APPENDIX A

Technical Working Group:
Evaluation of Previous Estimates of Safe Yield and Similar Studies
for the Indian Wells Valley Groundwater Basin

APPENDIX A

TECHNICAL WORKING GROUP:

EVALUATION OF PREVIOUS ESTIMATES OF SAFE YIELD AND SIMILAR STUDIES FOR THE INDIAN WELLS VALLEY GROUNDWATER BASIN

Table of Contents

1.0 Introduction 1

2.0 Literature Review of Previous Studies 2

2.1 Groundwater Recharge 2
  2.1.1 Recharge from Direct Precipitation and Local Runoff 2
  2.1.2 Mountain Front Recharge 2
  2.1.3 Underflow from Rose Valley Basin 2
  2.1.4 Geothermal Leakage 3
  2.1.5 Leakage and Releases from Los Angeles Aqueduct 6
  2.1.6 Water Distribution System Leakage 7
  2.1.7 Irrigation Return Flows 9
  2.1.8 Percolation from Wastewater Treatment Ponds 9
  2.1.9 Summary of Prior Recharge Estimates 10
2.2 Groundwater Discharge 12
  2.2.1 Groundwater Pumping 12
  2.2.2 Evapotranspiration 13
    2.2.2.1 Brown & Caldwell (B&C) Model 14
    2.2.2.2 Desert Research Institute (DRI) Model 14
  2.2.3 Subsurface Outflow 17
  2.2.4 Summary of Groundwater Discharge 17
2.3 Limitations and Considerations 17

3.0 Estimated Recharge from Basin Characterization Model 17

3.1 BCM Results 18
3.2 Estimate of Mountain Front Recharge 21

3.3 Limitations and Considerations 23

4.0 Sustainable Yield Defined by the Groundwater Sustainability Plan 23

4.1 Preliminary Review of GSP Data, as Related to Estimates of Safe Yield 24

4.1.1 Impact of Specific Yield 24

4.1.2 Initial Estimates of Safe Yield from Change in Groundwater Storage 26

4.1.2.1 Consideration of Additional Water Level Data 30

4.1.2.2 Consideration of Hydrologic Conditions 33

4.1.2.3 Updated 77 Thiessen Polygons 33

4.2 Limitations and Considerations 36

5.0 Calculation Areas for Independent Estimates of Safe Yield Utilizing Change in Groundwater Storage 37

6.0 Summary and Conclusions 40

7.0 References 41

Figures

No.	Description	Page
1	Los Angeles Aqueduct Section through IWV Basin	8
2	Estimates of Groundwater Pumping in IWV Basin (1980-2023)	13
3	Distribution of Vegetation and Bare Ground within the Area of ET used in the DRI Groundwater Model	15
4	Evapotranspiration Zones used in the GSP Model	16
5	Drainage Area for Indian Wells Valley Groundwater Basin (IWV Watershed)	18
6	Precipitation in Indian Wells Valley Watershed by Water Year	19
7	Precipitation Volume for Indian Wells Valley Watershed by Water Year	19
8	Precipitation Volume for Indian Wells Valley Watershed by Month	20
9	Combined Recharge and Runoff Volume in Indian Wells Valley Watershed by Water Year	21
10	Precipitation Zones for Indian Wells Valley Watershed	22
11	Recharge and Runoff Volume by Precipitation Zone and Water Year	23
12	41 Thiessen Polygons used for Change in Storage Calculations	27
13	Supplemental Water Level Measurements in Thiessen Polygon Area TP-4	31
14	77 Thiessen Polygons Used for Change in Storage Calculations	35
15	Extended 85 Polygon Area	38

Tables

No. Description Page

1 Summary of Groundwater Recharge Estimates for Indian Wells Valley Groundwater Basin 4
2 Summary of Recharge to Indian Wells Valley Groundwater Basin from Previous Investigations. 11
3 Mapped Zones with Associated ET Rates and Extinction Depths 14
4 Calibrated ET Rates and Extinction Depths used in the GSP Model 14
5 GSP Groundwater Recharge Estimate for Indian Wells Valley Groundwater Basin 24
6 GSP-Estimated Annual Change in Groundwater Storage Water Years 2016 through 2020.......... 28
7 GSP-Estimated Annual Groundwater Pumping for Water Years 2016 through 2020 29
8 Derived Yield using Groundwater Pumping and Change in Groundwater Storage from the WY 2020 GSP Annual Report 29
9 Indian Wells Valley Groundwater Storage Change Calculations 32
10 Annual Precipitation at China Lake NAF Station 33
11 Derived Yield using Groundwater Pumping and Change in Groundwater Storage from the WY 2022 GSP Annual Report 34
12 TWG Independent Estimates of Safe Yield using Various Calculation Areas for Change in Groundwater Storage (2014-2023)... 39

Acronyms, Abbreviations, and Initialisms

Abbrev.	Description
%	percent
A	area (in acres)
AF	acre-feet
AFY	acre-feet per year
AF/Y	acre-feet per year
B&C	Brown and Caldwell
BBRM	Bootstrap Brute-Force Recharge Model
BCM	Basin Characterization Model
bgs	below ground surface
District	Indian Wells Valley Water District
DRI	Desert Research Institute
DWR	California Department of Water Resources
EIR	Environmental Impact Report
ET	evapotranspiration
ft	feet
ft/yr	feet per year
Geoscience	Geoscience Support Services, Inc.
GDE	groundwater dependent ecosystem(s)
GSP	Groundwater Sustainability Plan
GW	groundwater
HGZ	Hydrogeologic Zone
HLTL	Haiwee to Los Angeles Transport Loss
in	inch
in/yr	inches per year
IWV	Indian Wells Valley
IWV Basin	Indian Wells Valley Groundwater Basin
IWVGA	Indian Wells Valley Groundwater Authority
K&S	Krieger & Stewart Engineering Consultants
KCWA	Kern County Water Agency
LA	Los Angeles
LAA	Los Angeles Aqueduct
LADWP	Los Angeles Department of Water and Power
LSCE	Luhdorff & Scalmanini Consulting Engineers
m	meter

msl	mean sea level
NAF	Naval Air Force
NAWS	Naval Air Weapons Station
No.	number
PRISM	Parameter-elevation Regression Independent Slope Model
Q_{in}	groundwater recharge (AFY)
Q_{out}	groundwater discharge (AFY)
ΔS	change in groundwater storage (AFY)
SGMA	Sustainable Groundwater Management Act
Sy	specific yield
TP	Thiessen polygon
T/R-S	township/range-section
TWG	Technical Working Group
USGS	United States Geological Survey
ΔWL	Change in water level
WRCC	Western Regional Climate Center
WWTP	Wastewater Treatment Plant
WY	Water Year (October 1 through September 30)

APPENDIX A

TECHNICAL WORKING GROUP:

EVALUATION OF PREVIOUS ESTIMATES OF SAFE YIELD AND SIMILAR STUDIES FOR THE INDIAN WELLS VALLEY GROUNDWATER BASIN

1.0 Introduction

This appendix was prepared to accompany the Technical Working Group's (TWG's) analysis entitled "Assessment of Safe Yield for the IWV Basin," and provides supplemental discussion of the methodical approach the TWG used to develop an appropriate estimate of safe yield for the Indian Wells Valley Groundwater Basin (IWV Basin). Specifically, these steps included:

1. Reviewing and evaluating existing studies and published literature with previous estimates of groundwater recharge and/or safe yield.
2. Evaluating mountain front recharge using the United States Geological Survey (USGS) Basin Characterization Model (BCM), a publicly available grid-based model developed to help estimate water balance terms such as recharge and runoff.
3. Assessing the appropriateness of the sustainable yield implemented in the IWV Groundwater Sustainability Plan (GSP) based on available information and review of previous studies.
4. Conducting initial calculations of safe yield using only supporting information found in the GSP and subsequent annual reports available at the time to evaluate consistency with sustainable yield used in the GSP. These initial calculations also included consideration of potential impacts of additional data, hydrologic base period, and different areas of calculation.
5. Conducting an independent analysis of safe yield using the TWG's professional judgement to select the most technically defensible methodology and data, as detailed in the main TWG paper, "Assessment of Safe Yield for the IWV Basin."

A critical evaluation is included of the limitations of each groundwater recharge and/or safe yield estimate evaluated under Steps 1 through 4, which ultimately informed the TWG more comprehensive and rigorous evaluation of safe yield (Step 5). In addition, discussion is provided regarding the assessment of different calculational areas over which to consider the change in groundwater storage in support of the TWG's independent analysis.

2.0 Literature Review of Previous Studies

The TWG reviewed more than two dozen reports of previous geologic and hydrologic investigations in the IWV Basin and surrounding areas. Many of these reports provided estimates of groundwater recharge and discharge terms or discussed water budget terms in general. Estimates of water budget terms from the reviewed reports are provided in **Table 1** below while a potential range[1] of total groundwater recharge in the IWV Basin is summarized in **Table 2**. The following subsections provide descriptions of the recharge and discharge terms from these previous investigations.

2.1 Groundwater Recharge

2.1.1 Recharge from Direct Precipitation and Local Runoff

The IWV Basin has an arid, high-desert climate with cool winters and hot summers. Long-term average annual rainfall (from 1945 through 2023) is 3.4 inches (WRCC Station 041733 at China Lake Naval Air Force [NAF] base), with most precipitation occurring between November and March; although summer thunderstorms do occur. Given the low rates of precipitation and relatively high rates of potential evapotranspiration (ET) across the basin floor, previous investigations involving the estimation of groundwater flow budgets generally disregard recharge from direct precipitation and local runoff as being negligible. Much greater precipitation, including snow accumulation, occurs on the surrounding mountain ranges, making mountain front recharge the primary recharge mechanism for precipitation in IWV Basin.

While precipitation does not represent an important or measurable contribution to groundwater recharge, the TWG believes that the water requirements of native vegetation in the basin (particularly those identified in the China Lake playa area as representing potential groundwater dependent ecosystems [GDEs]) are largely met through direct precipitation and local runoff (i.e., surface water budget components that do not enter the groundwater system as recharge). Any remaining water requirements not met through soil moisture from direct precipitation are assumed to be met through the uptake of shallow groundwater in the playa area (i.e., ET; see **Section 2.2.2**).

2.1.2 Mountain Front Recharge

Recharge from mountain front runoff refers to infiltration of streamflow from mountain fronts adjacent to alluvial basins. Mountain front recharge estimates from previous studies summarized in **Table 2** average approximately 8,700 acre-ft per year (AFY). In the coming months mountain front recharge will be further evaluated with groundwater flow model simulations, in progress, by Ramboll.

2.1.3 Underflow from Rose Valley Basin

Underflow refers to groundwater flow between adjacent basins, subbasins, or management areas. In cases where groundwater flows into the basin, subbasin, or management area in question from an adjacent basin, subbasin, or management area, it is considered a recharge source. Rose Valley underflow

---

[1] The TWG has used its collective professional judgment to determine which values of the various water budget components in Table 1 are reasonable and which are technically unreasonable and should be excluded from further consideration. The reasonable values and their averages are presented in Table 2.

has been separated from actual mountain front recharge estimates in **Table 1**. Groundwater underflow from Rose Valley from previous investigations averages approximately 2,200 AFY. Underflow will be further evaluated with Ramboll groundwater flow model simulations in the coming months.

2.1.4 Geothermal Leakage

One of the reports reviewed (Bean, 1989) provided an estimate of geothermal leakage of 100 AFY, while Erskine (1989) listed it as a source of groundwater recharge. A 1989 geochemistry study of the IWV Basin (Whelan et al., 1989) also noted that temperature and geochemistry measurements indicate geothermal leakage into the basin. In addition, there has been discussion of possible geothermal heat and gases in deeper groundwater in the Basin through brackish water project investigations. Geothermal leakage from previous investigations is 100 AFY; however, given the limited study of this water budget element, the volume of geothermal leakage should be investigated further.

