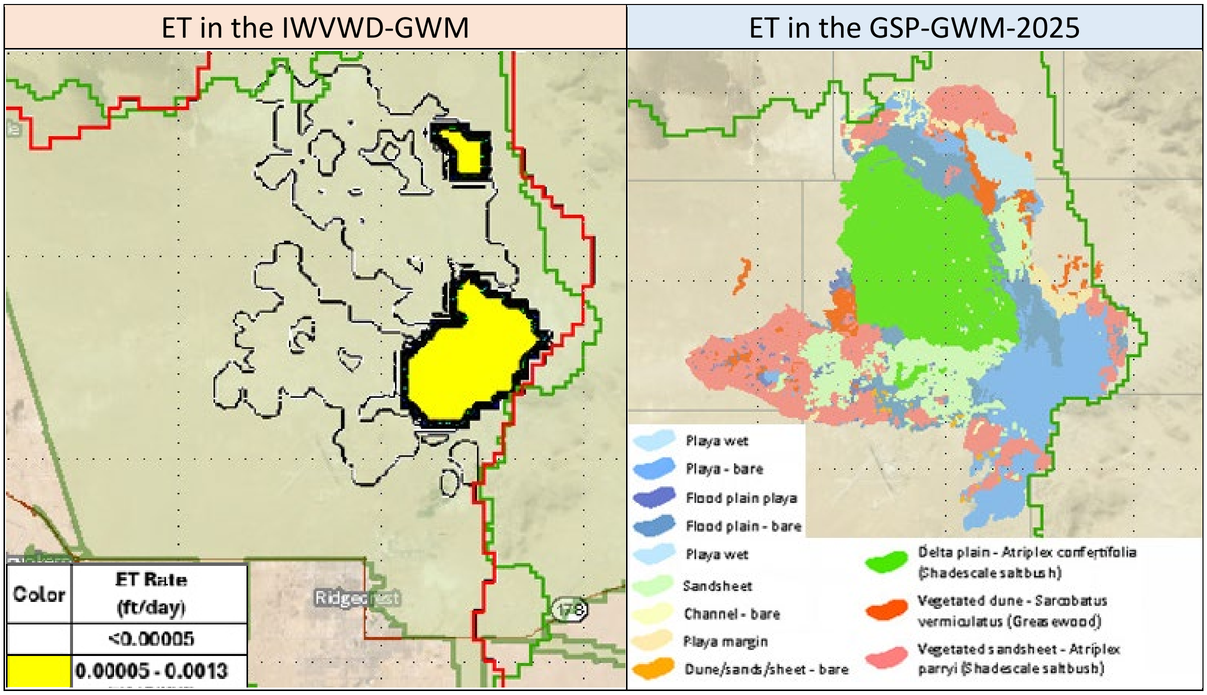

ET in the IWVWD-GWM
ET in the GSP-GWM-2025
Color
ET Rate (ft/day)
<0.00005
0.00005 - 0.0013
Ridgecrest
178
Playa wet
Playa - bare
Flood plain playa
Flood plain - bare
Playa wet
Sandsheet
Channel - bare
Playa margin
Dune/sands/sheet - bare
Delta plain - Atriplex confertifolia (Shadescale saltbush)
Vegetated dune - Sarcobatus vermiculatus (Greasewood)
Vegetated sandsheet - Atriplex parryi (Shadescale saltbush)

Figure 6. Maps comparing the differences in the spatial assignment of ET in the IWVWD-GWM (left) and the GSP-GWM-2025 (right).

The GSP-GWM-2025 simulates between 4,191 and 7,025 AFY of ET, which represents between about 34% and 136% of assigned inflows on a yearly basis. Simulated flow to pumping wells in the GSP-GWM-2025 therefore constitutes between about -36 and 66% of the total inflows.

The water budget data indicate that between 43 and 97% of the simulated inflows is captured by wells leaving somewhere between about 3 and 57% to flow to the playas and out as ET. Only between 0.1 and 0.6% of the simulated flow crosses the eastern boundary into the Salt Wells Valley.

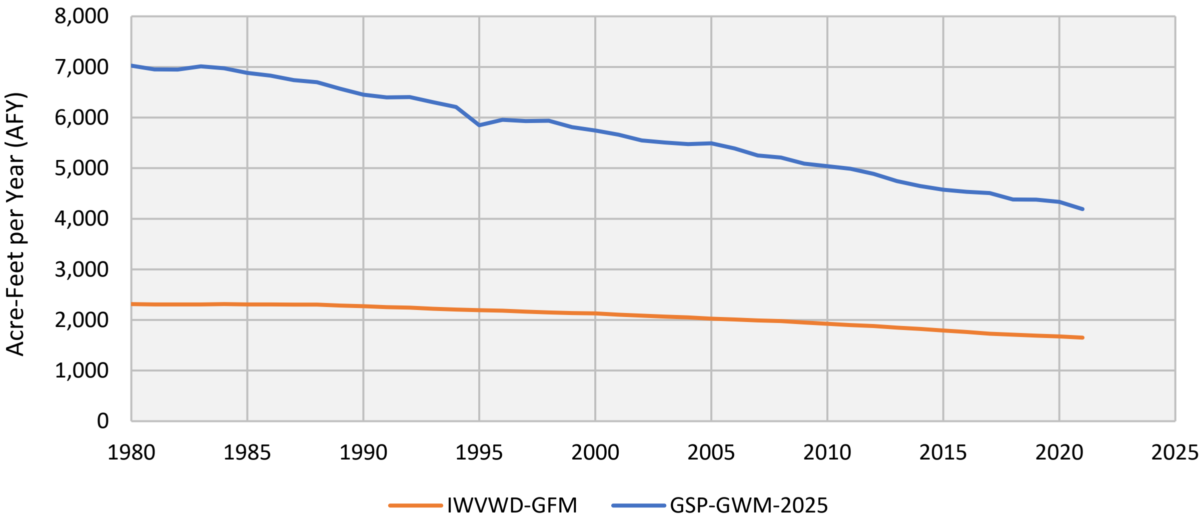


Figure 7. Comparison of transient ET simulated by the GSP-GWM-2025 and the IWVWD-GWM between 1980 and 2021.

4.7.1.4. Simulated Overdraft

Overdraft, as defined by total outflows minus total inflows, simulated by the IWVWD-GWM reflects the spikes in recharge depicted on Figure 5. Figure 8 provides a plot showing that the simulated flood events in the IWVWD-GWM create a sufficient rise in groundwater elevations to result in negative overdraft for four of the flood years. Such a rise would be widespread and apparent in groundwater elevations yet there is no record of mounding in the well data.

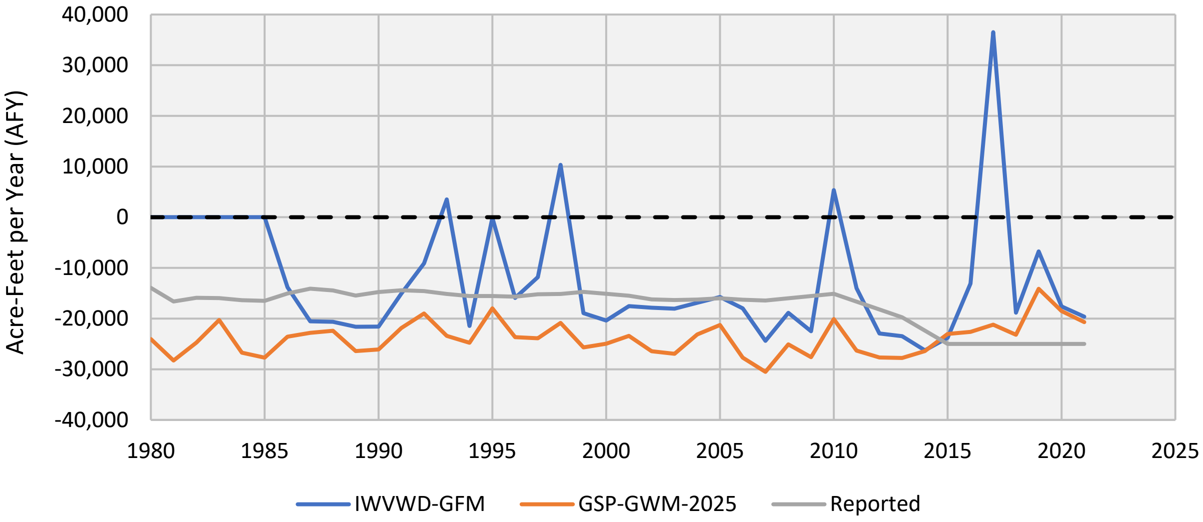


Figure 8. Comparison of simulated overdraft (outflows – inflows) in the GSP-GWM-2025 and IWVWD-GWM by calendar year between 1980 and 2021.

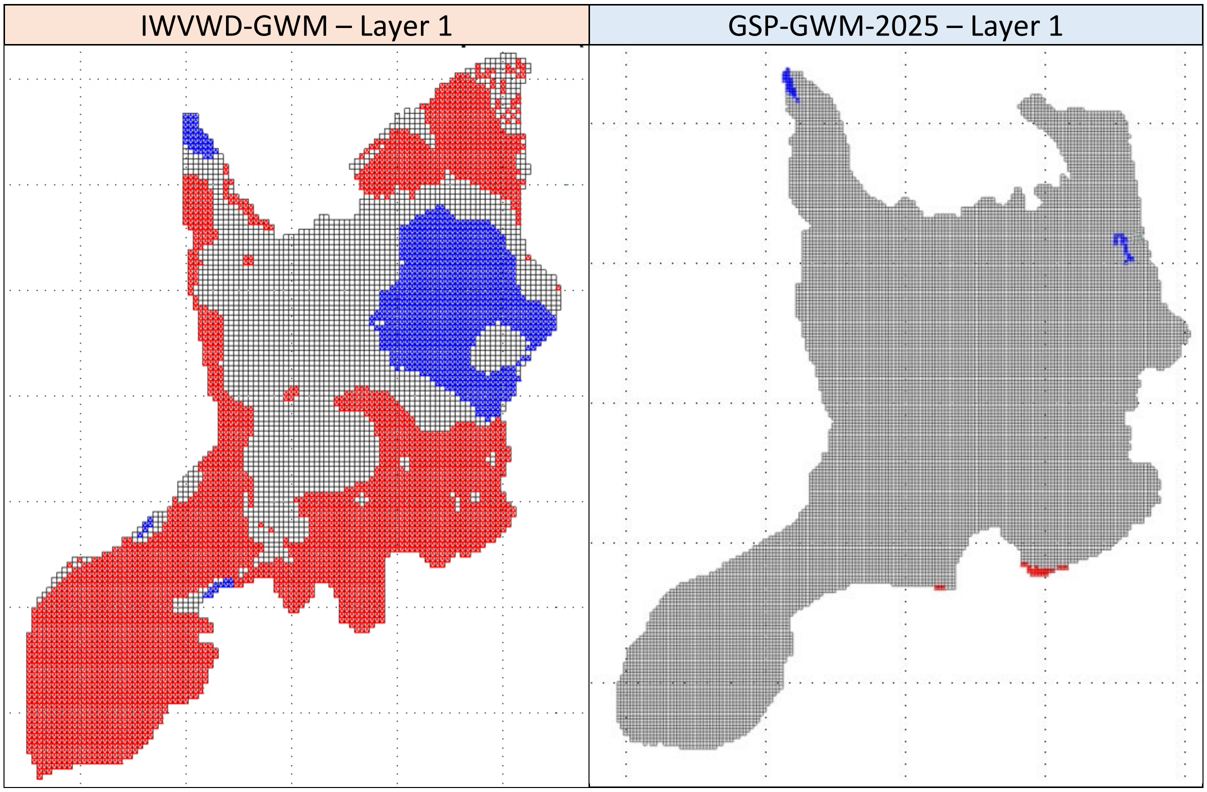
4.7.2. Dry and Flooded Cells

Evaluating the distribution of dry and flooded cells (Figure 9) is part of a first-order calibration. Dry cells occur when the model-simulated groundwater level is below the bottom of the cell. Flooded cells occur where the simulated groundwater level is above the top of the cell. Conceptually, dry cells would correspond to areas within the model domain that are expected to be drained, which shouldn't correspond to much, if any, of the model domain. Flooded cells would be expected in the simulation in areas representing wetlands or lakes, depending on how the model is designed. In the IWVGB, I wouldn't expect to see any flooded cells as there are no perennial wetlands or lakes.