Table 1. Summary of Groundwater Recharge Estimates for Indian Wells Valley Groundwater Basin (in AFY)

Study	Period	INFLOW															Notes
		Mountain Front Recharge								Other Recharge						Total Recharge	
		Sierra Nevada Mountains	Coso Range	Argus Range	El Paso Mountains	Volcanics	Total Mountain Front Recharge			Underflow from Rose Valley	Geothermal Leakage	Leakage from Los Angeles (LA) Aqueduct	Water Distribution System Leakage	Irrigation Return Flow	Percolation from Wastewater Treatment Ponds		
							Low	Average	High								
Thompson (1929)		27,000*	12,000*	-	-	-	39,000*	39,000*	39,000*	10,000*	-	-	-	-	-	49,000*	Estimates of runoff, not groundwater recharge (though paper postulates that most runoff will percolate before evapotranspiration (ET)). **Not used in calculation of average mountain front recharge or Rose Valley underflow**.
Kunkel and Chase (1969)	1912	11,000 - 15,000				-	11,000	13,000	15,000	-	-	-	-	-	-	11,000 – 15,000	Perennial yield = 12,000 AFY Unclear if Rose Valley underflow is included in estimate.
	1953	11,000 - 15,000				-				-	-	-	-	-	-		
Bloyd and Robson (1971)		6,235	3,170		400	-	9,805	9,805	9,805	45*	-	-	-	-	60-660	9,910 – 10.510	Recharge from wastewater reported for deep aquifer only (assumed half of recharge made it to deep aquifer). Average percolation from wastewater treatment ponds from 1954-1968 is 300 AFY.
Dutcher and Moyle (1973)	1912	-	-	-	-	-	11,000	11,000	11,000	-	-	-	-	-	-	11,000	Perennial yield = 10,000 AFY Based on Kunkel and Chase estimate. Unclear if Rose Valley underflow is included.
Bean (1989)		6,300	2,000	1,000	400	-	9,700	9,700	9,700	400*	100	900	500	-	1,000	12,600	Bean included an additional 2,500 AFY for Sierra NV granitic regional underflow, which has been disproven. Therefore, this additional recharge was not included here.
Berenbrock and Martin (1991)	1985	6,280	3,170		400	-	9,850	9,850	9,850	-	-	-	-	100*	1,000	10,950	Return flow ("Shrubbery-Irrigation Recharge") = 100 AFY after 1953 and zero prior to 1953. **Represents a limited area and was not used for calculation of average return flow**.
Anderson et al. (1992)	1981-2010	700 - 15,000 (Best estimate = 4,100)				-	700*	4,100	15,000	-	-	-	-	-	-	700 – 15,000	Calculated by McGraw et al. (2016) based on equation from Anderson et al. Best estimate used for average value. Original study did not specifically look at Indian Wells Valley Groundwater Basin. **Low value not used for calculation of average mountain front recharge**.
US Bureau of Reclamation (1993)		3,000	-	-	-	-	3,000	5,000	6,000	-	-	-	-	-	-	-	High estimate included additional 3,000 AFY from Little Lake area (Rose Valley)
		6,000	-	-	-	-				-	-	-	-	-	-	-	
		6,000	-	-	-	-				3,000	-	-	-	-	-	-	
Watt (1993)		8,900	1,000		-	-	9,900	9,900	9,900	-	-	-	-	-	-	-	
Gillespie and Thyne (1996)		36,700*	-	-	-	-	36,700*	36,700*	36,700*	2,400	-	-	-	-	-	-	Southwest recharge includes southern Sierra Nevada and El Paso. Sierra Nevada recharge includes postulated fracture flow, since disproven. **Not included in calculation of average mountain front recharge**. Rose Valley estimate includes approx. 2,400 AFY surface flow and 2,400 AFY groundwater underflow
Bauer (2002)		-	-	-	-	-	-	-	-	3,300	-	-	-	-	-	-	
Brown & Caldwell (2006)		-	-	-	-	-	-	-	-	2,100	-	-	-	-	-	-	

Study	Period	INFLOW															Notes
		Mountain Front Recharge								Other Recharge						Total Recharge	
							Total Mountain Front Recharge										
		Sierra Nevada Mountains	Coso Range	Argus Range	El Paso Mountains	Volcanics	Low	Average	High	Underflow from Rose Valley	Geothermal Leakage	Leakage from Los Angeles (LA) Aqueduct	Water Distribution System Leakage	Irrigation Return Flow	Percolation from Wastewater Treatment Ponds		
Brown & Caldwell (2009)	1953, 1985, 2006	5,900	300	1,600	50	-	7,850	7,850	7,850	1,000	-	-	-	-	-	8,850	Return flow accounted for through net pumping (pumping reduced by 20%)
Todd (2014)	2010	3,090 - 5,890	300	1,600	50	-	5,040	6,440	7,840	1,000	-	-	80	1,600 - 2,100	630	7,720 – 11,650	Todd estimated 630 AFY of percolation from WWTPs becomes groundwater recharge to the shallow aquifer, but did not include this value in their water budget (which was restricted to the principal aquifer)
USGS (2020)	1981-2010	4,923	741	1,006	186	1,824	8,680	8,680	8,680	-	-	-	-	-	-	-	742 AFY included in Sierra Nevada recharge for runoff recharge from Rose Valley, which is not the same as underflow inflow from Rose Valley
DBSA (2021)		-	-	-	-	-	-	-	-	2,400	-	-	-	-	-	-	Revised model estimates replace previous work completed in 2011. Outflow values include flow to IWV and Coso Basin.
Guidehouse, Inc. (2022)		-	-	-	-	-	-	-	-	-	-	1,100	-	-	-	-	Guidehouse Inc. estimated leakage in the covered concrete conduit sections of the LA Aqueduct between Haiwee and Fairmont/Bouquet Reservoirs to be 7,650 AFY over the past 20 years. The TWG estimates leakage in the IWV portion at 1,100 AFY, incorporating losses.

* Considered an outlier due to limitations of the study.

2.1.5 Leakage and Releases from Los Angeles Aqueduct

Leakage from the Los Angeles Aqueduct (LA Aqueduct, or LAA) (see **Figure 1** below) was estimated by Bean (1989) to be approximately 900 AFY, based on recorded losses from the Los Angeles Department of Water and Power (LADWP) and adjusted for geology/soil type within IWV Basin as well as potential ET. Williams (2004) discusses leakage rates reported by LADWP and the District of 10 to 18%, respectively. Whelan and Baskin (1989), and Erskine (1989) also identify leakage from the LA Aqueduct as a source of recharge to the IWV Basin. Perennial ponded water and flow are observed directly beneath the LA Aqueduct in several of the creeks (e.g., Sand Canyon). These creeks are usually dry upstream from the LA Aqueduct and further downstream after the ponded water has infiltrated (Brown, 2016). Leakage from the LA Aqueduct from previous investigations is estimated at 900 AFY; however, additional analysis is needed to evaluate the data and assumptions used to develop the leakage estimates presented above.

Guidehouse (2022) reported that water loss from the South Haiwee Reservoir to the Los Angeles Filtration Plant (also called the Haiwee to Los Angeles Transport Loss [HLTL]) averaged approximately 7,600 AFY over the past 20 years. If all 7,600 AFY were attributed to leakage, then the portion of the two LA Aqueducts that cross the IWV Basin would account for approximately 1,600 AFY of that 7,600 AFY total water loss. In reality, the HLTL is a combination of evaporative loss and aqueduct leakage.

The TWG prepared an estimate of evaporative losses for the open channel portions and reservoirs within the South Haiwee Reservoir to Los Angeles Filtration Plant portions of the aqueducts. These open channel portions and reservoirs consist of the following 11 items:

• LAA 1 Haiwee Power Plant Bypass	approximately 2 miles
• Fairmont Reservoir	approximately 28 acres
• San Francisquito Surge Tank	approximately 0.2 acres
• Bouquet Reservoir	approximately 628 acres
• LADWP Power Station 1 Pond	approximately 0.6 acres
• Drinkwater Reservoir	approximately 4 acres
• LAA1 Cascade Bypass	approximately 0.2 miles
• LAA2 Cascade Bypass	approximately 0.67 miles
• San Fernando Power Plant to LAA1/LAA2 Confluence	approximately 0.2 miles
• Foothills Power Plant to LAA1/LAA2 Confluence	approximately 0.6 miles
• LAA1/LAA2 to Los Angeles Filtration Plant	approximately 0.4 miles

The estimate of total water loss due to evaporation from these open channels and reservoirs is approximately 2,500 AFY (based on a pan evaporation rate of 60 inches per year, and a pan/lake conversion factor of 0.75).

Assuming that 2,500 AFY are evaporative losses, then the remaining 5,100 AFY of the total 7,600 AFY of HLTL would be associated with leakage from the aqueducts. In this case, if 5,100 AFY were attributed to leakage, then the portion of the two LA Aqueducts that cross the IWV Basin would account for approximately 1,100 AFY of that system leakage.

The estimate of 1,100 AFY of leakage from the LA Aqueducts within the IWV Basin is similar to the estimate of 900 AFY provided by Bean (1989). For the purposes of this analysis, it is estimated that the leakage from the LA Aqueducts that cross the IWV Basin range from a low of 900 AFY to a high of 1,100 AFY.

There have also been purposeful emergency releases from the LA Aqueduct in the past, where water is not inadvertently lost through leakage but rather purposefully discharged into the IWV Basin. Releases occurred in 2017 and in 2023 and exceeded 10,000 AF. These releases may contribute meaningful amounts of groundwater recharge when considered in a longer-term analysis of safe yield for the basin. Additional research is needed to determine what these amounts are, when they occurred, and estimate what portion of the discharge(s) recharged groundwater in order to include these volumes in the historic water budget and model simulations.

2.1.6 Water Distribution System Leakage

Water distribution system leakage refers to deep percolation of water that has leaked from water distribution pipelines owned and operated by potable water purveyors. Estimates of distribution system leakage from previous studies range from 80 AFY (Todd, 2014; McGraw et al., 2016) to 500 AFY (Bean, 1989).

Water audit reports prepared by the District for Water Years (WYs) 2016-2017, 2017-2018, and 2018-2019 and submitted to the California Department of Water Resources (DWR) indicate that system losses (total production minus authorized consumption) for the District were approximately 10% of the total supply. Due to system improvements, including pipeline and service lateral replacements, system losses were reduced to approximately 6% of the total supply in 2021-2022. The 6% water loss figure is anticipated to remain fairly constant going forward. Based on District records, groundwater pumping by the District was approximately 6,500 AFY in 2016-2017, but has gradually decreased due to state conservation mandates to approximately 6,000 AFY by 2021-2022. This corresponds to approximately 650 AFY (2017 - 10% loss rate) to approximately 360 AFY (2022 - 6% loss rate) of recharge from system losses, which are consistent with the higher-range estimates from previous studies. The 360 AFY recharge rate is not expected to increase significantly. Estimates of historical water distribution system losses should be considered in a long-term water budget analysis for the determination of safe yield and in model simulations. The impact of subsurface caliche should also be evaluated when considering percolation and evaporation of system leakage.

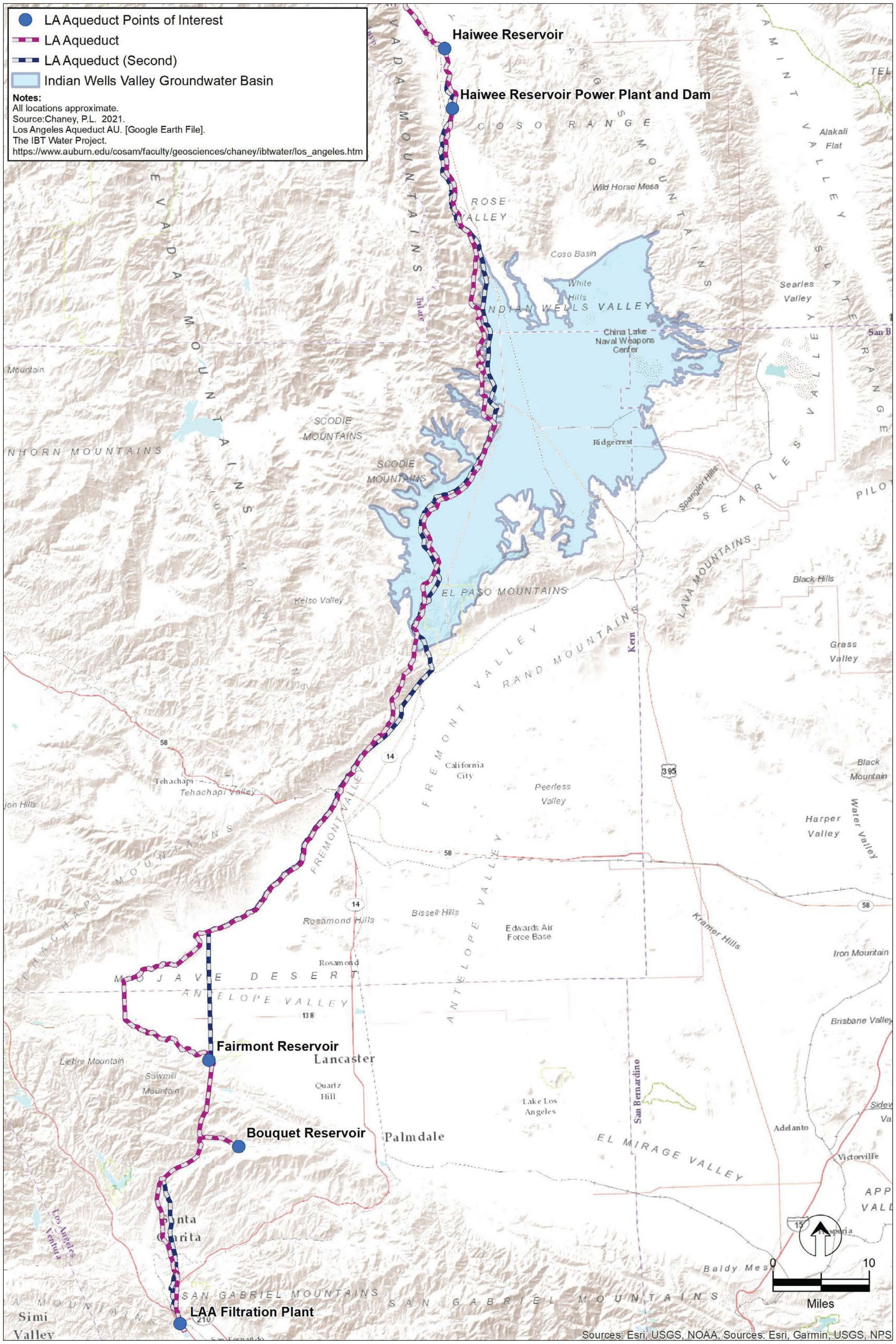


Figure 1. Los Angeles Aqueduct Section through IWV Basin

2.1.7 Irrigation Return Flows

Irrigation return flow refers to the portion of applied water that infiltrates to a depth beyond the root zone from which removal by ET occurs and eventually reaches the underlying water table. This can include return flow from agricultural irrigation, landscape irrigation associated with municipal, industrial, and domestic water use, and the deep percolation of leachate from septic systems.