Both models contain both dry and flooded cells in the uppermost layer. While there are just a few of each in the GSP-GWM-2025, both are pervasive in the IWVWD-GWM. The flooded cells in the IWVWD-GWM covering the "China Lake" playa are most concerning because they indicate that the model is not able to reasonably simulate a water budget characteristic of the basin. A cursory evaluation of simulated heads in the area reveal that the simulated reservoir is, in places, more than 20 feet above land surface.

Considering the simulation of low ET discussed above, the pervasive simulation of flooded cells indicates that the simulation of discharge cannot keep pace with the simulation of inflow resulting in a simulated reservoir of groundwater storage that extends above land surface. In short, the model simulates the presence of a lake that doesn't exist. To varying extents, the flooded cells are present across all stress periods and in every layer of the model, revealing that this is likely a systemic problem rather than with assignments unique specific stress periods.

The flooded cell problem also directly effects the model-simulation of the impact of pumping on aquifer storage and thus the estimation of safe yield. At face value, the IWVWD-GWM simulates about 42% less reduction in storage than the GSP-GWM-2025 indicating a higher potential safe yield for the same magnitude of pumping. After accounting for the magnitude of water erroneously stored above land surface however, that difference falls to only about 17% less change in storage indicating a lower safe yield for the same pumping.


IWVWD-GWM – Layer 1

GSP-GWM-2025 – Layer 1

Figure 9. Comparison of dry and flooded cells in layer-1 of the GSP-GWM-2025 (right), and IWVWD-GWM (left). Dry cells are colored red and flooded cells are colored blue. Gray lines define the respective model grids.

4.7.3. Calibration to Observed Groundwater Levels

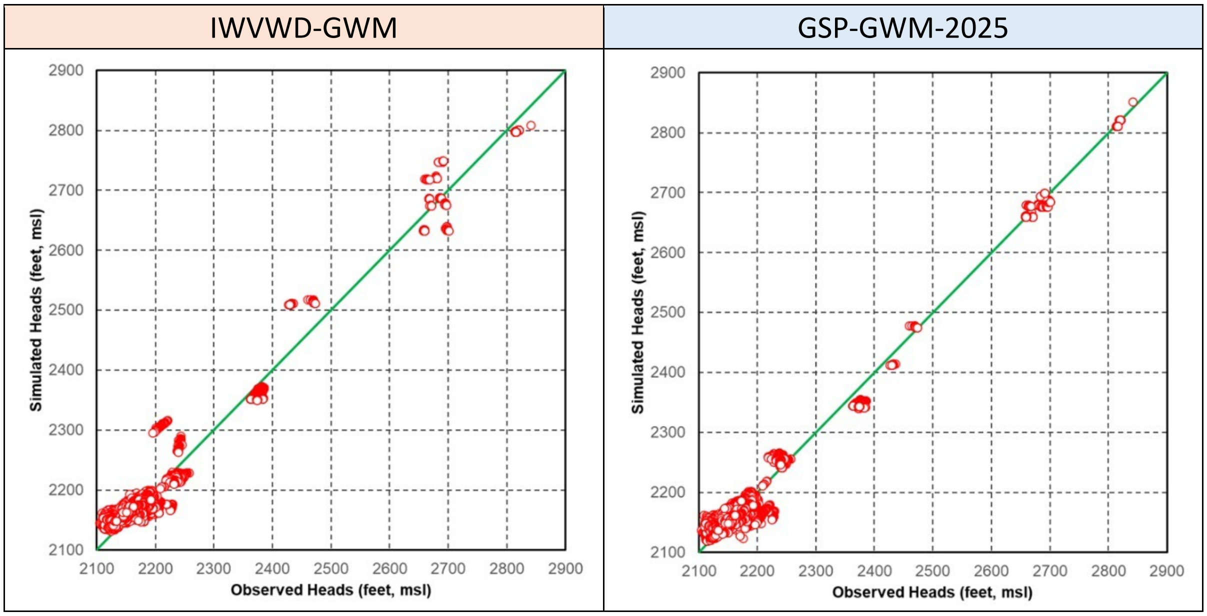
The degree to which a model-simulated groundwater levels match a set of observed values provides a measure of model reliability. In order to compare the two models using this metric, Stetson extracted simulated groundwater levels from both models such that the degree of fit could be determined using the same set of wells and water level observations. Figure 10 through Figure 14 show the results.

Residual statistics are similar for both models and both would typically be considered acceptably calibrated to observed groundwater levels (Table 3). Generally, the GSP-GWM-2025 yields a closer fit to the set of observed groundwater elevations, e.g. smaller RMSE and smaller range in residuals.

There are significant differences however (Figure 11 through Figure 14), particularly in the degree to which the respective models simulate observed water levels at specific wells. Considering those differences relative to the significantly different recharge assignments, simulated natural discharge, fault-controlled compartmentalization, and extent and magnitude of erroneously simulated flooding at the land surface, indicate that the GSP-GWM-2025 better simulates the controlling hydrologic conditions in the IWVGB and is a more reliable predictive tool.

Table 3. Comparison of Calibration Statistics for the GSP-GWM-2025 and IWVWD-GWM.

Statistic	IWVWD-GWM	GSP-GWM-2025
Number of Wells	164	164
Number of Observations	6,373	6,373
Max Observed Water Level	2,840.94	2,840.94
Min Observed Water Level	2,104.03	2,104.03
Residual Mean (ft)	-3.43	5.72
Absolute Residual Mean (ft)	14.49	14.05
Residual Std. Deviation (ft)	20.29	17.98
RMS Error (ft)	20.58	18.86
Min. Residual (ft)	-103.46	-53.33
Max. Residual (ft)	68.05	69.89
NRMSE (RMSE/ObsRange)	2.79%	2.56%



IWVWD-GWM

GSP-GWM-2025

Figure 10. Plots showing simulated vs. observed groundwater levels for the IWVWD-GWM (left) and the GSP-GWM-2025 (right) where the green line depicts a perfect fit. Note the tighter cluster of points around the green line in the GSP-GWM-2025 plot.

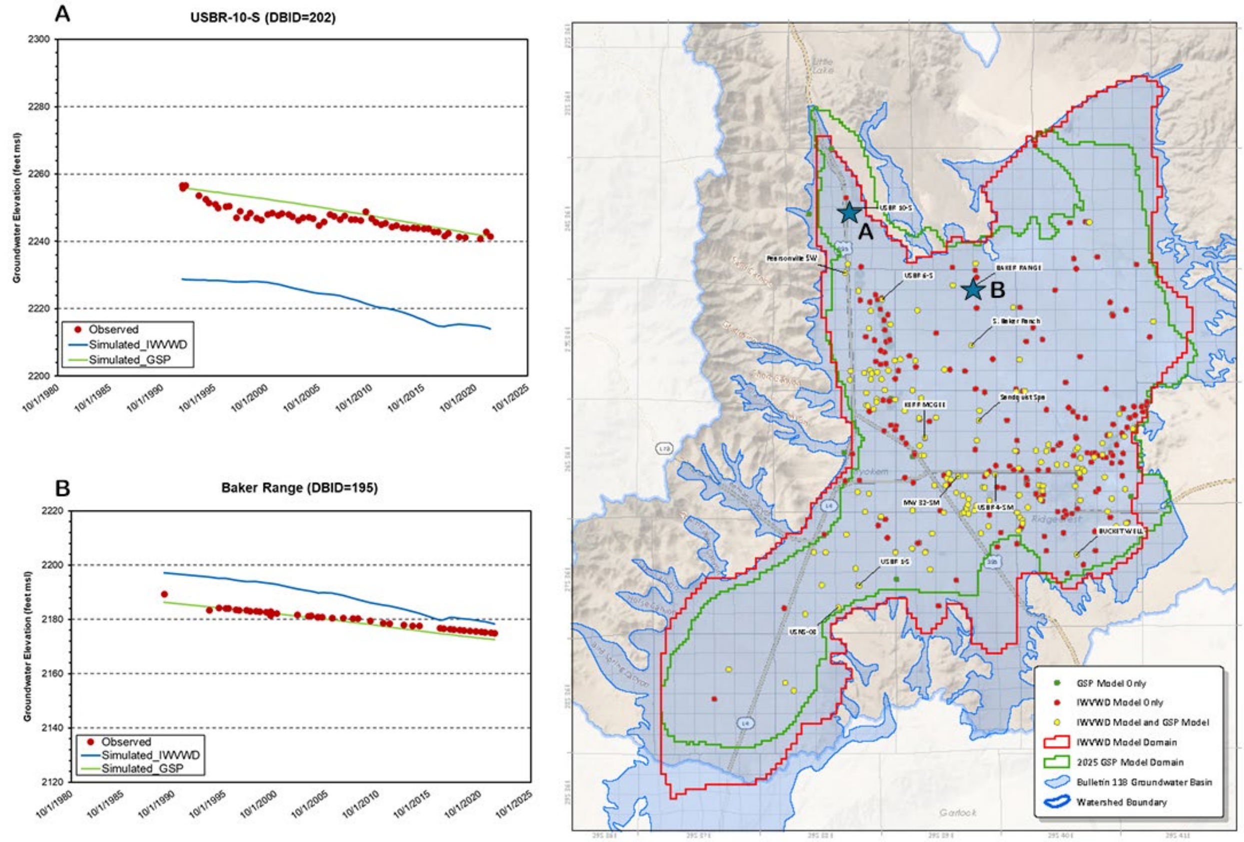


Figure 11. Comparison of model-simulated groundwater levels to observed levels at wells USBR-10-S (A) and Baker Range (B) exported from the GSP-GWM-2025 (green line) and the IWVWD-GWM (blue line). Note closer match to data produced by the GSP-GWM-2025.