Return flows are discussed by Berenbrock and Martin (1991), who cite an observed recharge mound in the shallow aquifer near the community of China Lake, presumably from landscape irrigation and leakage from distribution systems. They estimated this recharge, which they referred to as “shrubbery-irrigation recharge,” to be approximately 100 AFY. However, this estimate was restricted to the localized groundwater mound. Agricultural return flows are typically around 18 to 25% of applied water[2]. In recent decades, return flows have been estimated at 11% for alfalfa and 5% for pistachios[3]. Agricultural pumping in the IWV Basin has been approximately 12,000 to 14,000 AFY over the last 40 years (see Table 3-1 in IWVGA, 2020b); thus, applying a 10% return flow rate, for example, return flows would be approximately 1,200 to 1,400 AFY. Todd (2014) provides an estimate of return flows from irrigation to the principal aquifer for the entire IWV Basin, ranging from 1,600 to 2,100 AFY. Given the depth to groundwater beneath agricultural areas (i.e., greater than 200 feet (ft) below ground surface [bgs]), these return flows would likely take many decades to reach the groundwater surface (Izbicki et al. 2000). That is, the recharge benefit from agricultural pumping in the past few decades have yet to be realized. Additional return flows should also be considered for the shallow aquifer system.

Given the magnitude of these previous estimates and the fact that irrigation, especially that for agriculture, has been occurring for over 100 years, this groundwater recharge term should be considered in the water budget analysis and model simulations.

2.1.8 Percolation from Wastewater Treatment Ponds

According to Todd (2014), “*Ridgecrest and NAWS (Naval Air Weapons Station China Lake) share a wastewater treatment plant (WWTP) that was designed to dispose of water by evaporation and percolation from approximately 200 acres of storage ponds located on NAWS south of the China Lake playa. Inflow to the WWTP was 2,600 to 2,900 AFY during 2005 to 2012.*” After accounting for recycled water use and estimated evaporation, Todd estimated that approximately 630 AFY of treated wastewater was available for recharge to the shallow groundwater system. Berenbrock and Martin (1991) had a similar estimate of recharge from wastewater percolation of 1,000 AFY. This recharge was not accounted for in Todd’s groundwater budget because of “*thick clay layers separating the shallow aquifer from the principal aquifer between the WWTP and China Lake playa*” (Todd, 2014). Other studies also support the separation of shallow and deeper groundwater in the northeastern IWV Basin (TriEco Tt, 2012).

---

[2] For example, agricultural return flows were assumed to be 25% of applied water in the adjudication of the Antelope Valley Groundwater Basin (Beeby et al., 2010). A water use and return flow analysis conducted by Stetson Engineers, Inc. for Temecula-Murrieta Groundwater Basin found that agricultural return flows ranged from 18% to 19% for the period from 2005 through 2015 (Stetson, 2016). Recent modeling in the Las Posas Valley Groundwater Basin found agricultural return flow to be approximately 20% (UWCD, 2018).

[3] Meadowbrook Dairy has estimated 11% return flows based on irrigation water use efficiency for alfalfa, and pistachios have been estimated to have irrigation rerun flows of 5% based on drip irrigation water use efficiency.

The Indian Wells Valley Groundwater Authority (IWVGA) has recognized the shallow system in other parts of the basin as a source of groundwater through its proposed Shallow Well Mitigation Program (IWVGA, 2020a), and the WY 2021 GSP Annual Report (IWVGA, 2022) notes observed mounding in groundwater elevation contours near the wastewater treatment plant at NAWS China Lake (and reports 800 acre-feet (AF) of groundwater recharge from wastewater spreading in 2021). However, limited paired monitoring data characterizing hydraulic gradients between the shallow and deep systems create uncertainty regarding meaningful groundwater recharge and contribution to basin safe yield.

Potential recharge to the shallow system, such as percolation from wastewater treatment ponds, will be considered in model simulations. In addition to the potential recharge that can occur from the shallow system to the deeper system, water in the shallow aquifer may satisfy part of the estimated ET that would otherwise be assumed to come from deeper groundwater – thereby leading to an underestimation of the safe yield.

One additional source of recharge not considered to date is leakage from sewer pipes within the IWV Basin. Sewerage collection systems are commonly built with vitrified clay pipes with un-sealed bell-end joints. These pipes have a design “sweat factor” for exfiltration of sewer fluids. They are also prone to leaks at the pipe joints and at cracks commonly found in sewer laterals and even some sewer mainlines. No estimates of these sewer pipe losses have been made for the IWV Basin, and no value has been included in the estimates of recharge presented herein. Therefore, additional analysis of this potential water budget element is needed.

2.1.9 Summary of Prior Recharge Estimates

Based on previous estimates of individual groundwater recharge terms (from **Table 1** and discussed in the preceding subsections), a potential range of total groundwater recharge in the IWV Basin is summarized in **Table 2** below. IWV Basin recharge is currently being reevaluated in the Ramboll groundwater flow model, in progress.

Table 2. Summary of Recharge to Indian Wells Valley Groundwater Basin from Previous Investigations

Recharge Term	Range of Recharge from Previous Investigations[1] [AFY]			Recharge from GSP [AFY]	Source/Notes
	Low	High	Average		
Recharge from Direct Precipitation	0	0	0	0	Given the low rates of precipitation and relatively high rates of potential ET across the basin floor, recharge from direct precipitation and local runoff is generally considered to be negligible. However, it likely satisfies much of the native vegetation water demand.
Mountain Front Recharge	3,000	15,000	8,666	5,250	Range of mountain front recharge shown here based on recharge from previous investigations (see **Table 1**).
Underflow from Rose Valley	1,000	3,300	2,171	2,400	Gillespie and Thyne (1996) Rose Valley estimate of 4,800 AFY includes 2,400 AFY of groundwater underflow.
Geothermal Leakage	0	100	50	0	Geothermal leakage estimate from Bean (1989).
Leakage from LA Aqueduct	900	1,100	1,000	0	LA Aqueduct leakage estimated at 900 to 1,100 AFY based on aqueduct loss reporting from LADWP between Haiwee Reservoir and Fairmont Reservoir by Bean (1989) and Guidehouse, Inc. (2022), minus losses. It is unclear whether purposeful releases from the LA Aqueduct contribute to long-term groundwater supply.
Water Distribution System Leakage	80	360	220	0	Leakage estimates based on Todd (2014) and 2022 District pumping with an assumed 10% loss (from water loss audit). The leakage estimate of 500 AFY from Bean (1989) was excluded here since there does not seem to be a good rationale for this higher value. Additional system leakage may also come from Inyokern Community Services District.
Irrigation Return Flows	1,600	2,100	1,850	0	Return flow estimates from Todd (2014). "Shrubbery Irrigation Recharge" from Berenbrock and Martin (1991) not included because their estimate was made for a localized area. Based on a return flow rate of 10%, for example, agricultural return flows alone (not including return flows from urban applications and septic systems) may be 1,200 to 1,400 AFY.
Percolation from Wastewater Treatment Ponds	0	0	0	0	Estimates from Bean (1989), Berenbrock and Martin (1991), Todd (2014), and Provost and Pritchard Consulting Group (2015, as cited in WY 2021 Annual GSP Report (IWVGA, 2022)) range from 630 to 1,000 AFY of recharge. However, due to uncertainties regarding the connectivity of the shallow and deep aquifer systems and direction of hydraulic gradients in the area of wastewater spreading, recharge has been conservatively estimated to be zero here.

TOTAL RECHARGE	**6,600**	**22,000**	**14,000**	**7,650**
Difference from GSP Estimate	-1,050	14,350	6,350	0

[1] The TWG has used its collective professional judgment to determine which values of the various water budget components in **Table 1** are reasonable and which are technically unreasonable and should be excluded from further consideration. This includes removal of outlier values noted in the Source/Notes column and **Table 1**.

2.2 Groundwater Discharge

Groundwater is discharged from the IWV Basin primarily through groundwater pumping and by ET, though some subsurface outflow has also been considered in previous investigations. Groundwater discharge should also be considered in the determination of safe yield and model simulations.

2.2.1 Groundwater Pumping

Historical pumping data are generally only available for a handful, but the most significant, of basin pumpers comprising more than 80 percent of total groundwater production in WY 2022. The TWG reviewed available data sources of estimated and reported groundwater pumping, which include: Indian Wells Valley Cooperative Groundwater Management Group (Cooperative Group) (used in the current IWV GSP; IWVGA, 2020b), Pumping Verification Report (IWVGA, 2020c), GSP annual reports (IWVGA, 2020d, 2021, 2022, 2023, and 2024), and initial disclosures[4] filed by parties in the pending comprehensive groundwater basin adjudication. Differences in pumping exist between the various sources of data, as demonstrated in **Figure 2** below, which reveals a level of uncertainty associated with various sources of estimated pumping. Data availability and reliability have improved over time, as described below and in the main paper.

Values from the Pumping Verification Report are generally lower than other pumping estimates, but Verification Report pumping is missing sources of pumping – particularly pumping from Mojave Pistachios, which began pumping in 2011. In addition, pumping estimates in the Pumping Verification Report seem to be missing at a greater frequency from 2017 through 2019, including Navy pumping and estimates of private well and orchard pumping. These missing pumping estimates, among others, may explain the described lower pumping estimates. With the exception of the Pumping Verification Report, the other sources of groundwater pumping align fairly well from 2014 on, clearly indicating an increase in data reliability after the passage of the Sustainable Groundwater Management Act (SGMA) in 2014 and the required reporting of pumping of non-de minimis wells in the IWV Basin. All sources of pumping data shown in **Figure 2** indicate a decreasing trend over the last 10 years, with groundwater pumping on the order of 20,000 to 30,000 AFY.

---

[4] The term “initial disclosures” refers to legally-required disclosures provided in approximately May 2024 from parties to the IWV Basin’s ongoing comprehensive adjudication. Those disclosures provided each party’s groundwater pumping information for a 10-year period, along with other information.