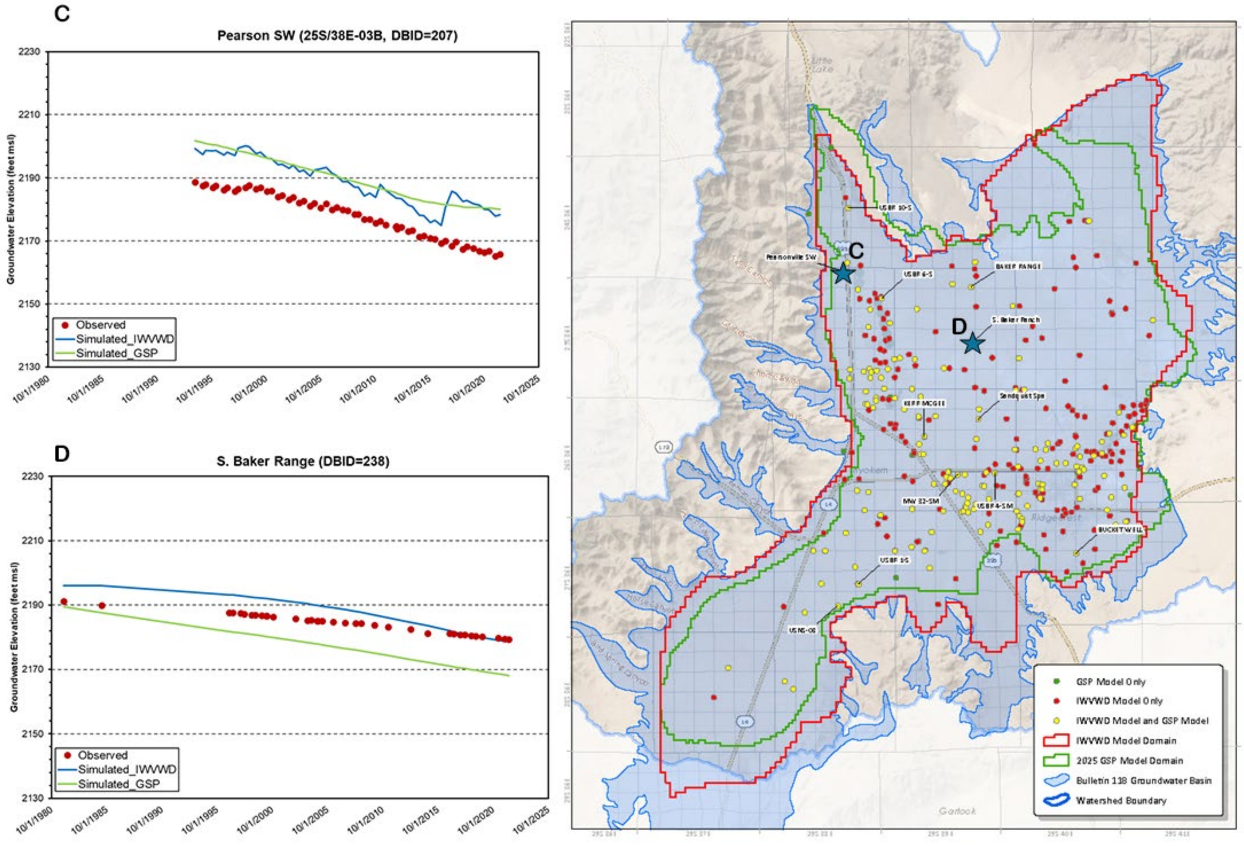


Figure 12. Comparison of model-simulated groundwater levels to observed levels at wells Pearson SW (C) and S. Baker Range (D) exported from the GSP-GWM-2025 (green line) and the IWVWD-GWM (blue line). Note the spikes in groundwater levels simulated by the IWVWD-GWM due to the proximity of the well to the mountain front recharge assignments and no apparent spikes or mounding in apparent in the well data. Deviations from the observed data at S. Baker Range (D) are similar in both models; GSP-GWM-2025 generally under-estimates while IWVWD-GWM generally over-estimates.

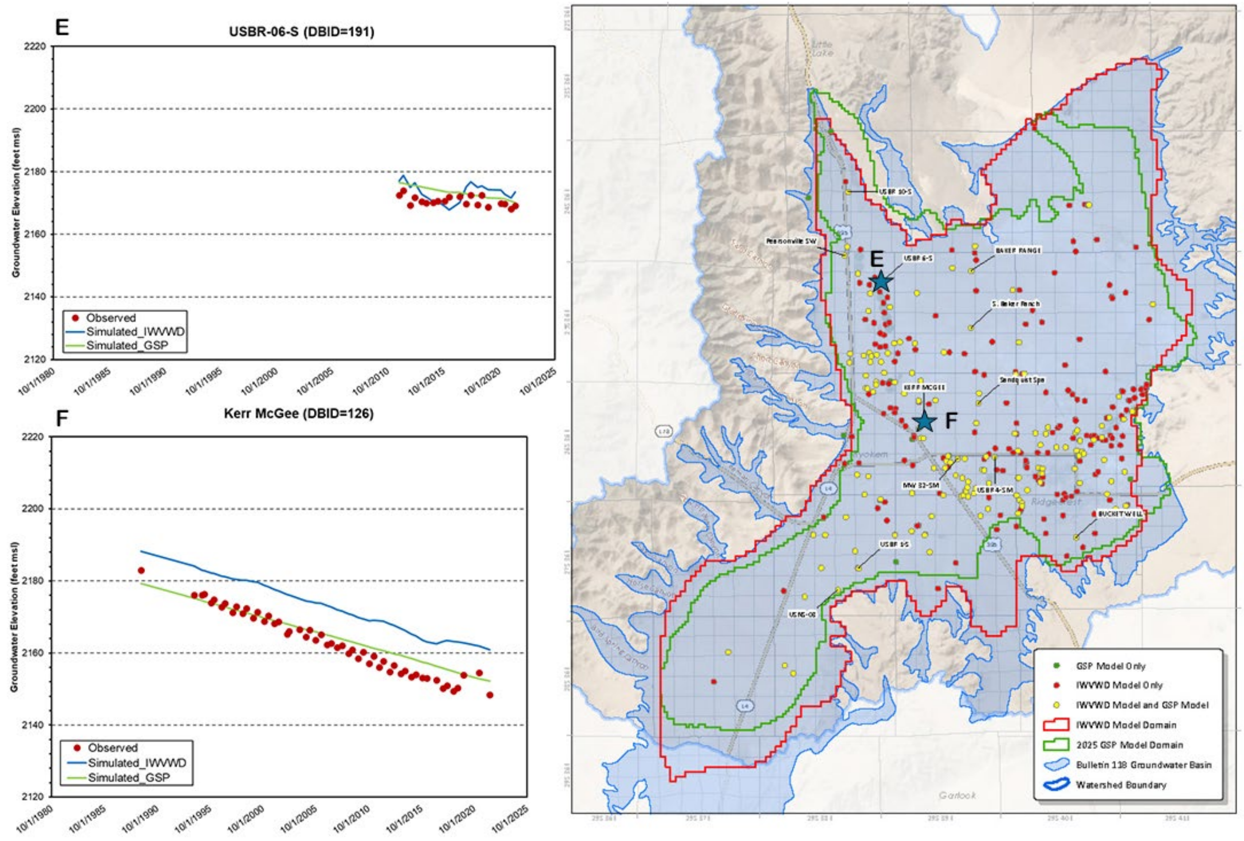


Figure 13. Comparison of model-simulated groundwater levels to observed levels at wells USBR-06-S (E) and Kerr McGee (F) exported from the GSP-GWM-2025 (green line) and the IWVWD-GWM (blue line). The GSP-GWM-2025 under-estimates the variability in the observed data at USBR-06-S while the IWVWD-GWM over-estimates it. The GSP-GWM-2025 better simulates the data at Kerr McGee.

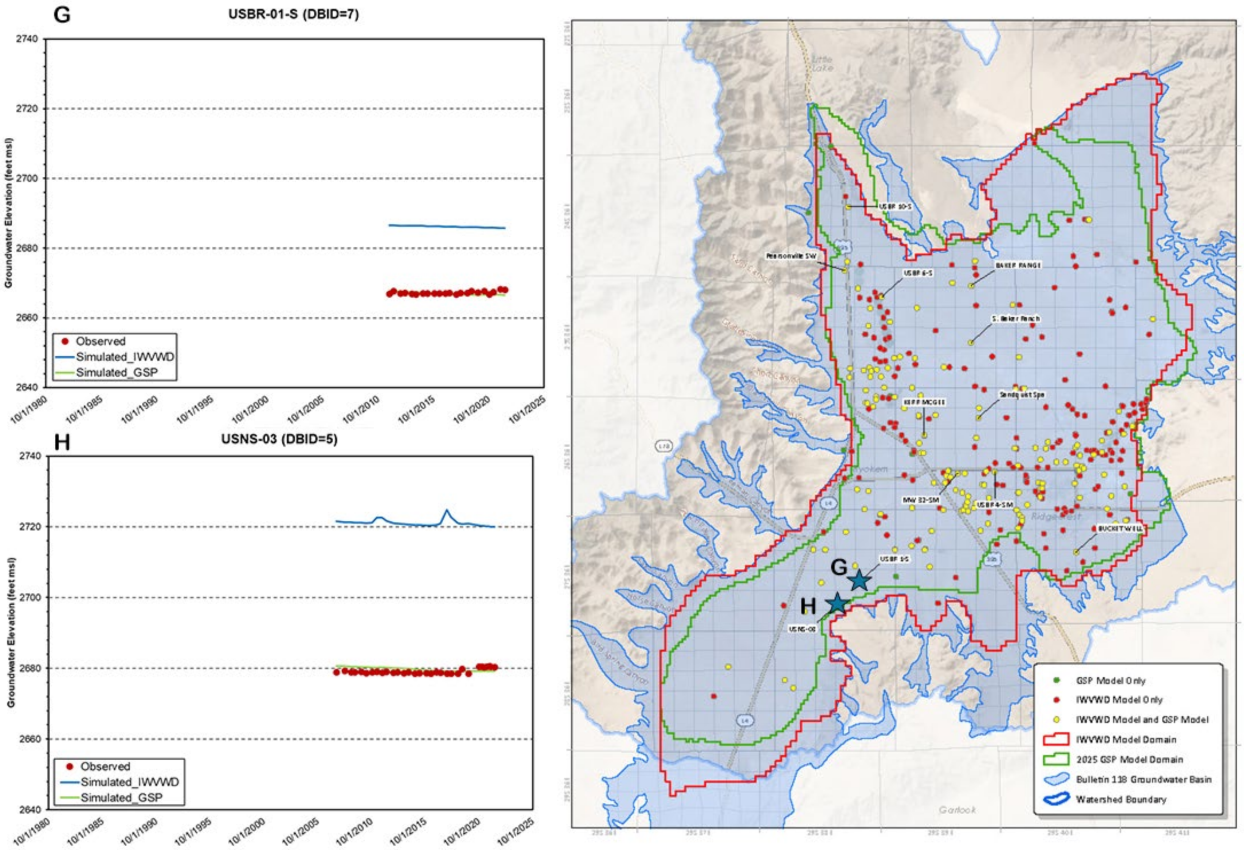


Figure 14. Comparison of model-simulated groundwater levels to observed levels at wells USBR-01-S (G) and USNS-03 (H) exported from the GSP-GWM-2025 (green line) and the IWVWD-GWM (blue line). The IWVWD-GWM significantly over-estimates groundwater levels at both wells while the GSP-GWM-2025 closely matches the data at both locations.