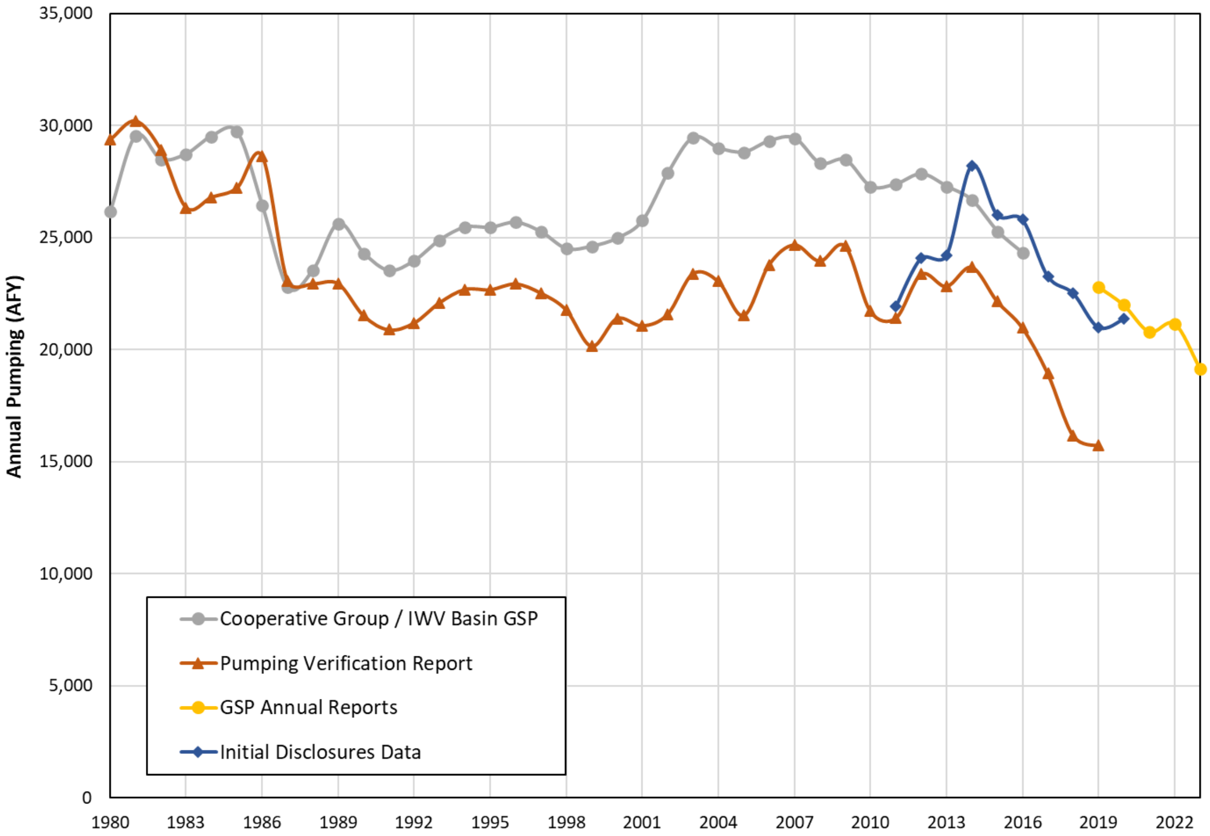


Figure 2. Estimates of Groundwater Pumping in IWV Basin (1980-2023)

2.2.2 Evapotranspiration

Desert basins in California are characterized by low precipitation and high temperatures, creating arid conditions where water is scarce. ET plays a significant role in the water balance of these arid ecosystems and has implications for both natural environments and human water needs.

In desert ecosystems, desert shrubs, including wildflowers, typically have shallow root systems that do not penetrate very deep into the soil. They rely on capturing moisture from the surface and complete their life cycle within a short period following seasonal rains. However, the depth of plant roots can vary widely depending on various factors, including the specific type of vegetation, soil composition, and water availability. Some desert plants develop deep root systems that can penetrate several meters (tens of feet) into the soil. These deep-rooted plants are often able to tap into groundwater tables or reach moisture stored in deep soil layers. Mesquite trees and certain other desert shrubs found in the IWV Basin are known for deep taproots, which can be as deep as 25 m.[5]

A brief summary of approaches used in the existing IWV Basin groundwater models to quantify ET are described below:

---

[5] https://www.iwvwd.com/wp-content/uploads/2013/07/Approved-Plant-List-111312.pdf

2.2.2.1 Brown & Caldwell (B&C) Model

In their steady-state model, B&C used a simplified approach assuming the volume of ET per year in 1920 was equal to the 1920 total estimated flow into the basin (B&C, 2009). Similar to Berenbrock and Martin (1991), a maximum depth to water at which ET could occur was adjusted during transient model calibration to a depth of 15 feet, with a maximum rate of ET set at 1.0 feet per year. For the transient model simulation period from 1920 to 2006, the simulated ET rate varies from 9,000 AFY to 4,700 AFY.

2.2.2.2 Desert Research Institute (DRI) Model

To delineate different ET zones, the Desert Research Institute (DRI) model (McGraw et al., 2016) revised and extended the previous vegetation map of Lee (1912). Based on this revised vegetation map, two conceptual ET zones were defined. The first zone is larger, comprising primarily the bare soil (playa), pickleweed, saltgrass and all vegetation types outside the greasewood unit. The second, smaller zone, represents the greasewood unit (area shown with a red line on **Figure 3**). The ET rates and extinction depths of the conceptual model are shown in **Table 3**.

Table 3. Mapped Zones with Associated ET Rates and Extinction Depths (McGraw et al., 2016)

ET Zone	ET Rate [ft/yr]	Extinction Depth [ft]
All vegetation outside greasewood unit	5.7	10
Greasewood unit	2.4	33

The ET rates and extinction depth parameters were revised during the model calibration process to obtain a better fit between the observed and simulated heads in the playa area. The final calibrated ET rates and extinction depths are listed in **Table 4** and the location of the ET zones is shown in **Figure 4**. The steady-state groundwater model simulated a total of 7,510 AFY outflow from the basin as ET, while the transient model simulated a decline in ET from 7,600 AFY in 1922 to 2,852 AFY in 2016 (DRI, 2020).

Table 4. Calibrated ET Rates and Extinction Depths used in the GSP Model (DRI, 2020)

ET Zone	ET Rate [ft/yr]	Extinction Depth [ft]
Greasewood	2.4	16.4
Dune Phreatophytes	7.2	16.4
Other Phreatophytes	7.2	4.9
Bare Playa	7.2	4.9

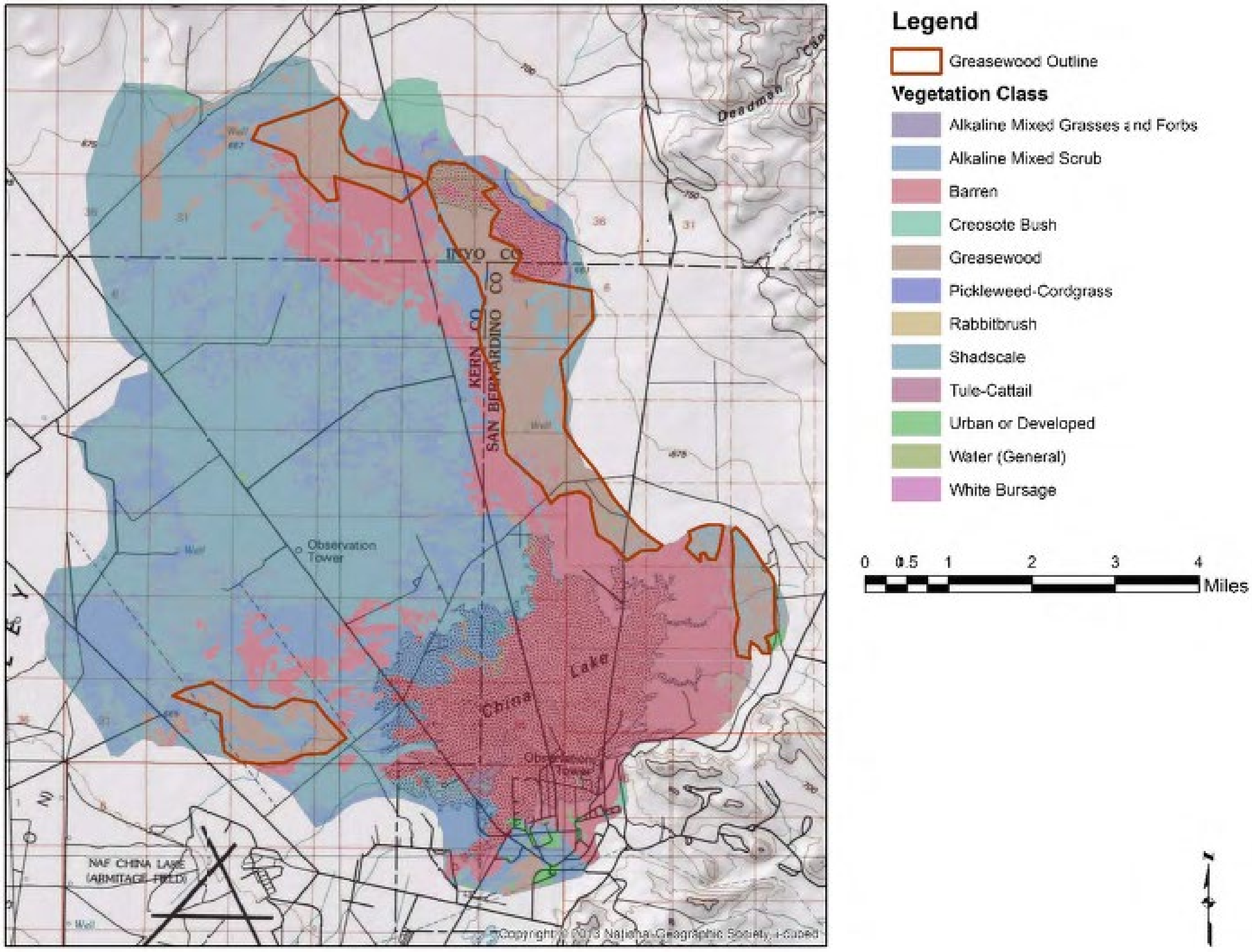


Figure 3. Distribution of Vegetation and Bare Ground within the Area of ET used in the DRI Groundwater Model (McGraw et al., 2016, Figure 15)

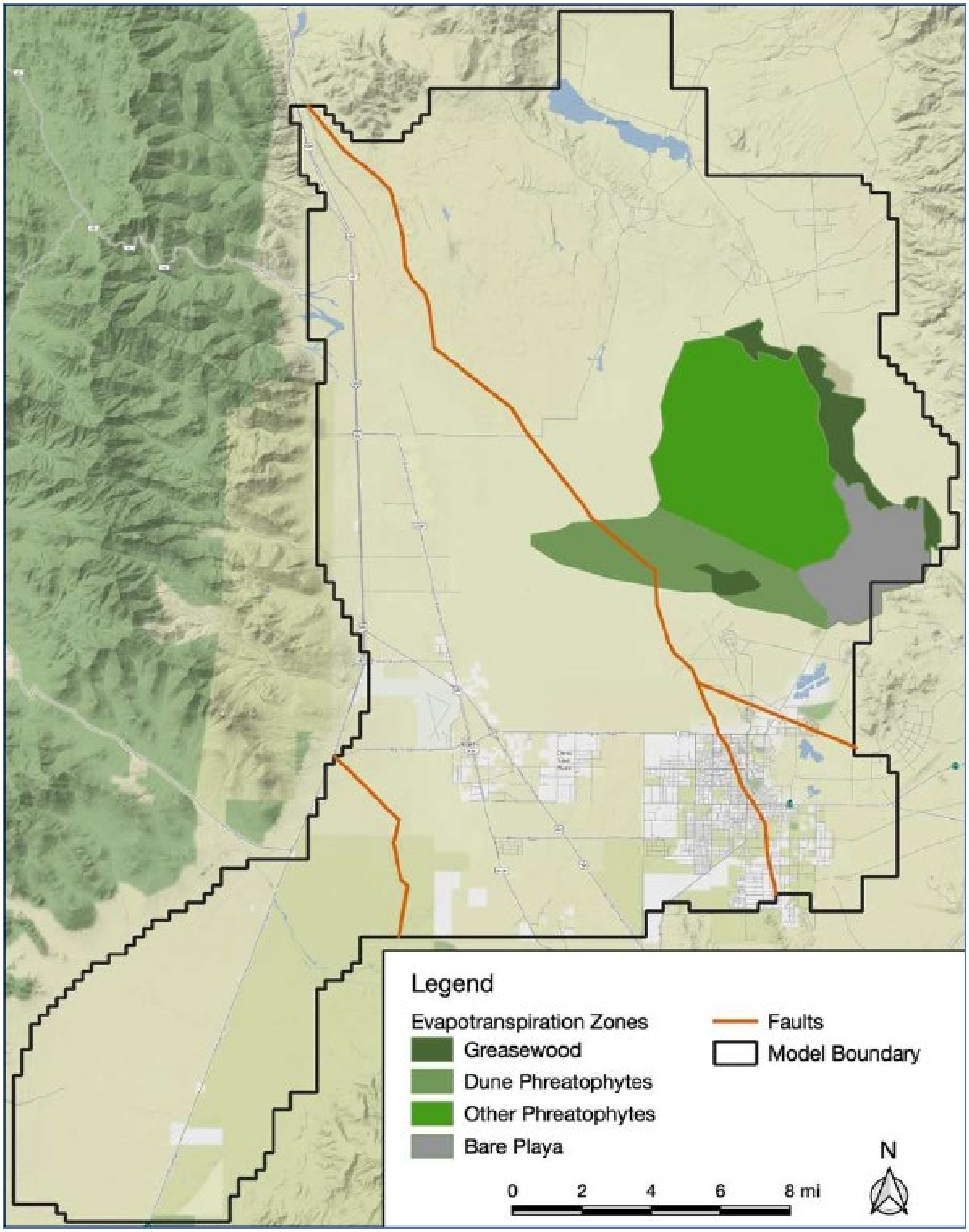


Figure 4. Evapotranspiration Zones used in the GSP Model (DRI, 2020)

2.2.3 Subsurface Outflow

Interbasin subsurface outflow (groundwater discharge) to Salt Wells Valley has been reported at 50 to 100 AFY (IWVGA, 2020b; McGraw et al., 2016).