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Record of Reported Overdraft - IWV: 1920-2025

8/14/2025

Year	Total Pumping (AFY)	Overdraft (AFY)	Sources Pumping/Overdraft	Period (Years)	Estimated Storage Loss Over Period (AFY)	Rate of Increase in Storage Loss (AFY/year)
1920	1,000	301	3/3	NA	0[a]	NA
1953	8,726	4,000	3/1	33	29,748	112
1985	24,739	16,515	3/2	32	283,247	391
2010	22,300	15,100	4/4	25	384,520	-57
2015	25,285	25,000	5/5	5	101,958	1,980
2025	25,285	25,000	6/6	10	250,000	0
Estimated Storage Loss over 105 Years (1920 to 2025):					1,049,474	
Average Rate of Increased Storage Loss (AFY per year):						485

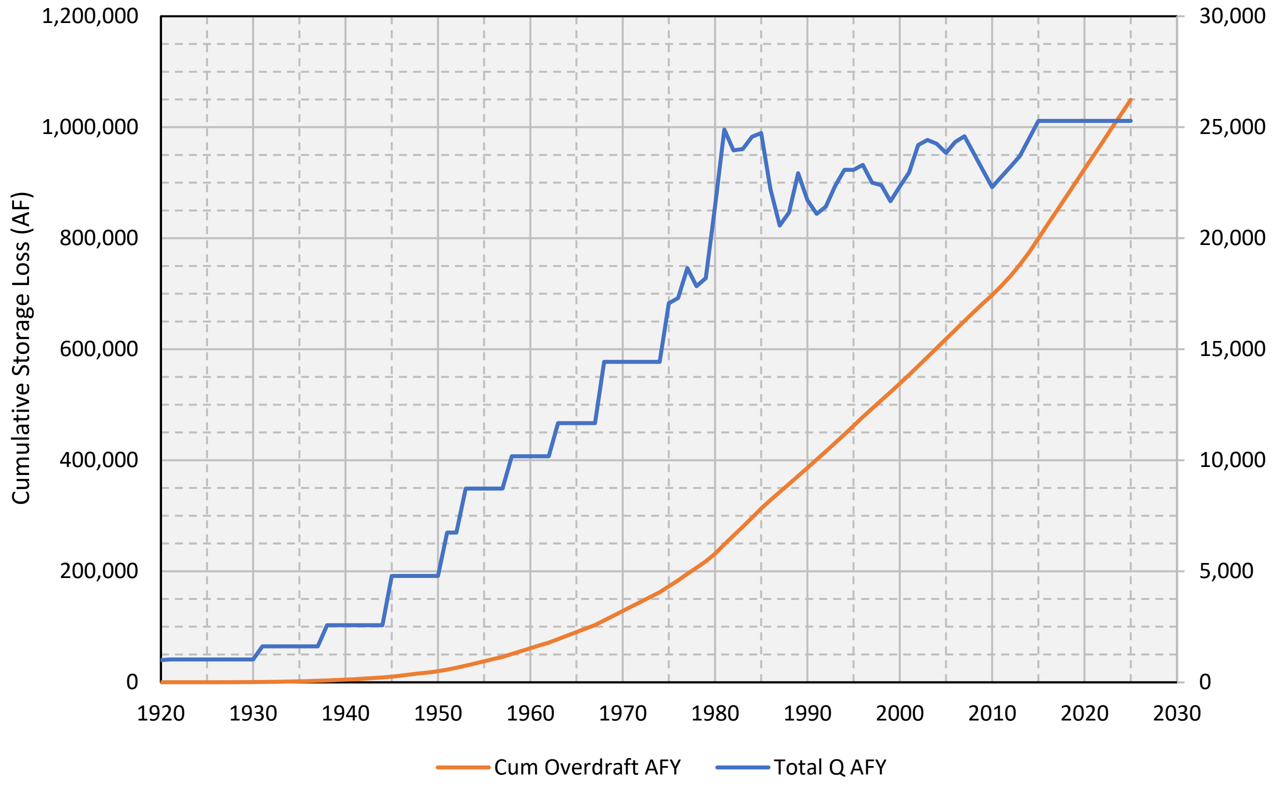
Data Sources

1) Kunkel and Chase (1969)
2) Average of values reported by Bean (1989) and Berenbrock & Martin (1991)
3) Brown and Caldwell (2009)
4) Todd Engineers (2014)
5) Stetson Engineers (2024)
6) Assume 2015 rates remained constant

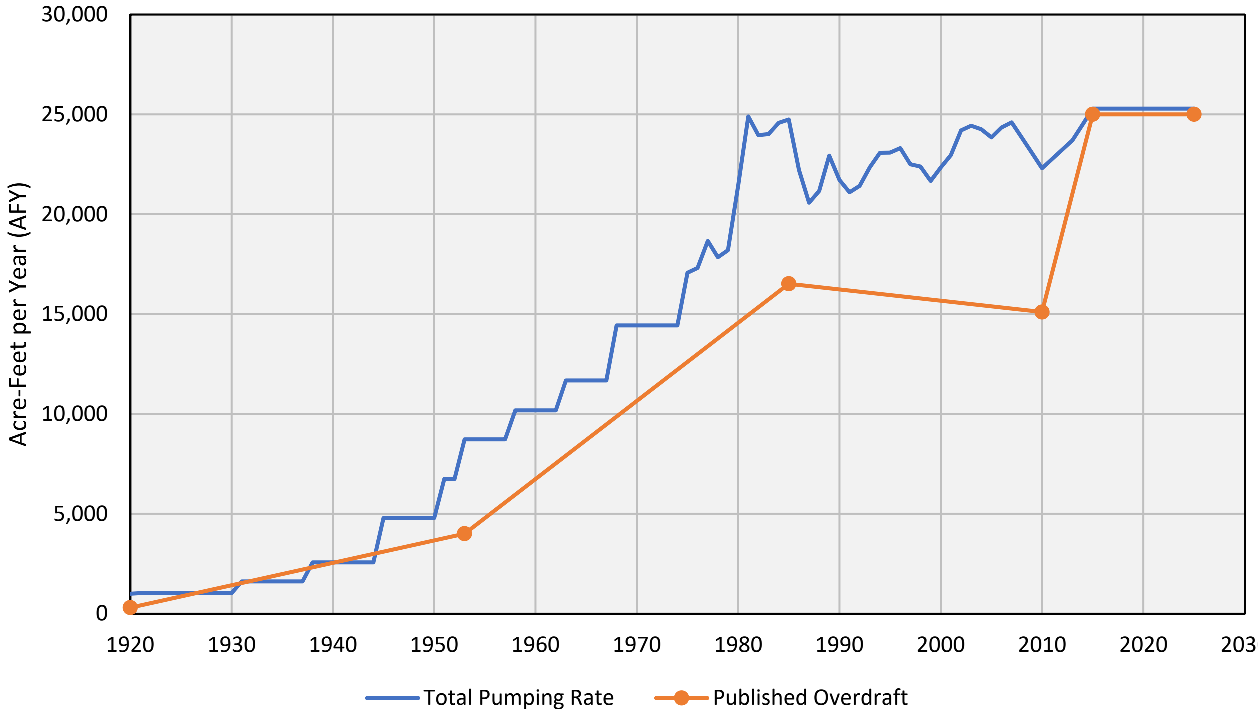
Notes

a) Assume no storage loss despite value reported

Cumulative Storage Loss & Total Annual Pumping



Reported Pumping & Overdraft



Compilation of Reported Pumping and Overdraft - Indian Wells Valley 8/14/2025

Year	Total Q AFY	Data Source Pumping	Published Overdraft AFY	Data Source Overdraft	Overdraft Est for Pumping	Cum Overdraft AFY
1920	1,000	6	0	7	0	0
1921	1,027	6	-	-	14	14
1922	1,027	6	-	-	14	28
1923	1,027	6	-	-	14	42
1924	1,027	6	-	-	14	56
1925	1,027	6	-	-	14	70
1926	1,027	6	-	-	14	84
1927	1,027	6	-	-	14	98
1928	1,027	6	-	-	14	112
1929	1,027	6	-	-	14	126
1930	1,027	6	-	-	14	140
1931	1,614	6	-	-	318	458
1932	1,614	6	-	-	318	776
1933	1,614	6	-	-	318	1,093
1934	1,614	6	-	-	318	1,411
1935	1,614	6	-	-	318	1,729
1936	1,614	6	-	-	318	2,047
1937	1,614	6	-	-	318	2,365
1938	2,567	6	-	-	811	3,176
1939	2,567	6	-	-	811	3,988
1940	2,567	6	-	-	811	4,799
1941	2,567	6	-	-	811	5,610
1942	2,567	6	-	-	811	6,421
1943	2,567	6	-	-	811	7,233
1944	2,567	6	-	-	811	8,044
1945	4,786	6	-	-	1,960	10,004
1946	4,786	6	-	-	1,960	11,964
1947	4,786	6	-	-	1,960	13,924
1948	4,786	6	-	-	1,960	15,885
1949	4,786	6	-	-	1,960	17,845
1950	4,786	6	-	-	1,960	19,805
1951	6,740	6	-	-	2,972	22,777
1952	6,740	6	-	-	2,972	25,748
1953	8,726	6	4,000	8	4,000	29,748
1954	8,726	6	-	-	4,000	33,748
1955	8,726	6	-	-	4,000	37,748
1956	8,726	6	-	-	4,000	41,748
1957	8,726	6	-	-	4,000	45,748
1958	10,179	6	-	-	5,136	50,884
1959	10,179	6	-	-	5,136	56,020
1960	10,179	6	-	-	5,136	61,155
1961	10,179	6	-	-	5,136	66,291
1962	10,179	6	-	-	5,136	71,426
1963	11,671	6	-	-	6,302	77,728
1964	11,671	6	-	-	6,302	84,030

GeoHydros

Compilation of Reported Pumping and Overdraft - Indian Wells Valley 8/14/2025

Year	Total Q AFY	Data Source Pumping	Published Overdraft AFY	Data Source Overdraft	Overdraft Est for Pumping	Cum Overdraft AFY
1965	11,671	6	-	-	6,302	90,331
1966	11,671	6	-	-	6,302	96,633
1967	11,671	6	-	-	6,302	102,935
1968	14,433	6	-	-	8,460	111,395
1969	14,433	6	-	-	8,460	119,855
1970	14,433	6	-	-	8,460	128,316
1971	14,433	6	-	-	8,460	136,776
1972	14,433	6	-	-	8,460	145,236
1973	14,433	6	-	-	8,460	153,697
1974	14,433	6	-	-	8,460	162,157
1975	17,067	6	-	-	10,519	172,676
1976	17,309	6	-	-	10,708	183,384
1977	18,656	6	-	-	11,761	195,145
1978	17,843	6	-	-	11,125	206,270
1979	18,198	6	-	-	11,403	217,673
1980	21,441	6	-	-	13,937	231,610
1981	24,894	6	-	-	16,636	248,247
1982	23,957	6	-	-	15,904	264,150
1983	24,013	6	-	-	15,948	280,098
1984	24,569	6	-	-	16,382	296,480
1985	24,739	6	16,515	9	16,515	312,995
1986	22,212	6	-	-	15,049	328,044
1987	20,573	6	-	-	14,098	342,142
1988	21,157	6	-	-	14,437	356,579
1989	22,926	6	-	-	15,463	372,042
1990	21,716	6	-	-	14,761	386,803
1991	21,096	6	-	-	14,401	401,205
1992	21,418	6	-	-	14,588	415,793
1993	22,351	6	-	-	15,130	430,923
1994	23,078	6	-	-	15,551	446,474
1995	23,079	6	-	-	15,552	462,026
1996	23,305	6	-	-	15,683	477,709
1997	22,499	6	-	-	15,215	492,925
1998	22,388	6	-	-	15,151	508,076
1999	21,668	6	-	-	14,733	522,809
2000	22,333	6	-	-	15,119	537,928
2001	22,955	6	-	-	15,480	553,408
2002	24,198	6	-	-	16,201	569,609
2003	24,428	6	-	-	16,335	585,944
2004	24,253	6	-	-	16,233	602,177
2005	23,846	6	-	-	15,997	618,174
2006	24,336	6	-	-	16,281	634,455
2007	24,593	6	-	-	16,430	650,885
2008	23,829	7	-	-	15,987	666,872
2009	23,064	7	-	-	15,543	682,416

Compilation of Reported Pumping and Overdraft - Indian Wells Valley 8/14/2025

Year	Total Q AFY	Data Source Pumping	Published Overdraft AFY	Data Source Overdraft	Overdraft Est for Pumping	Cum Overdraft AFY
2010	22,300	2	15,100	2	15,100	697,516
2011	22,767	7	-	-	16,648	714,163
2012	23,233	7	-	-	18,195	732,359
2013	23,700	2	-	-	19,743	752,102
2014	24,493	7	-	-	22,372	774,474
2015	25,285	4	25,000	7	25,000	799,474
2016	25,285	7	-	-	25,000	824,474
2017	25,285	7	-	-	25,000	849,474
2018	25,285	7	-	-	25,000	874,474
2019	25,285	7	-	-	25,000	899,474
2020	25,285	7	-	-	25,000	924,474
2021	25,285	7	-	-	25,000	949,474
2022	25,285	7	-	-	25,000	974,474
2023	25,285	7	-	-	25,000	999,474
2024	25,285	7	-	-	25,000	1,024,474
2025	25,285	2	25,000	7	25,000	1,049,474

Sources

1 Bloyd, R.M., and S.G. Robson, 1971. Mathematical groundwater model of Indian Wells Valley, California, U.S. Geological Survey Open-File Report, 36 p. Table 5, pdf-39.

2 Todd Engineers (Todd), 2014. Indian Wells Valley Resource Opportunity Plan, Water Availability and Conservation Report. Prepared for Kern County Planning and Community Development Department. Table 1, pdf-20.

3 Stetson Engineers (Stetson), 2020. Groundwater Sustainability Plan for the Indian Wells Valley Groundwater Basin, Bulletin 118 Basin No. 6-054, Indian Wells Valley Groundwater Authority. Table 3-7, pdf-157.

4 Stetson Engineers (Stetson), 2020. Groundwater Sustainability Plan for the Indian Wells Valley Groundwater Basin, Bulletin 118 Basin No. 6-054, Indian Wells Valley Groundwater Authority. Table 3-1, pdf-139.

5 Berenbrock, C., and P. Martin. 1991. “The Ground Water Flow System in the Indian Wells Valley, Kern, Inyo, and San Bernardino Counties, California.” USGS Water Resources Investigations Report 89 4191. Supplemental Data D1, pdf-80.

6 Brown and Caldwell, 2009. Indian Wells Valley basin groundwater model and hydrogeologic study. Final report. Prepared for Indian Wells Valley Water District, Ridgecrest, CA. Appendix A, pdf-75.

7 My estimation: Pumping = linear change between reported values, overdraft = 0 for 1020 and same value as 2015 for 2025

8 Kunkel, F., and G.H. Chase, 1969. “Geology and Groundwater in the Indian Wells Valley, California.” USGS Open File Report 69 329.

9 Average of values reported by Bean (1989) and Berenbrock & Martin (1991)

Total Reported Recharge (AFY)

Pub Year	Authors	Mt Front	GW Inflow	Total	Min	Max	Notes
1969	Kunkel and Chase	-	-	11,000	-	-	Estimate for 1912. Based on ET estimates from Lee (1913) updated using aerial photos, ET studies and measured water table declines between 1912 and 1953.
1969	Kunkel and Chase	-	-	8,000	8,000	15,000	Estimate for 1953. Low value is etimated ET updated from Lee (1913) using aerial photos and ET rate studies. High value is from GW flow calculation using Darcy's Law, gradient across the 1921 2,200-foot water level contour, and transmissivity estimated from pump tests and extrapolated to 400-foot aquifer thickness, where an additional 3,000 AFY of potential underflow through the lower permeability older alluvium sediments is discounted.
1971	Bloyd and Robson	9,803	45	9,848	-	-	Estimated mountain front recharge and inflow from Rose Valley using an analytical model relating recharge from precipitation to elevation.
1973	Dutcher and Moyle	-	-	11,000	-	-	Estimate for 1912. From Kunkel and Chase (1969).
1986	St. Amand	-	-	11,000	-	-	
1989	Bean	9,700	400	10,100	-	-	Estimate for Circa 1989. Commissioned to evauate "open" vs "closed" basin conceptual model. Author favors the closed-basin model. Recharge estimates based on review of published values and author's professional experience.
1991	Berenbrock and Martin	9,852	-	9,852	-	-	Limited to their assignment of mountain front recharge. Omitting 1,100 AFY of artificial recharge from WWTF discharge to shallow aquifer.
1993	Watt	9,900	-	9,900	-	-	
1995	Gillespie & Thyne	6,809	952	7,761	7,761	9,061	Estimate for 1995. Estimates for recharge from surface flow. Estimates from GW flux calculations are discounted. High estimated inflow from Rose Valley includes 1,300 AFY surface flow from Little Lake which is attributable to high precipitation that year.
2009	Brown and Caldwell	7,521	1,300	8,821	-	-	Recharge for 1920 started at 11,000 reduced through GW model calibration. Pumping assumed same as estimated by Berenbrock and Martin (1991).
2010	Epstein et al.	9,300	-	9,300	5,800	12,000	
2014	Todd Engineers	6,440	1,000	7,440	6,040	8,840	Estimate for Circa 2014. Estimates based on author's review of published values from other researchers and author's professional experience.
2016	DRI	5,250	2,400	7,650	-	-	Estimate for Circa 2016. Recharge and ET independently estimated. Distribution and magnitude adjusted through groundwater model calibration.
2019	USGS	7,938	742	8,680	-	-	Estimate for 1981-2010. Recharge estimated derived from application of the Basin Characterization Model.
2019	USGS	5,379	597	5,976	-	-	Estimate for 2000-2013. Recharge estimated derived from application of the Basin Characterization Model.

Total Reported Recharge - Statistics (AFY)					
	Mt Front	GW Inflow	Total	Min	Max
Count	11	8	15	4	4
Max	9,900	2,400	11,000	8,000	15,000
Min	5,250	45	5,976	5,800	8,840
Range	4,650	2,355	5,024	2,200	6,160
Average	7,990	930	9,089	6,900	11,225
Standard Deviation	1,827	708	1,500		
Average (1989 - 2019)	***7,809***	***1,056***	***8,548***	*6,534*	*9,967*
Standard Dev (1989-2019)	*1,819*	*661*	*1,328*		

Estimated Range in Mountain Front Recharge (AFY)

Avg-1 StDev	Avg+1 StDev
6,000	9,600

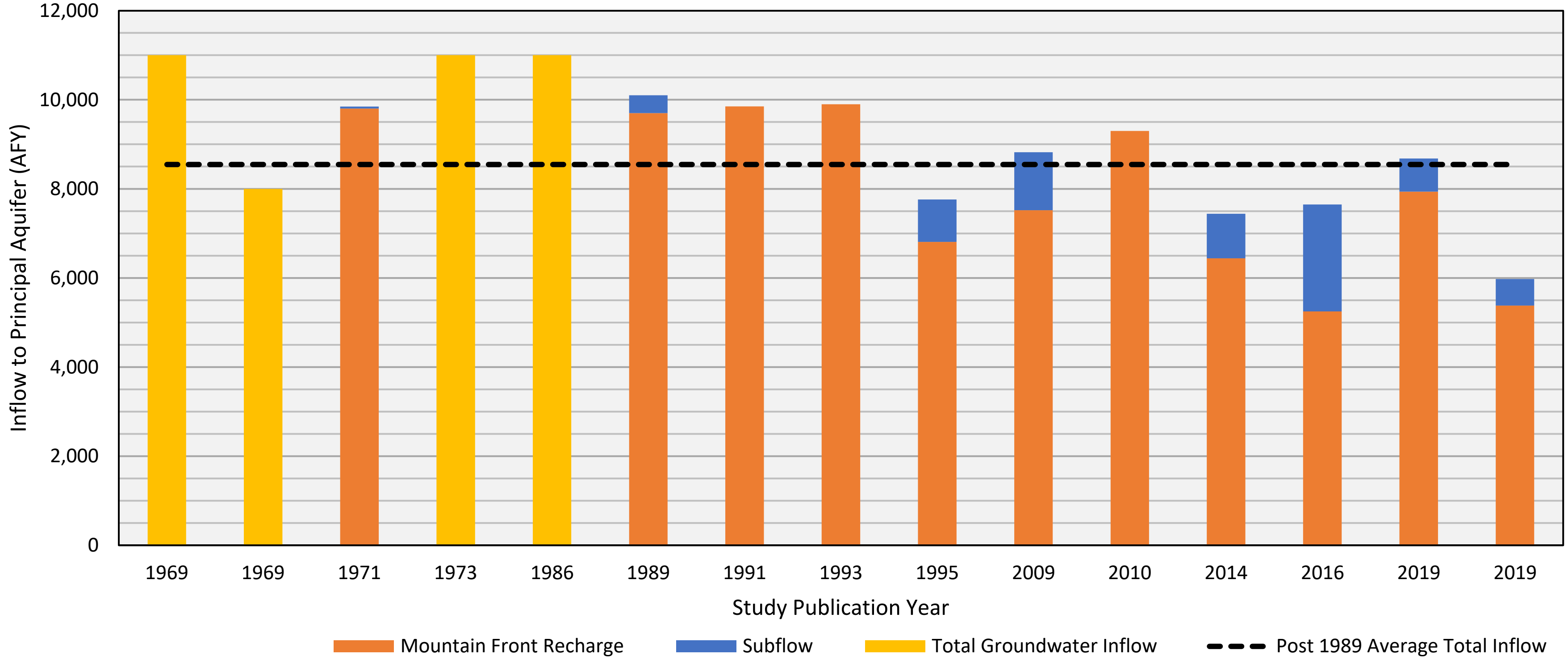
Estimated Range in Total Groundwater Inflow (AFY)

Avg-1 StDev	Avg+1 StDev
7,200	9,900

Estimated Safe Yield (Total Estimated Groundwater Inflow - 15%)