2.2.4 Summary of Groundwater Discharge

While groundwater pumping is fairly well constrained, data are currently limited for evaluating groundwater discharge in the form of ET and subsurface outflow, particularly with regards to shallow groundwater levels. In addition, while ET can be a considerable component of the overall water cycle, this outflow term may be met through water in the unsaturated zone and/or shallow groundwater system. OpenET[6] provides access to high-resolution ET data, which can be valuable to estimate ET rates for the basin, in addition to previous investigations that have already been completed within the basin. Ramboll is currently assessing available data and information, including OpenET, in their development of a new groundwater flow model for the IWV Basin. This model will incorporate assumptions for ET and other recharge terms discussed in **Section 2.1** to evaluate a more comprehensive water budget. However, due to the uncertainties associated with the independent estimation of various water budget terms, a method of estimating safe yield that takes into account both inflows and outflows (i.e., entire system response to changes in groundwater elevation and storage) is considered to be more representative, such as the calculations presented in **Section 4.1.2** and the TWG's "Assessment of Safe Yield for the IWV Basin."

2.3 Limitations and Considerations

Estimates of recharge for the development of a groundwater budget or safe yield can be challenging – particularly as there is no direct way to quantify the amount of recharge for many inflow terms. Estimating individual groundwater inflow and outflow components carries a significant amount of uncertainty. Additional uncertainty can exist due to lack of observed or applicable data and the various assumptions used by researchers in the estimation of recharge or discharge volumes. Therefore, estimates of safe yield may be more appropriately estimated using observable data – namely, measured water level elevations and reported groundwater pumping.

3.0 Estimated Recharge from Basin Characterization Model

The USGS BCM is a regional water balance model designed to evaluate factors that affect recharge in groundwater basins (Flint et al., 2004; Flint and Flint, 2007a,b; Flint et al., 2013; Flint et al., 2021). The BCM is described as a monthly, distributed-parameter, water balance method that models the interactions of climate (rainfall and temperature) with empirically measured landscape attributes, including topography, soils, and underlying geology. The grid-based model calculates the water balance (the amount of water in each of the fractions of the total water budget, including runoff, recharge, and evapotranspiration) for each 18-acre cell (270-meter (m) resolution) in a given watershed by using

---

[6] https://openetdata.org/

topography, soil classification, geology, vegetation coverage, precipitation, and air-temperature data. The BCM was utilized to estimate precipitation, recharge, and runoff within the IWV drainage area (**Figure 5**).

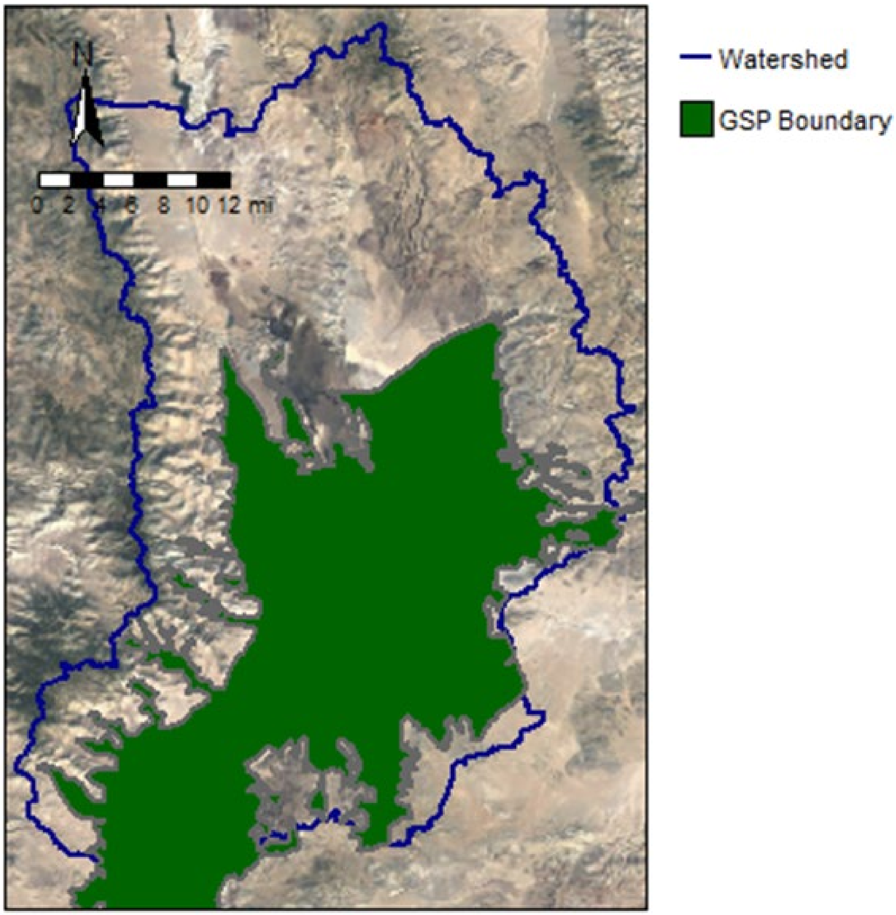


Figure 5. Drainage Area for Indian Wells Valley Groundwater Basin (IWV Watershed)

3.1 BCM Results

Mean annual rainfall (per WY) across the IWV Watershed from 2011 through 2020 is approximately 6.4 inches, which amounts to approximately 446,000 AFY of precipitation. Based on local conditions and BCM results, the majority of precipitation is removed via evaporation or transpiration. **Figure 6** through **Figure 8** show the amount of precipitation by WY and month.

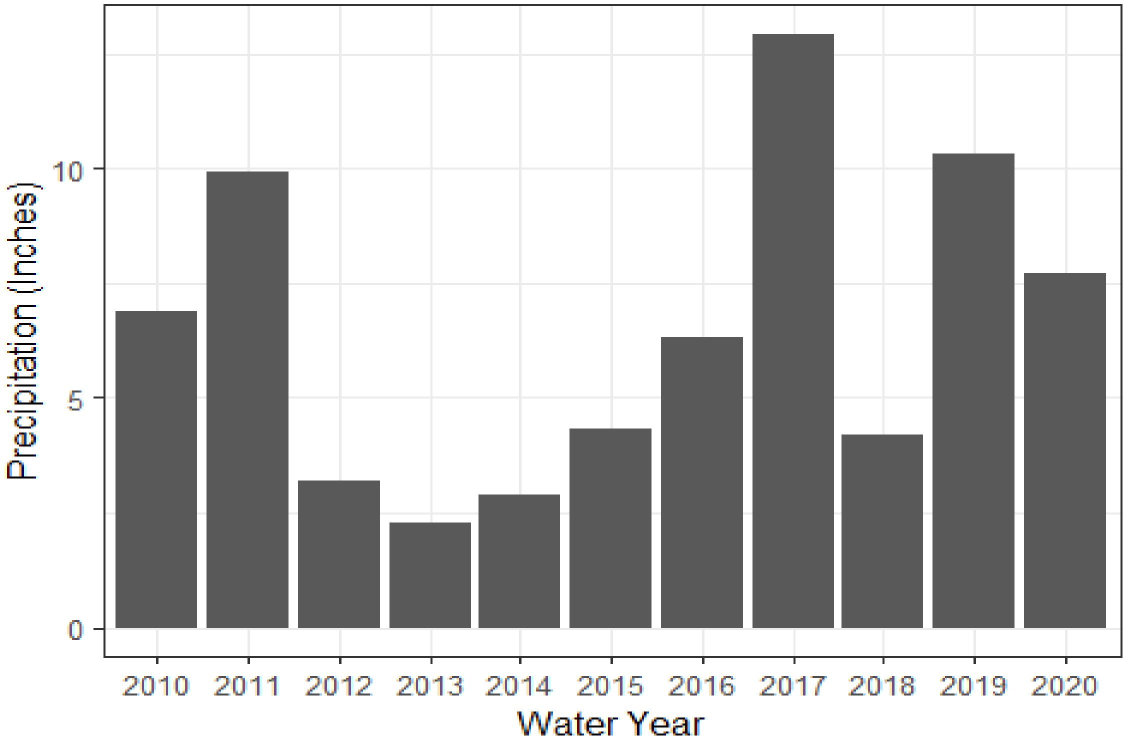


Figure 6. Precipitation in Indian Wells Valley Watershed by Water Year

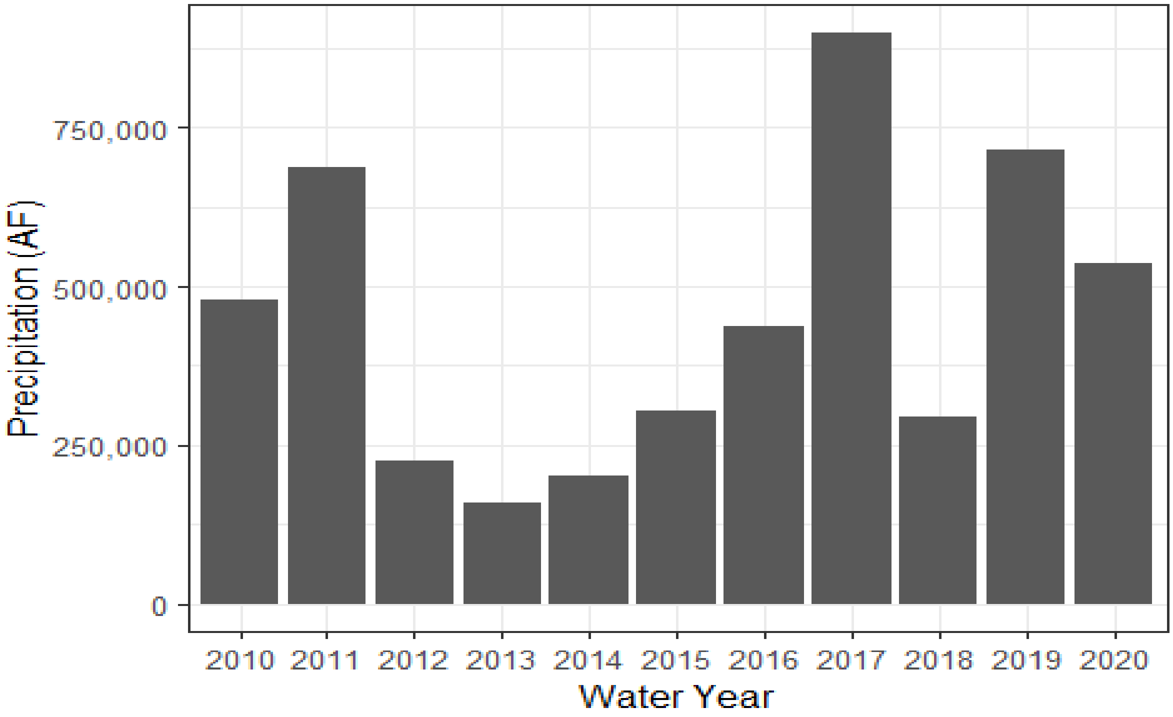


Figure 7. Precipitation Volume for Indian Wells Valley Watershed by Water Year

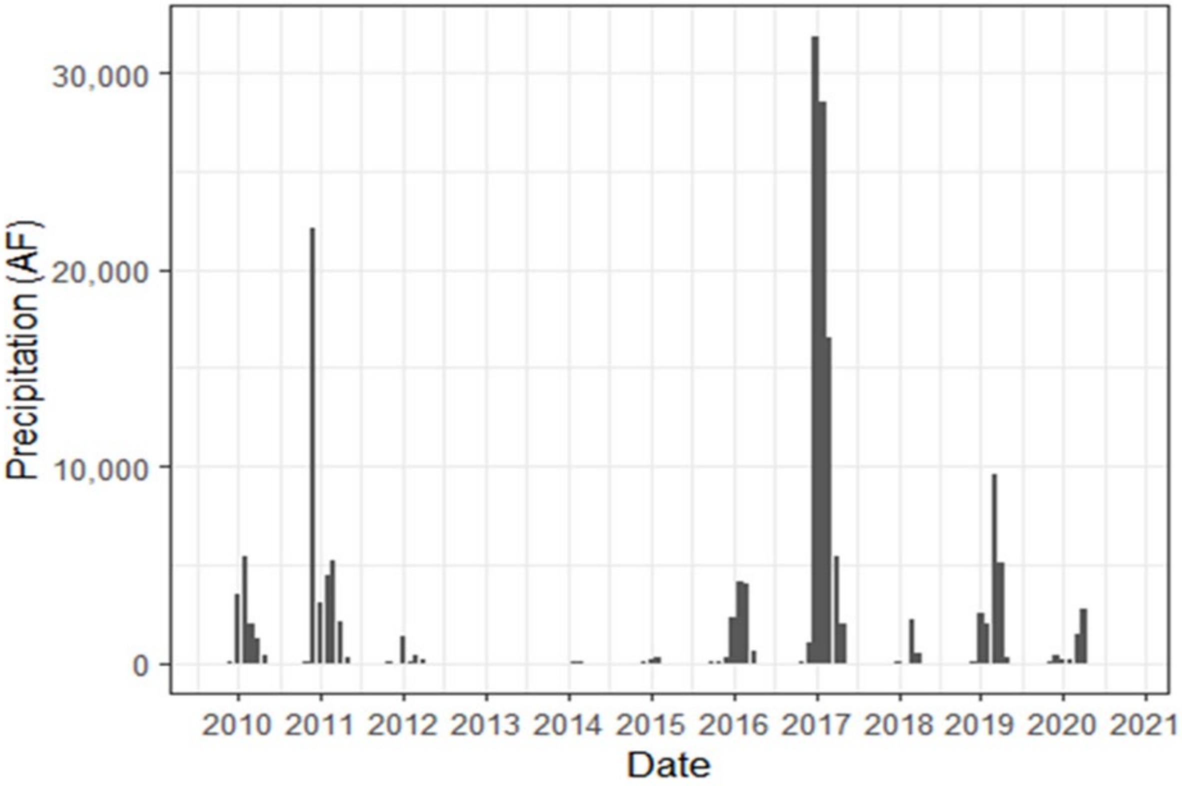


Figure 8. Precipitation Volume for Indian Wells Valley Watershed by Month

In this analysis, the generation of runoff and recharge are considered the same due to the internally draining geometry of the IWV Watershed. Recharge and runoff together generate typically 0 to 14 percent of precipitation totals and average approximately 18,000 AFY from 2010 to 2020, as shown by the dashed line in **Figure 9**.

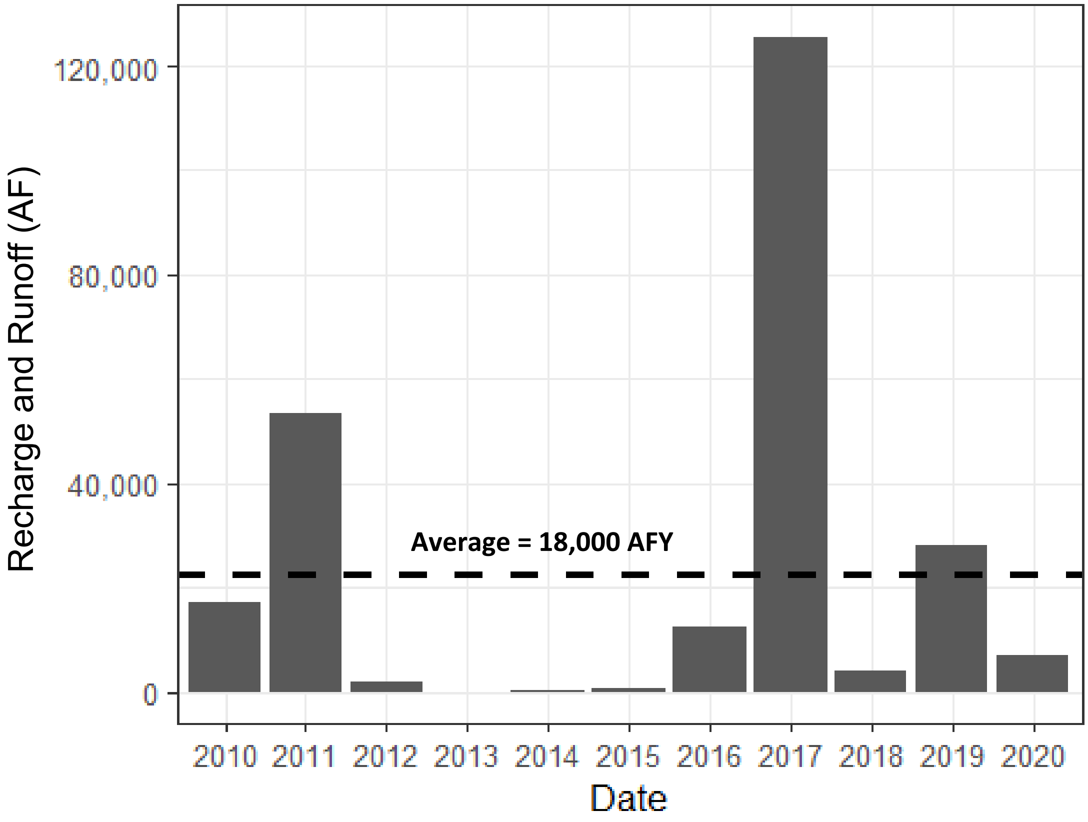


Figure 9. Combined Recharge and Runoff Volume in Indian Wells Valley Watershed by Water Year

3.2 Estimate of Mountain Front Recharge

As discussed in **Section 2.1.2**, mountain front recharge estimates have been conducted for the last 100 years. Estimates of mountain front recharge were also conducted here using the BCM data presented above. To remain consistent with previous studies, the watershed was split into different precipitation zones (**Figure 10**). These zones are based on Parameter-elevation Regressions on Independent Slopes Model (PRISM) 30-year normal precipitation values and include greater than 8 inches, 5 to 8 inches, and less than 5 inches. The precipitation zone characterized as greater than 8 inches will typically account for 68 to 100% of the total recharge and runoff in the watershed. The 5- to 8-inch zone accounts for 0 to 31% of total watershed recharge and runoff while the 5 inches or less zone only accounts for a maximum amount of 2.7% (**Figure 11**).

As illustrated in the figures below, while the areas receiving less than 8 inches of precipitation per year do not produce a great percentage of recharge and runoff, this smaller percentage can be significant in wetter WYs, such as in 2017. Distinct thresholds also exist for precipitation that will result in recharge in any given year in IWV Basin, overcoming the soil storage, ponding, transpiration and evaporative demands, and these thresholds vary throughout the IWV Basin as a result of the distribution of the different water balance components. The USGS (2020) applied the BCM in IWV Basin, at the direction of Kern County and under a state-funded grant, to estimate the groundwater recharge over the following two historical time periods:

- 1981-2010: 8,680 AFY, and
- 2000-2013: 6,000 AFY.

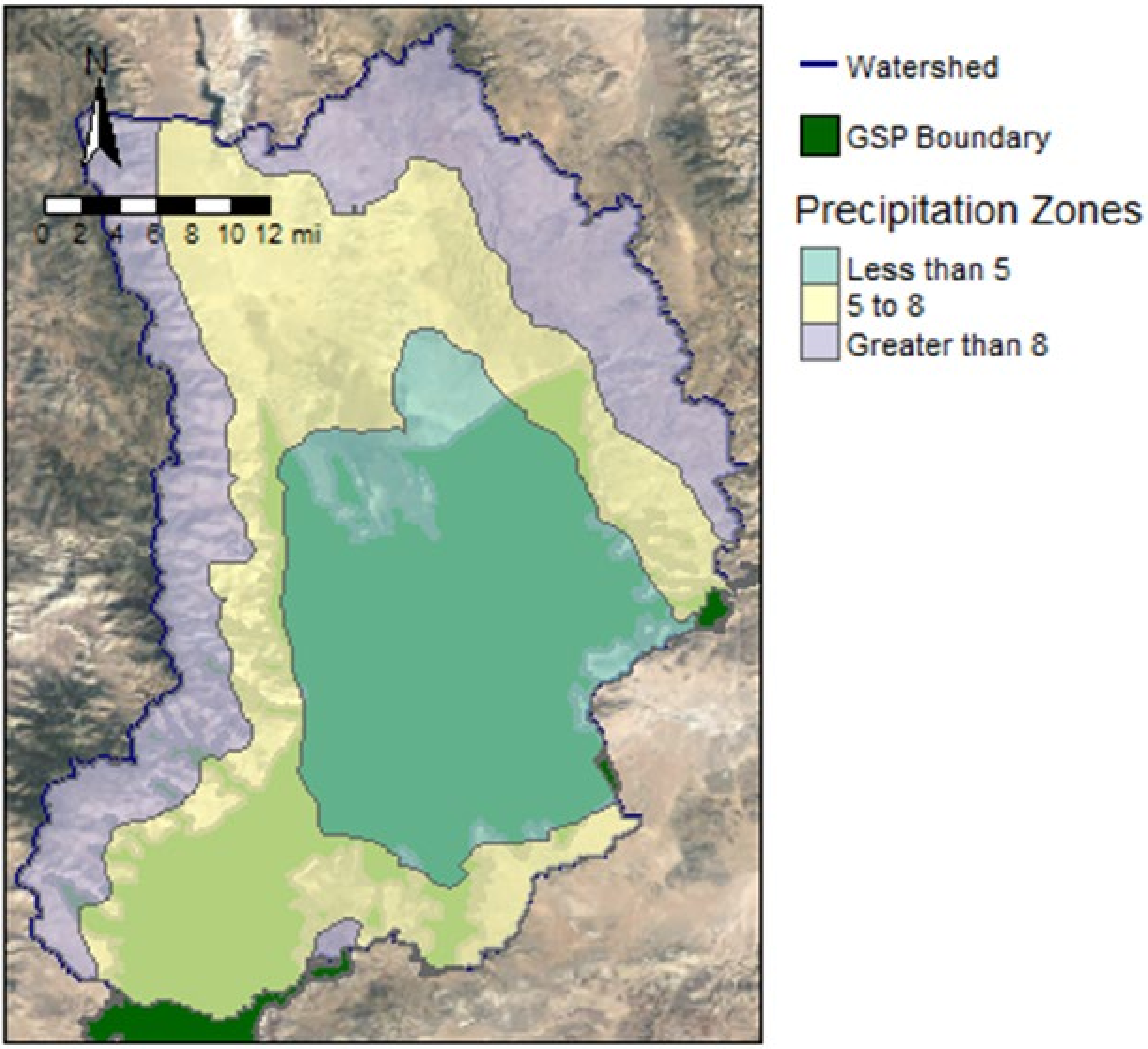


Figure 10. Precipitation Zones for Indian Wells Valley Watershed

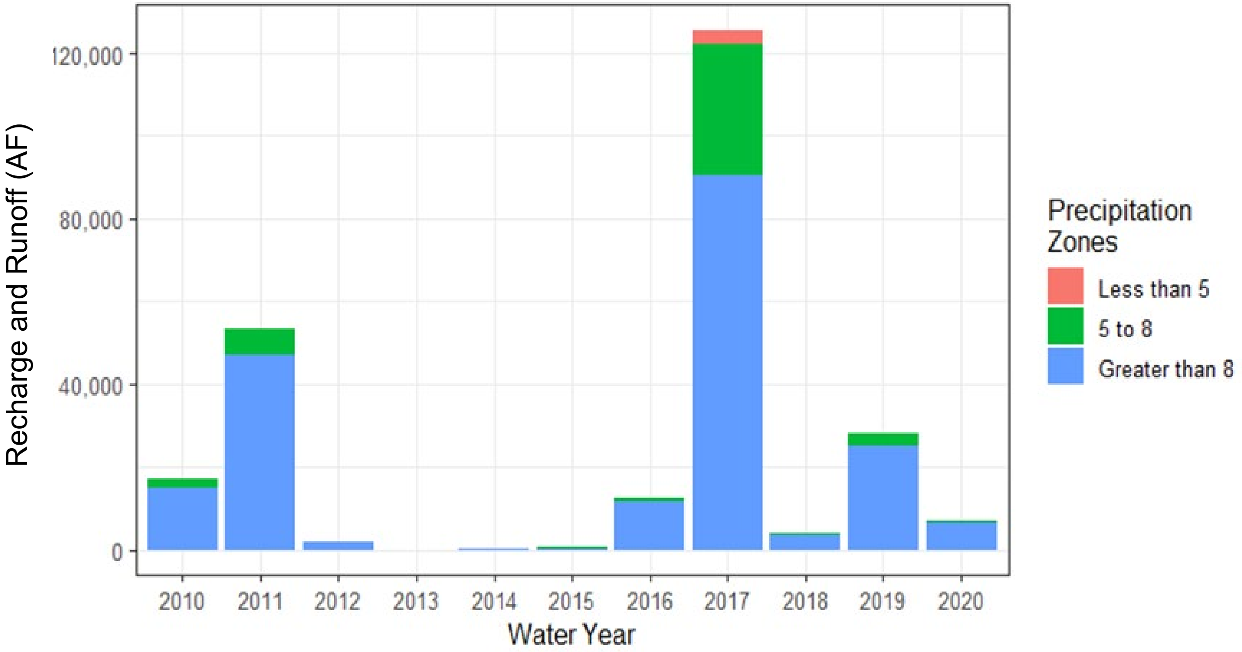


Figure 11. Recharge and Runoff Volume by Precipitation Zone and Water Year

3.3 Limitations and Considerations

As noted above, recharge values estimated by the BCM are just for in-basin mountain front recharge; they exclude groundwater underflow from the Rose Valley and do not include other forms of recharge to the IWV Basin (e.g., return flows, wastewater spreading, etc.).