Min	Max
6,100	8,400

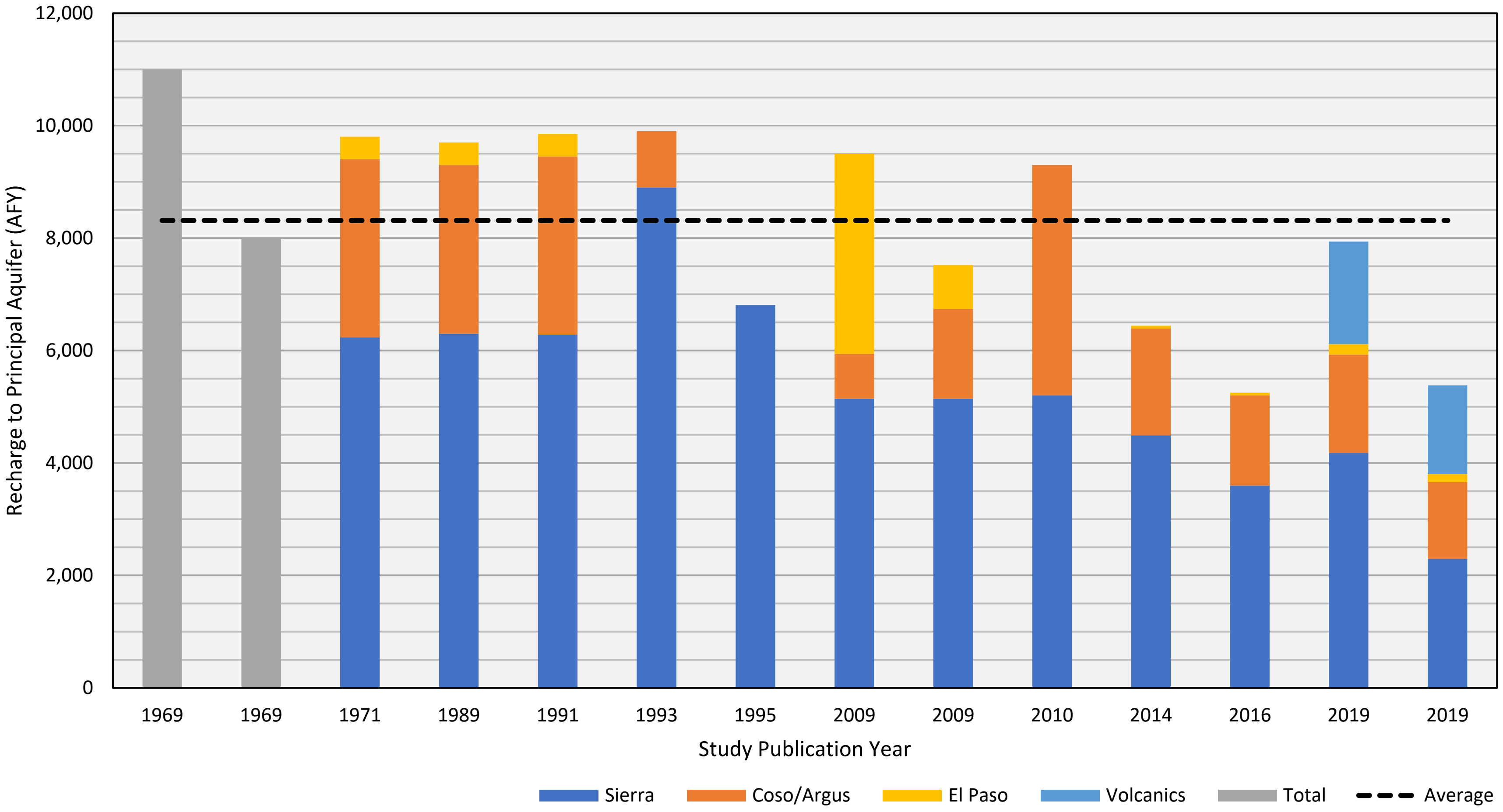
Published Recharge Estimates Over Time



Reported Mountain Front Recharge

Data Source		Sierra Mountain Front					Northeast Mts			Southwest Mts				
Pub Year	Authors	South	North	Total Min	Max	BestEst	Coso	Argus	Total	ElPaso	Volcan-ics	Total Min	Max	BestEst
1969	Kunkel and Chase	-	-	-	-	-	-	-	-	-	-	-	-	11,000
1969	Kunkel and Chase	-	-	-	-	-	-	-	-	-	-	-	-	8,000
1971	Bloyd and Robson	4,490	1,745	-	-	6,235	1,590	1,578	3,168	400	-	-	-	9,803
1973	Dutcher and Moyle	-	-	-	-	-	-	-	-	-	-	-	-	-
1986	St. Amand	-	-	-	-	-	-	-	-	-	-	-	-	-
1989	Bean	-	-	-	-	6,300	2,000	1,000	3,000	400	-	-	-	9,700
1991	Berenbrock and Martin	4,129	2,153	-	-	6,282	-	-	3,170	400	-	-	-	9,852
1992	Anderson et al.	-	-	-	-	-	-	-	-	-	-	-	-	-
1993	Watt	-	-	-	-	8,900	-	-	1,000	-	-	-	-	9,900
1995	Gillespie & Thyne	3,913	2,896	-	-	6,809	-	-	-	-	-	-	-	6,809
2009	Brown and Caldwell	-	-	-	-	5,140	-	-	800	3,560	-	-	-	9,500
2009	Brown and Caldwell	-	-	-	-	5,140	-	-	1,600	781	-	-	-	7,521
2010	Epstein et al.	-	-	-	-	5,200	-	4,100	4,100	-	-	-	-	9,300
2014	Todd Engineers	-	-	3,090	5,890	4,490	-	-	1,900	50	-	5,040	7,840	6,440
2016	DRI	1,500	2,100	-	-	3,600	-	-	1,600	50	-	-	-	5,250
2019	USGS	-	-	-	-	4,181	741	1,006	1,747	186	1,824	-	-	7,938
2019	USGS	-	-	-	-	2,295	536	829	1,365	144	1,575	-	-	5,379
	Count	4	4	1	1	12	4	5	11	9	2	1	1	14
	Max	4,490	2,896	3,090	5,890	8,900	2,000	4,100	4,100	3,560	1,824	5,040	7,840	11,000
	Min	1,500	1,745	3,090	5,890	2,295	536	829	800	50	1,575	5,040	7,840	5,250
	Range	2,990	1,151	0	0	6,605	1,464	3,271	3,300	3,510	249	0	0	5,750
	Average	3,508	2,224	3,090	5,890	**5,381**	**1,217**	**1,703**	2,132	**663**	**1,700**	5,040	7,840	**8,314**
	Median	4,021	2,127	3,090	5,890	5,170	1,166	1,006	1,747	400	1,700	5,040	7,840	8,650
	Average (1989 - 2019)	*3,181*	*2,383*	*3,090*	*5,890*	*5,303*	*1,092*	*1,734*	*2,028*	*696*	*1,700*	*5,040*	*7,840*	***7,963***

Published Mountain Front Recharge Estimates Over Time

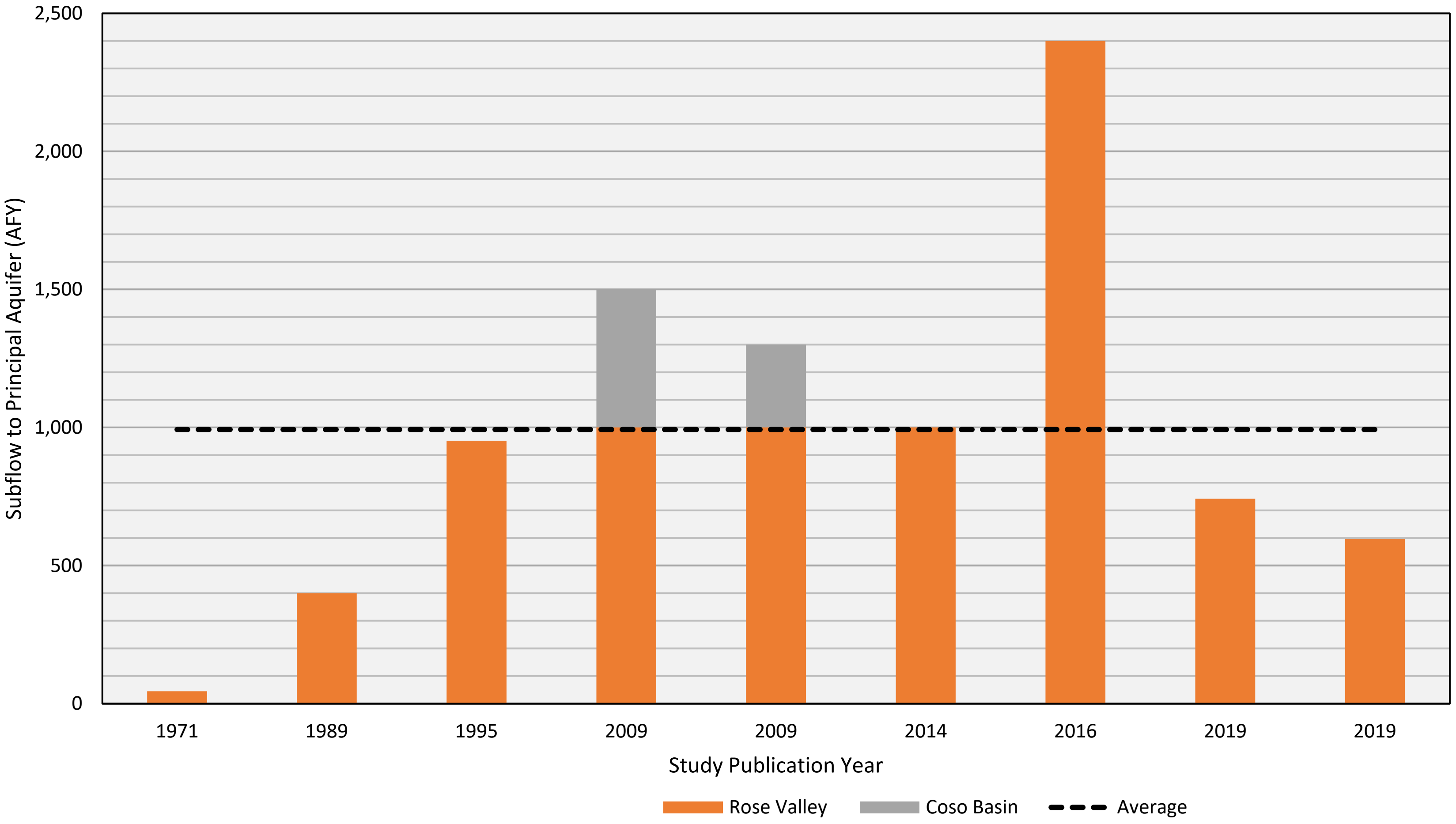


Reported Groundwater Inflow

Data Source		RoseValley			Coso Basin	Total		
Pub Year	Authors	Min	Max	BestEst	BestEst	Min	Max	BestEst
1969	Kunkel and Chase	-	-	-	-	-	-	-
1969	Kunkel and Chase	-	-	-	-	-	-	-
1971	Bloyd and Robson	-	-	45	-	-	-	45
1973	Dutcher and Moyle	-	-	-	-	-	-	-
1986	St. Amand	-	-	-	-	-	-	-
1989	Bean	-	-	400	-	-	-	400
1991	Berenbrock and Martin	-	-	-	-	-	-	-
1992	Anderson et al.	-	-	-	-	-	-	-
1993	Watt	-	-	-	-	-	-	-
1995	Gillespie & Thyne	952	2,252	952	-	952	2,252	952
2009	Brown and Caldwell	-	-	1,000	500	-	-	1,500
2009	Brown and Caldwell	-	-	1,000	300	-	-	1,300
2010	Epstein et al.	-	-	-	-	-	-	-
2014	Todd Engineers	-	-	1,000	-	-	-	1,000
2016	DRI	-	-	2,400	-	-	-	2,400
2019	USGS	-	-	742	-	-	-	742
2019	USGS	-	-	597	-	-	-	597
Count		1	1	9	2	1	1	9
Max		952	2,252	2,400	500	952	2,252	2,400
Min		952	2,252	45	300	952	2,252	45
Range		0	0	2,355	200	0	0	2,355
Average		952	2,252	**904**	**400**	952	2,252	**993**
Median		952	2,252	952	400	952	2,252	952

GeoHydros

Published Subflow Estimates Over Time

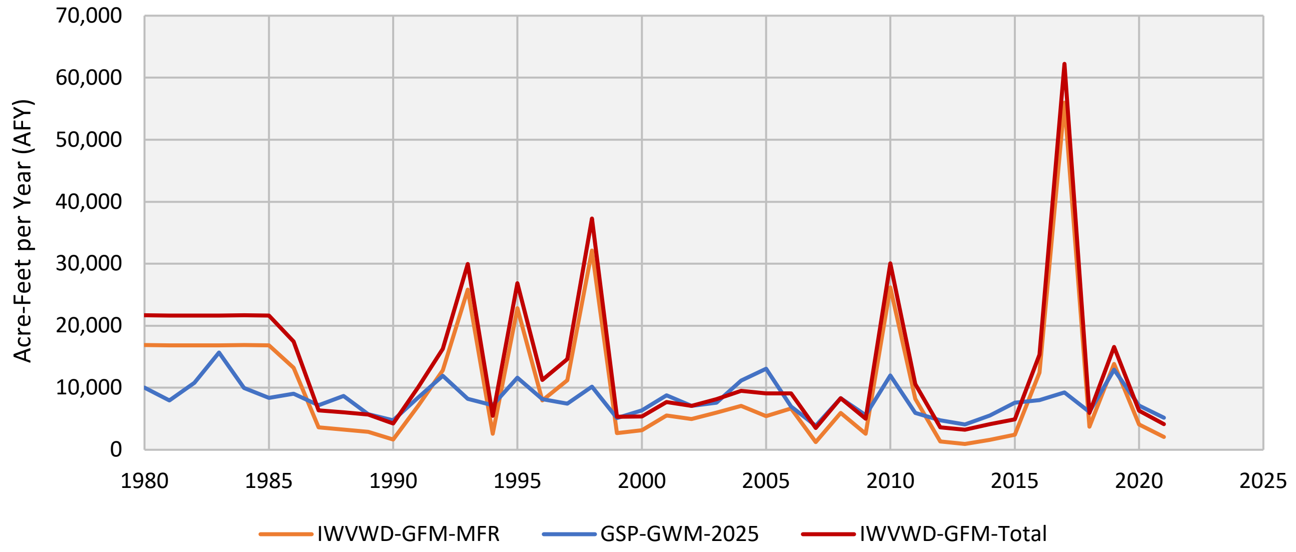


Model Water Budget Comparisons - IWVGB 8/14/2025

TWG Model (IWVWD Model)					Calculations				
Year	Mountain Front Recharge	Return Flow	ET	Pumping	Total Recharge	Net Storage Change	Return Flow as % Pumping	% Flow to ET	% Flow to Wells
1980	16,868	4,832	2,314	19,386	21,700	0	24.9%	10.7%	89.3%
1981	16,822	4,819	2,308	19,333	21,641	0	24.9%	10.7%	89.3%
1982	16,822	4,819	2,308	19,333	21,641	0	24.9%	10.7%	89.3%
1983	16,822	4,819	2,308	19,333	21,641	0	24.9%	10.7%	89.3%
1984	16,868	4,832	2,314	19,386	21,700	0	24.9%	10.7%	89.3%
1985	16,822	4,819	2,308	19,333	21,641	0	24.9%	10.7%	89.3%
1986	13,238	4,197	2,307	28,945	17,435	-13,817	14.5%	13.2%	86.8%
1987	3,612	2,748	2,304	24,603	6,360	-20,547	11.2%	36.2%	63.8%
1988	3,261	2,768	2,303	24,368	6,029	-20,642	11.4%	38.2%	61.8%
1989	2,874	2,785	2,285	24,997	5,659	-21,623	11.1%	40.4%	59.6%
1990	1,631	2,594	2,271	23,540	4,225	-21,586	11.0%	53.8%	46.2%
1991	7,075	2,976	2,255	22,879	10,051	-15,083	13.0%	22.4%	77.6%
1992	12,807	3,484	2,243	23,169	16,291	-9,121	15.0%	13.8%	86.2%
1993	25,810	4,128	2,221	24,211	29,938	3,506	17.1%	7.4%	92.6%
1994	2,580	2,896	2,207	24,728	5,476	-21,459	11.7%	40.3%	59.7%
1995	22,833	4,008	2,192	24,774	26,841	-125	16.2%	8.2%	91.8%
1996	7,974	3,274	2,184	24,990	11,248	-15,926	13.1%	19.4%	80.6%
1997	11,197	3,435	2,164	24,289	14,632	-11,821	14.1%	14.8%	85.2%
1998	32,116	5,174	2,150	24,816	37,290	10,324	20.8%	5.8%	94.2%
1999	2,670	2,627	2,137	22,080	5,297	-18,920	11.9%	40.3%	59.7%
2000	3,171	2,191	2,129	23,616	5,362	-20,383	9.3%	39.7%	60.3%
2001	5,536	2,180	2,106	23,165	7,716	-17,555	9.4%	27.3%	72.7%
2002	4,964	2,128	2,087	22,853	7,092	-17,848	9.3%	29.4%	70.6%
2003	5,993	2,162	2,067	24,148	8,155	-18,060	9.0%	25.3%	74.7%
2004	7,095	2,388	2,052	24,306	9,483	-16,875	9.8%	21.6%	78.4%
2005	5,451	3,616	2,026	22,796	9,067	-15,755	15.9%	22.3%	77.7%
2006	6,641	2,448	2,009	25,064	9,089	-17,984	9.8%	22.1%	77.9%
2007	1,230	2,268	1,992	25,897	3,498	-24,391	8.8%	56.9%	43.1%
2008	5,965	2,361	1,977	25,203	8,326	-18,854	9.4%	23.7%	76.3%
2009	2,588	2,423	1,949	25,565	5,011	-22,503	9.5%	38.9%	61.1%
2010	26,172	3,889	1,924	22,775	30,061	5,362	17.1%	6.4%	93.6%
2011	8,204	2,380	1,899	22,695	10,584	-14,010	10.5%	17.9%	82.1%
2012	1,370	2,270	1,881	24,698	3,640	-22,939	9.2%	51.7%	48.3%
2013	939	2,299	1,850	24,861	3,238	-23,473	9.2%	57.1%	42.9%
2014	1,597	2,555	1,822	28,594	4,152	-26,264	8.9%	43.9%	56.1%
2015	2,428	2,483	1,791	26,902	4,911	-23,782	9.2%	36.5%	63.5%
2016	12,447	2,909	1,763	26,691	15,356	-13,098	10.9%	11.5%	88.5%
2017	55,966	6,268	1,729	23,991	62,234	36,514	26.1%	2.8%	97.2%
2018	3,730	2,224	1,709	23,087	5,954	-18,842	9.6%	28.7%	71.3%
2019	13,823	2,783	1,690	21,656	16,606	-6,740	12.9%	10.2%	89.8%
2020	4,069	2,218	1,676	22,206	6,287	-17,595	10.0%	26.7%	73.3%
2021	2,058	2,079	1,651	22,096	4,137	-19,610	9.4%	39.9%	60.1%
Statistics									
Max	*55,966*	*6,268*	*2,314*	*28,945*	*62,234*	*36,514*	*26.1%*	*57.1%*	*97.2%*
Min	*939*	*2,079*	*1,651*	*19,333*	*3,238*	*-26,264*	*8.8%*	*2.8%*	*42.9%*
Range	*55,027*	*4,189*	*663*	*9,612*	*58,996*	*62,778*	*17.4%*	*54.4%*	*54.4%*
Average	*10,289*	*3,204*	*2,068*	*23,604*	*13,493*	*-12,179*	*13.9%*	*25.2%*	*74.8%*
Median	*6,317*	*2,776*	*2,118*	*24,070*	*9,078*	*-17,215*	*11.3%*	*22.4%*	*77.6%*

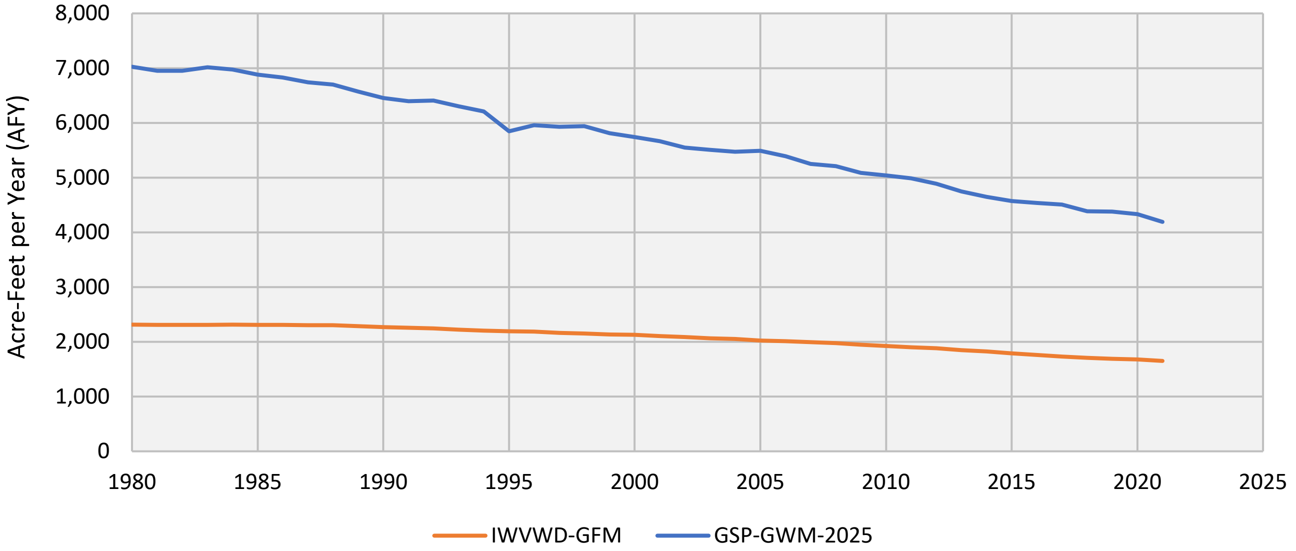
GSP-2025 Model					Calculations				**Reported Values**	
Year	Recharge	ET	Outflow to Salt Wells	Pumping	Net Storage Change	% Flow to ET	% Flow to Wells	% Flow to Salt Wells	Pumping	Overdraft
1980	10,024	7,025	36	27,025	-24,061	70.1%	29.9%	0.4%	21,441	-13,937
1981	7,968	6,952	35	29,271	-28,290	87.2%	12.8%	0.4%	24,894	-16,636
1982	10,814	6,949	34	28,560	-24,729	64.3%	35.7%	0.3%	23,957	-15,904
1983	15,682	7,013	35	28,912	-20,277	44.7%	55.3%	0.2%	24,013	-15,948
1984	9,951	6,974	34	29,657	-26,714	70.1%	29.9%	0.3%	24,569	-16,382
1985	8,346	6,882	33	29,149	-27,718	82.5%	17.5%	0.4%	24,739	-16,515
1986	9,040	6,828	33	25,764	-23,584	75.5%	24.5%	0.4%	22,212	-15,049
1987	7,187	6,740	32	23,221	-22,805	93.8%	6.2%	0.4%	20,573	-14,098
1988	8,662	6,699	31	24,345	-22,413	77.3%	22.7%	0.4%	21,157	-14,437
1989	5,739	6,569	30	25,553	-26,414	114.5%	-14.5%	0.5%	22,926	-15,463
1990	4,735	6,452	29	24,360	-26,105	136.3%	-36.3%	0.6%	21,716	-14,761
1991	8,428	6,398	28	23,877	-21,876	75.9%	24.1%	0.3%	21,096	-14,401
1992	11,908	6,406	28	24,473	-18,999	53.8%	46.2%	0.2%	21,418	-14,588
1993	8,212	6,302	27	25,288	-23,405	76.7%	23.3%	0.3%	22,351	-15,130
1994	7,168	6,208	26	25,713	-24,779	86.6%	13.4%	0.4%	23,078	-15,551
1995	11,649	5,848	27	23,771	-17,997	50.2%	49.8%	0.2%	23,079	-15,552
1996	8,141	5,957	25	25,831	-23,672	73.2%	26.8%	0.3%	23,305	-15,683
1997	7,441	5,931	26	25,374	-23,891	79.7%	20.3%	0.3%	22,499	-15,215
1998	10,201	5,938	26	25,087	-20,851	58.2%	41.8%	0.3%	22,388	-15,151
1999	5,133	5,809	25	24,990	-25,691	113.2%	-13.2%	0.5%	21,668	-14,733
2000	6,345	5,744	24	25,546	-24,968	90.5%	9.5%	0.4%	22,333	-15,119
2001	8,779	5,663	23	26,514	-23,422	64.5%	35.5%	0.3%	22,955	-15,480
2002	7,063	5,549	22	27,947	-26,456	78.6%	21.4%	0.3%	24,198	-16,201
2003	7,583	5,508	22	29,005	-26,951	72.6%	27.4%	0.3%	24,428	-16,335
2004	11,169	5,474	21	28,817	-23,144	49.0%	51.0%	0.2%	24,253	-16,233
2005	13,068	5,491	21	28,835	-21,279	42.0%	58.0%	0.2%	23,846	-15,997
2006	6,972	5,389	21	29,267	-27,705	77.3%	22.7%	0.3%	24,336	-16,281
2007	3,863	5,250	19	29,106	-30,513	135.9%	-35.9%	0.5%	24,593	-16,430
2008	8,329	5,209	18	28,182	-25,081	62.5%	37.5%	0.2%	23,829	-15,987
2009	5,591	5,088	17	28,088	-27,602	91.0%	9.0%	0.3%	23,064	-15,543
2010	11,973	5,040	17	27,001	-20,085	42.1%	57.9%	0.1%	22,300	-15,100
2011	5,942	4,988	16	27,265	-26,328	83.9%	16.1%	0.3%	22,767	-16,648
2012	4,735	4,886	15	27,503	-27,669	103.2%	-3.2%	0.3%	23,233	-18,195
2013	4,073	4,745	14	27,099	-27,785	116.5%	-16.5%	0.3%	23,700	-19,743
2014	5,517	4,646	13	27,276	-26,418	84.2%	15.8%	0.2%	24,493	-22,372
2015	7,593	4,574	13	26,041	-23,034	60.2%	39.8%	0.2%	25,285	-25,000
2016	7,988	4,534	12	26,060	-22,619	56.8%	43.2%	0.2%	25,285	-25,000
2017	9,246	4,508	12	25,916	-21,189	48.8%	51.2%	0.1%	25,285	-25,000
2018	6,103	4,382	11	24,905	-23,195	71.8%	28.2%	0.2%	25,285	-25,000
2019	12,909	4,377	11	22,646	-14,125	33.9%	66.1%	0.1%	25,285	-25,000
2020	7,110	4,334	10	21,272	-18,506	61.0%	39.0%	0.1%	25,285	-25,000
2021	5,191	4,191	9	21,691	-20,700	80.7%	19.3%	0.2%	25,285	-25,000
Statistics										
Max	*15,682*	*7,025*	*36*	*29,657*	*-14,125*	*136.3%*	*66.1%*	*0.6%*	*25,285*	*-13,937*
Min	*3,863*	*4,191*	*9*	*21,272*	*-30,513*	*33.9%*	*-36.3%*	*0.1%*	*20,573*	*-25,000*
Range	*11,819*	*2,834*	*27*	*8,385*	*16,388*	*102.4%*	*102.4%*	*0.5%*	*4,712*	*11,063*
Average	*8,180*	*5,701*	*23*	*26,338*	*-23,882*	*76.0%*	*24.0%*	*0.3%*	*23,438*	*-17,424*
Median	*7,978*	*5,704*	*24*	*26,051*	*-23,782*	*75.7%*	*24.3%*	*0.3%*	*23,503*	*-15,967*