4.0 Sustainable Yield Defined by the Groundwater Sustainability Plan

Pursuant to SGMA, a GSP for the IWV Basin was developed by the IWVGA in 2020. The initial IWV GSP submittal was conditionally approved by DWR in January 2022. DWR has indicated that GSPs are expected to change and improve over time in light of new data and analyses. While conditional approval of the initial submittal has been granted, the GSP could be determined to be out of compliance at a future date based on annual report reviews and five-year evaluations by DWR.

The GSP includes historical, current, and future groundwater budgets, as well as an estimate of the basin's sustainable yield. The GSP set sustainable yield as 7,650 AFY, as detailed in **Table 5**. This value drives basin management outlined in the GSP, including projects and management actions such as the Groundwater Augmentation Project and Shallow Well Mitigation Project and associated Basin Replenishment Fees (IWVGA, 2020a). As described in the main paper, safe yield will be considered and ultimately determined by the court in the pending groundwater basin adjudication of water rights.

Table 5. GSP Groundwater Recharge Estimate for Indian Wells Valley Groundwater Basin

Recharge Term	Recharge Rate [AFY]
Mountain Front Recharge	
Sierra Nevada – South	1,500
Sierra Nevada – North	2,100
Coso and Argus Ranges	1,600
El Paso Mountains	50
Underflow from Rose Valley	2,400
TOTAL	**7,650**

4.1 Preliminary Review of GSP Data, as Related to Estimates of Safe Yield

As part of the evaluation of previous estimates of safe yield and similar studies for the IWV Basin, the TWG conducted a preliminary review of the GSP's sustainable yield value. This initial review considered only information presented in the GSP and GSP annual reports and the impact of certain assumptions utilized by the IWVGA on an estimate of safe yield.

4.1.1 Impact of Specific Yield

The water budget analysis provided in the GSP utilizes the groundwater flow model developed by DRI (McGraw et al., 2016). This model is calibrated to the assumed groundwater recharge volume of 7,650 AFY. Therefore, it is useful to include a discussion here on the impact of modeled aquifer parameters – particularly specific yield (Sy). Sy, or storage coefficient, refers to the volume of water released from storage by an unconfined aquifer per unit surface area of aquifer per unit decline of the hydraulic head, and is unitless (Freeze and Cherry, 1979). In unconfined aquifers, it is basically equivalent to the specific yield; in confined aquifers it depends on elastic compression of the aquifer. In other words, Sy is the amount of water that is actually available for groundwater pumping, when sediments or rocks are drained due to lowering of groundwater levels.

The Equation of Continuity, as applied to groundwater recharge and discharge, may be expressed as:

$$Q_{in} = Q_{out} +/- \Delta S \quad \text{.......... (Eqn. 1)}$$

Where:

Q_{in} = Recharge [AFY]; from GSP = 7,650 AFY
Q_{out} = Discharge [AFY]; long-term average from GSP (1975 – 2015) = 25,778 AFY
ΔS = Change in Groundwater Storage [AFY]

Change in groundwater storage can also be expressed as:

$$\Delta S = A \times Sy \times \Delta WL \quad \text{.......... (Eqn. 2)}$$

Where:

ΔS = Annual Change in Groundwater Storage [AF]
A = Area [acres]
Sy = Specific Yield [unitless]
ΔWL = Annual Change in Water Level [ft]

Substituting in Equation No. 2 for change in storage and rearranging to solve for change in water level produces:

$\Delta WL = (Q_{in} - Q_{out}) / (A \times Sy)$ .... *(Eqn. 3)*

Where:

ΔWL = Change in Water Level [ft]
A = Basin Area [acres]. IWV Groundwater Basin = 382,000 acres
Sy = Specific Yield [unitless]. From DRI model (McGraw et al., 2016) = 0.225

General values from the GSP modeling effort indicate a change in water level of approximately -0.211 feet per year (ft/yr) across the entire groundwater basin:

-0.211 ft/yr = (7,650 AFY – 25,778 AFY) / (382,000 acres x 0.225)

Holding the pumping, basin area, and change in water level steady allows the effect of changing Sy values to be seen on basin recharge:

$Q_{in} = Q_{out} \pm (A \times \Delta WL \times Sy)$ .... *(Eqn. 4)*

Q_{in} = 25,778 AFY – (382,000 acres)(0.211 ft/yr)(**0.20**) = 9,664 AFY
Q_{in} = 25,778 AFY – (382,000 acres)(0.211 ft/yr)(**0.175**) = 11,673 AFY
Q_{in} = 25,778 AFY – (382,000 acres)(0.211 ft/yr)(**0.15**) = 13,693 AFY
Q_{in} = 25,778 AFY – (382,000 acres)(0.211 ft/yr)(**0.125**) = 15,707 AFY

During GSP model calibration, the predetermined recharge value of 7,650 AFY (5,250 AFY natural recharge and 2,400 AFY basin interflow from Rose Valley) was held constant, relying on the adjustment of Sy and other aquifer parameters to achieve adequate calibration to observed groundwater elevations. As a result, the Sy values used in the DRI model (McGraw et al., 2016) based on the recharge estimate are too high and not considered representative of the aquifer sediments in the IWV Basin (see additional discussion in main TWG paper). The use of more representative values of Sy would dramatically increase the estimate of recharge.

For example, Kunkle and Chase (1969) provided estimates of Sy for the uppermost portion of the aquifer (i.e., HGZ-1) of between 9 and 13%, which would provide estimates of groundwater recharge (safe yield) of 15,304 and 18,527 AFY, respectively. ECORP Consultants, Inc. considered a value for Sy of 18% in their Environmental Impact Report (EIR) for the District's Water Supply Improvement Project (ECORP, 2012), corresponding to an estimated groundwater recharge of 11,270 AFY. An updated Hydrogeological Conceptual Framework (HCF) developed by Ramboll in 2024 used detailed well completion report lithologic descriptions, geophysical logs, and seismic lines to calculate net sand and net clay, resulting in Sy estimates that range from 6% to 17% (Ramboll, 2024; see also 2024 TWG storage paper).

As noted in Equation Nos. 1 through 4, the value of Sy used in any analysis of safe yield will also affect the estimate of storage loss. In addition, it will impact any estimate of groundwater in storage (see separate TWG paper "Assessment of Groundwater Storage for the Indian Wells Valley Groundwater Basin"). For example, an estimate of total groundwater in storage for the entire IWV Basin of 90,000,000 AF using a Sy of 22.5% would be reduced to 70,000,000 AF using a Sy of 17.5% (although this still represents a very large volume of water resource available for beneficial use).

4.1.2 Initial Estimates of Safe Yield from Change in Groundwater Storage

Since safe yield represents the amount of groundwater pumping that causes no change in groundwater storage, Equation No. 1 can also be expressed as:

Safe Yield = Pumping +/- Change in Storage... (Eqn. 5)

Change in storage over a given area is calculated using Equation No. 2, above. The Thiessen Polygon Method (Dunne and Leopold, 1978) is a graphical technique originally created to calculate average precipitation based on precipitation measurements from meteorological stations. The method has also been used widely to divide a basin into smaller areas based on where water level measurements are available. Wells are typically selected based on their groundwater level record and distribution throughout the basin. Thiessen polygons are then created using an automated ArcGIS Pro geoprocessing to form polygons surrounding each selected well location point. The value of the groundwater level in each individual well is assumed to represent the level throughout each individual polygon area. The annual change in groundwater storage is calculated for each polygon and summed to represent the total storage change for the basin. One of the benefits of considering safe yield in terms of change in groundwater storage is that the calculation 1) relies on measured data, such as water level measurements and recorded pumping; and 2) represents a complete accounting of all groundwater inflows and outflows without the uncertainty associated with estimating each individual water budget term.

To estimate the annual change in groundwater storage, the IWV 2020 GSP Annual Report prepared by Stetson Engineers entitled, "Indian Wells Valley Groundwater Basin GSP Annual Report Water Year 2020 (October 2019 to September 2020)" (IWVGA, 2021) delineated 41 polygons (**Figure 12**) using the Thiessen Polygon Method, and 41 selected wells. Annual changes in water level were based on the observed groundwater elevations at the 41 control wells and Sy values from the calibrated groundwater model (Appendix 3-H of the GSP: IWVGA, 2020b). Preliminary TWG evaluations of safe yield using the change in storage method utilized information provided in the WY 2020 GSP Annual Report (the best-available information at that time), including estimated pumping, water level information, and the 41 polygon areas, to provide an independent check on the reasonableness of the sustainable yield outlined in the GSP.

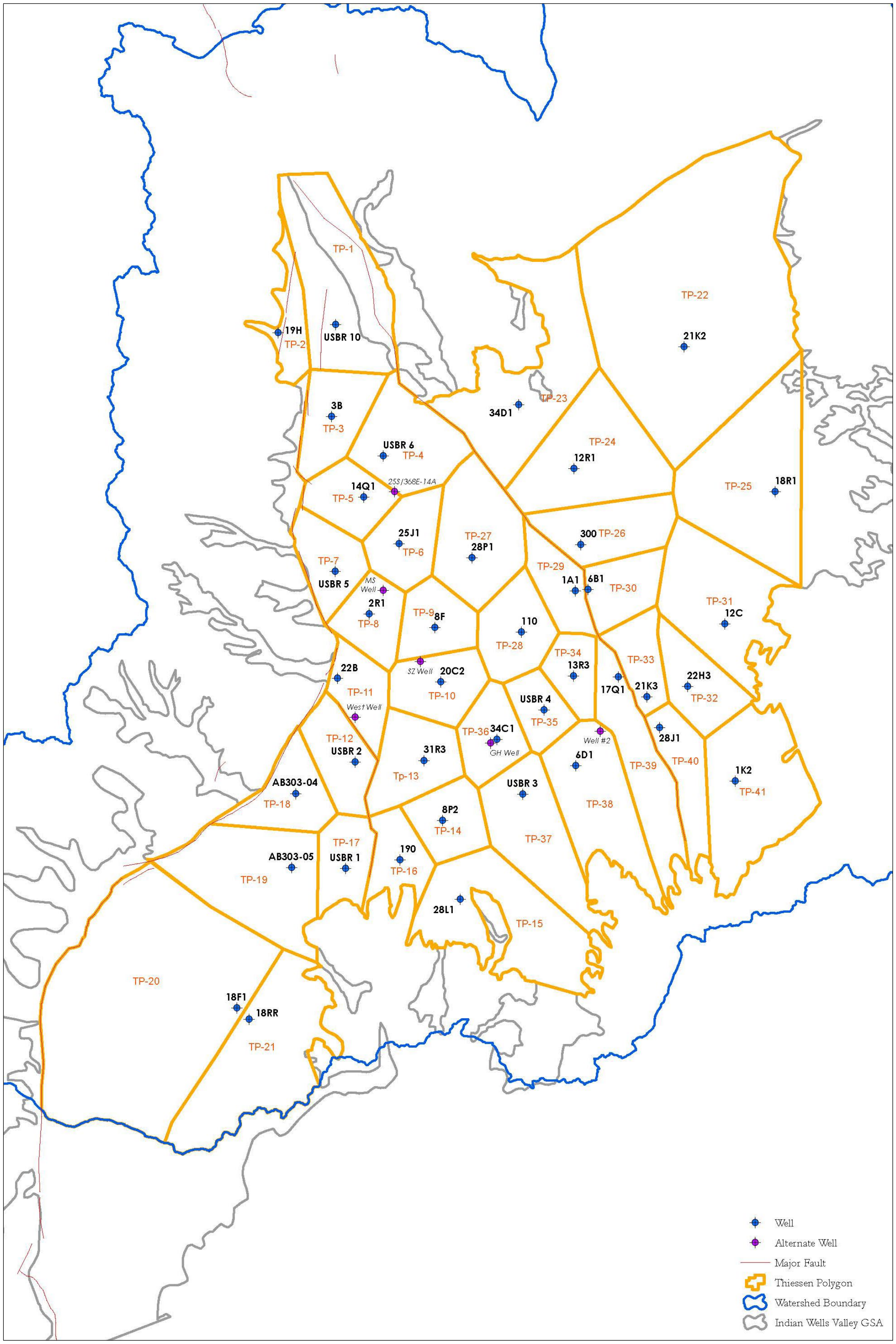


Figure 12. 41 Thiessen Polygons used for Change in Storage Calculations

(Source: Figure 5-5 in IWVGA, 2021)

This method of using observed data and model-calibrated data is often used in hydrologic analyses for calculating the change in groundwater storage. However, this method relies on the representativeness of water levels from a single well and one Sy value to characterize an entire polygon area. For example, the limited availability of wells with water level data causes the wells in the El Paso Subarea of IWV to be located away from the center of Polygons TP-20 and TP-21 (see **Figure 12**). Furthermore, these two polygons represent a very large area, which may cause greater uncertainty or errors in the change in storage calculations. This is an important consideration given that these two polygons generally show very significant increases in groundwater storage (i.e., rising groundwater elevations) compared to other polygons. In order to assess the sensitivity of calculated storage change to these areas, the preliminary analysis presented herein includes an adjusted annual GSP-calculated change in groundwater storage for which these two polygons in the El Paso Subarea were removed.