A - Recharge Comparison



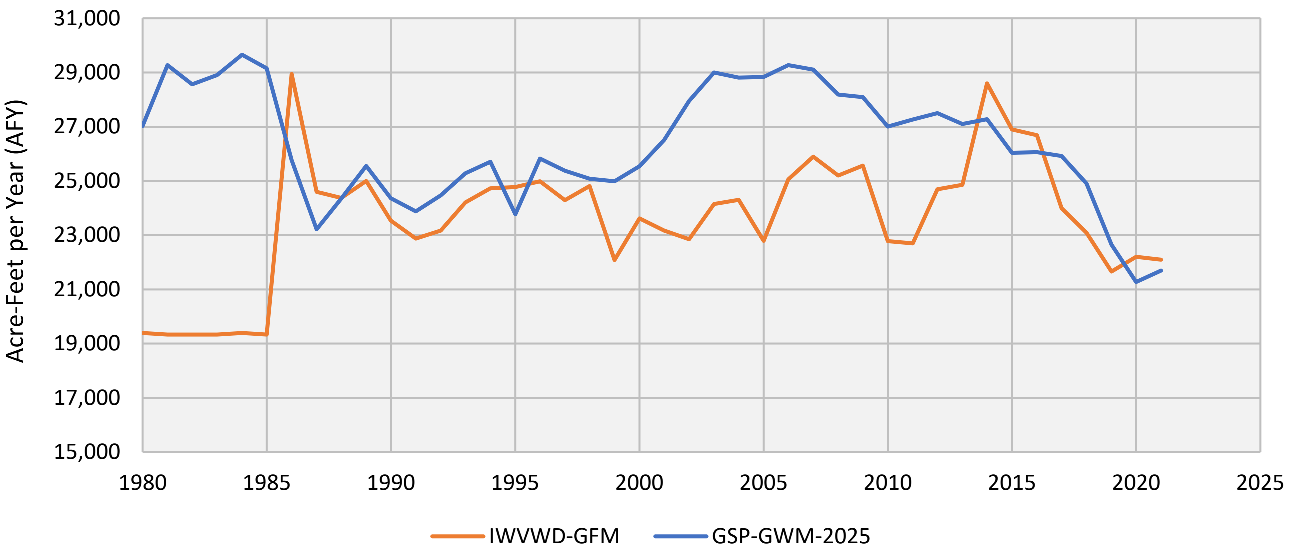
Spikes in IWVWD-GFM recharge are runoff floods that were assumed resulted in rechagre but there is no mounding in groundwater surface elevations apparent in nearby wells. This magnitude of recharge is therefore speculative and not supported by data or other published accounts.

B - ET Comparison



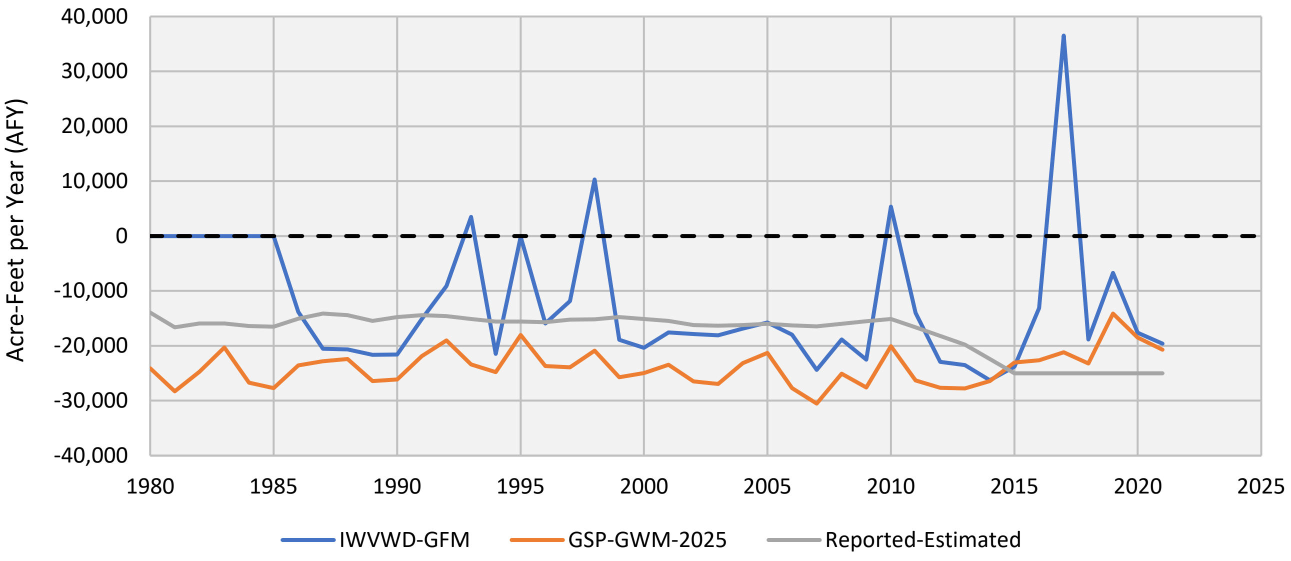
ET in the IWVWD-GFM is unreasonably low given the number of flooded cells across the playa areas that persist across the entire simulation period and the magnitude of the head in those cells above land surface. Correcting the flooded cells would bring the IWVWD-GFM ET closer to the GSP-GFM and also significantly ncrease the model-simulated impact to storage.

C - Pumping Comparison



IWVWD-GFM - no pumping first six years. GSP-GWM-2025 - more pumping across the simulation period.

D - Overdraft Comparison



IWVWD-GFM: Recharge spikes apparent in Chart A result in sufficient rise in groundwater elevations result in negative overdraft for four of the flood years. Such a rise would be widespread and apparent in groundwater elevations yet there is no record of mounding in the well data.

PROOF OF SERVICE

Mojave Pistachios, LLC; et al. v. Indian Wells Valley Groundwater Authority; et al.
Orange County Superior Court - Civil Complex Center
Case No.: 30-2021-01187275-CU-OR-CJC
Related to Case No.: 30-2021-01187589-CU-WM-CXC;
Related to Case No.: 30-2021-01188089-CU-WM-CXC;
Related to Case No.: 30-2022-01239479-CU-MC-CJC;
Related to Case No.: 30-2022-01249146-CU-MC-CJC
The Honorable William Claster, Dept. CX101

I, Marcella Correa declare:

I am a resident of the State of California and over the age of eighteen years and not a party to the within action. My business address is 1 Civic Center Circle P.O. Box 1059, Brea, California 92822. My email address is: mcorrea@rwglaw.com. On August 15, 2025, I served the within document(s) described as:

NOTICE OF INDIAN WELLS VALLEY GROUNDWATER AUTHORITY'S PRODUCTION OF EXPERT REPORT

on the interested parties in this action as stated on the attached mailing list.

☒ BY ELECTRONIC TRANSMISSION VIA CASE ANYWHERE.COM) Pursuant to Court's Order authorizing Electronic Service entered on December 2, 2022. I caused a true and correct copy of the above-entitled document(s) to be electronically served through Case Anywhere at www.caseanywhere.com addressed to all parties appearing on the electronic service list for the above-entitled case. The case Anywhere electronic service transmission confirmation will be maintained with a copy of the document(s) in our office.

☒ (BY E-MAIL) By transmitting a true copy of the foregoing document(s) to the e-mail addresses set forth above.

☒ (BY MAIL) By placing a true copy of the foregoing document(s) in a sealed envelope addressed as set forth above. I placed each such envelope for collection and mailing following ordinary business practices. I am readily familiar with this Firm's practice for collection and processing of correspondence for mailing. Under that practice, the correspondence would be deposited with the United States Postal Service on that same day, with postage thereon fully prepaid at Brea, California, in the ordinary course of business. I am aware that on motion of the party served, service is presumed invalid if postal cancellation date or postage meter date is more than one day after date of deposit for mailing in affidavit.

I declare under penalty of perjury under the laws of the State of California that the foregoing is true and correct.

Executed on August 15, 2025, at Brea, California.

Marcella Correa

Marcella Correa