Table 6 below shows the GSP-calculated annual change in groundwater storage for the Main Basin and El Paso Subarea from the WY 2020 GSP Annual Report. As shown, the average annual GSP-calculated change in groundwater storage for the IWV Basin for the period from WYs 2016 through 2020 was estimated to be approximately -7,737 AFY. It is important to note that the estimates of storage change presented below and in subsequent tables vary significantly year to year (over three orders of magnitude) and do not correlate well with changes in pumping (see **Table 7**) or precipitation (see **Table 10**). This suggests limitations in the data and/or method used for this estimation. Nevertheless, analysis using available information from GSP reporting, such as pumping and water level data, provides a comparison to the IWVGA GSP sustainable yield value of 7,650 AFY.

Table 6. GSP-Estimated Annual Change in Groundwater Storage Water Years 2016 through 2020

Water Year	Annual Change in Groundwater Storage for IWV Groundwater Basin (All 41 Polygons) [AFY]		
	IWV Main Basin	El Paso Subarea	Total
2016	-3,316	4,702	1,387
2017	-5,927	4,432	-1,495
2018	-19,382	-2,554	-21,936
2019	-10,459	10,326	-133
2020	-18,274	1,767	-16,508
Annual Average (2016 – 2020)	**-11,472**	**3,735**	**-7,737**

Note: A positive sign represents an increase in groundwater storage, while a negative sign indicates a decline in groundwater storage.

The WY 2020 GSP Annual Report provides an estimate of WY 2020 groundwater pumping. It was derived from pumping records submitted to the IWVGA plus IWVGA-assumed domestic pumping and was estimated to be 21,994 AF. The WY 2020 Annual Report also documents 22,810 AF of groundwater pumping for WY 2019 (Figure 5-6 of IWVGA, 2021).

According to the IWV Basin GSP (2020b), groundwater pumping for Calendar Year 2016 was estimated to be 24,314 AF. Since groundwater pumping for WYs 2016 through 2018 is not available in the GSP nor the 2020 Annual Report and for the purposes of this preliminary analysis, it was assumed that groundwater pumping in WY 2016 was the same as reported pumping for Calendar Year 2016. In addition, groundwater pumping for WYs 2017 and 2018 was estimated by linear interpretation using the pumping for 2016 and 2019.

Table 7 summarizes groundwater pumping, as available from GSP documents. As shown, the average annual groundwater pumping for the IWV Groundwater Basin for the period from WY 2016 through 2020 was estimated to be 23,248 AFY.

Table 7. GSP-Estimated Annual Groundwater Pumping for Water Years 2016 through 2020

Water Year	Source	Estimated Annual Groundwater Pumping [AFY]
2016	IWV Basin GSP (IWVGA, 2020b)	24,314
2017	Interpreted based on 2016 and 2019 values	23,813
2018	Interpreted based on 2016 and 2019 values	23,311
2019	2020 Annual Report (IWVGA, 2021)	22,810
2020	2020 Annual Report (IWVGA, 2021)	21,994
Average Annual Pumping (2016 - 2020)		**23,248**

The yield derived using the GSP storage change data from **Table 6**, GSP groundwater pumping from **Table 7**, and Equation No. 5 is provided in the following **Table 8**. As shown, the derived yield varies by year depending on the estimates of pumping and change in groundwater storage. Average derived safe yield during that period would be approximately 15,500 AFY.

Table 8. Derived Yield using Groundwater Pumping and
Change in Groundwater Storage from the WY 2020 GSP Annual Report

Water Year	Annual Groundwater Pumping[1] [AFY]	Change in Groundwater Storage [AFY]	Derived Yield [AFY]
2016	24,314	1,387	25,701
2017	23,813	-1,495	22,318
2018	23,311	-21,936	1,375
2019	22,810	-133	22,677
2020	21,994	-16,508	5,486
Average (2016 - 2020)	**23,248**	**-7,737**	**15,511**

[1] Refer to **Table 7** for sources of GSP-estimated pumping.

4.1.2.1 Consideration of Additional Water Level Data

As illustrated by the estimation presented in **Table 8**, safe yield is directly tied to assumptions of groundwater pumping and change in storage. The calculated change in storage is directly affected by changes in water levels observed in the 41 wells chosen to represent conditions in the polygon areas for the Thiessen analysis. Therefore, errors in these readings can significantly impact estimated storage and safe yield. Since the amount of groundwater pumping reported in the GSP and annual reports is relatively constant (ranging from approximately 22,000 to 24,000 AFY during the period from 2016 through 2020), differences in GSP-calculated change in groundwater storage (driven by water level readings at select wells) are the main factor for the differences in estimated yield presented in **Table 8**. Some of these fluctuations in water level may be due to annual changes in precipitation (discussed below), local, site-specific conditions at the wells, or errors in measurement (such as a non-static measurement). The following example shows how water level measurements used for the change in storage calculation can impact the results.

Table 9 below is a reproduction of Attachment F from the WY 2020 GSP Annual Report (IWVGA, 2021), which provides the values used for the change in storage calculations, including water level measurements from the 41 wells incorporated in the GSP annual report Thiessen Polygon analysis. Upon review of the change in depth to water level for 2020, two main polygon areas stood out: TP-4 and TP-27. These two polygon areas are in the northwest section of the basin near Brown Road, where much of the agricultural pumping occurs (refer to **Figure 12** for polygon areas). Despite WY 2020 being an above-normal precipitation year, the change in water level for TP-4 indicates a decline of 3.6 feet. Prior to this, the GSP annual report indicates the change in water level ranged from an increase of 1.3 feet to a decrease of 0.1 feet from 2016 through 2019. Supplemental water levels in the area (not provided in GSP reporting) indicate that water levels are generally flat and do not show a significant change (**Figure 13**). Revising the change in depth for TP-4 from -3.6 feet to 0 feet to reflect these supplementary water level measurements produces a corresponding increase in groundwater storage of approximately 5,000 AFY.

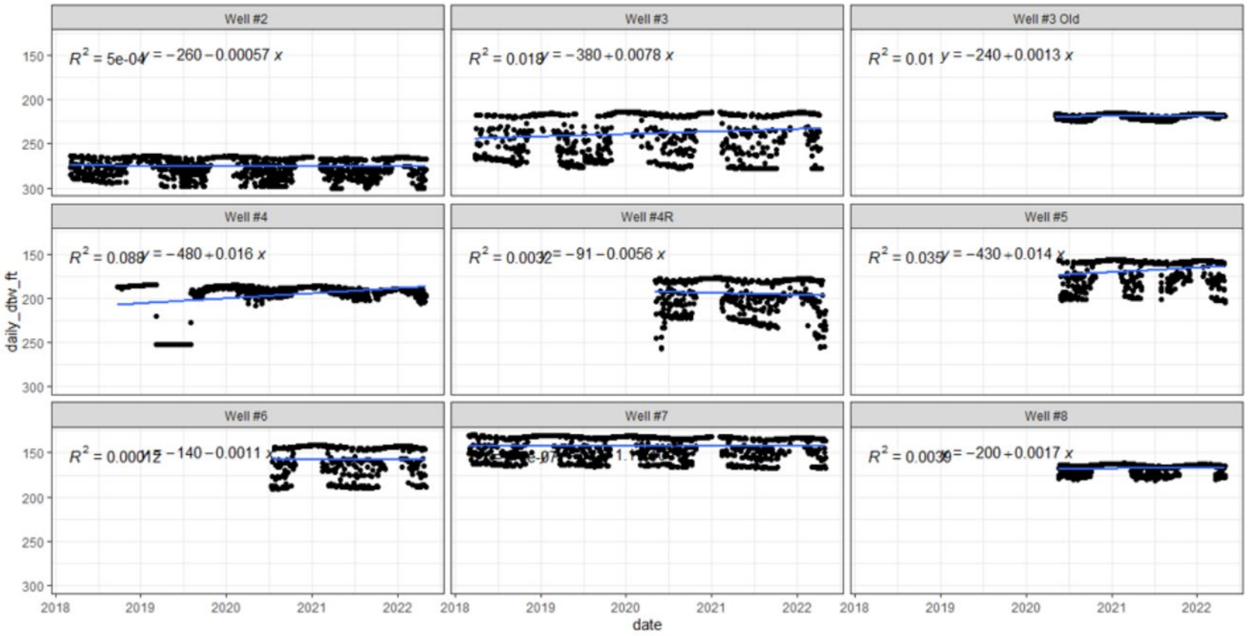


Figure 13. Supplemental Water Level Measurements in Thiessen Polygon Area TP-4

Similarly, the water level measurement used for TP-27 shows a drop of 10.8 feet in 2020 in the GSP annual report, based on an estimated and not measured water level. The largest decline in water level shown before this was 0.2 feet in 2018, a below-normal precipitation year. Observed water levels in wells from surrounding polygons (e.g., TP-4, TP-6, TP-9, TP-28, and TP-29) do not indicate this amount of change. If an average water level change from these surrounding areas is used, the change in storage for this one polygon area increases by nearly 19,000 AF. Collectively, these two changes for TP-4 and TP-27 produce a difference in the overall calculated change in groundwater storage of nearly 24,000 AF. Therefore, this simple exercise illustrates the sensitivity of change in storage calculations to water level measurements used and how much impact these changes could potentially have on estimates of safe yield.

Table 9. Indian Wells Valley Groundwater Storage Change Calculations
(Source: Modified from Attachment F in IWVGA, 2021)

Thiessen Polygon	State ID T/R-S	Basin Area	Specific Yield	Land Surface (ft, msl)	Aquifer Area (Acres)		Spring Depth to Water (Feet)						Change in Depth (Feet)					Annual Change in Storage (Acre-Feet)					5-year Cumulative Change
							2015	2016	2017	2018	2019	2020	2015 -2016	2016 -2017	2017 -2018	2018 -2019	2019 -2020	WY 2016	WY 2017	WY 2018	WY 2019	WY 2020	
TP-1	24S/38E-21A01	NW	0.21	2,559	11,675		315.5	315.6	316.5	316.9	318.0	319.6	-0.1	-0.9	-0.4	-1.1	-1.6	-245	-2,207	-981	-2,697	-3,923	-10,052
TP-2	24S/38E-19H	NW	0.21		2,840	1					8.2	7.9					0.3	-60	-537	-239	-656	179	-1,312
TP-3	25S/38E-03B	NW	0.21	2,456	4,655		284.8	285.7	286.3	286.7	288.1	289.5	-0.9	-0.6	-0.4	-1.4	-1.4	-880	-587	-391	-1,369	-1,369	-4,594
TP-4	25S/38E-12L01	NW	0.21	2,353	6,627		182.3	181.0	180.8	180.4	180.5	184.1	1.3	0.2	0.4	-0.1	-3.6	1,809	278	557	-139	-5,010	-2,505
TP-5	25S/38E-14Q01	NW	0.21	2,391	3,641	6	227.7	222.9	225.1	225.8	225.6		4.8	-2.2	-0.7	0.2	-2.3	3,670	-1,682	-535	153	-1,789	-184
TP-6	25S/38E-25J01	NW	0.21	2,277	4,192		111.2	114.2	115.7	114.6	115.4	112.7	-3.0	-1.5	1.1	-0.8	2.7	-2,641	-1,321	969	-704	2,377	-1,321
TP-7	25S/38E-34G01	NW	0.21	2,520	3,859		353.0	352.4	353.1	355.9	357.3	358.3	0.6	-0.7	-2.8	-1.4	-1.0	486	-567	-2,269	-1,135	-811	-4,295
TP-8	26S/38E-02R01	NW	0.21	2,398	3,511	6	231.9	232.9	233.3	234.5	236.4		-1.0	-0.4	-1.2	-1.9	-0.5	-737	-295	-885	-1,401	-339	-3,658
TP-10	26S/39E-20C02	NW	0.18	2,391	4,359	6	233.6	234.4	234.9	236.4	237.4		-0.8	-0.5	-1.5	-1.0	-0.6	-628	-392	-1,177	-785	-471	-3,452
TP-11	26S/38E-22B	SW	0.21	2,666	3,350	6	426.3	426.5	430.5	430.6	426.6		-0.2	-4.0	-0.1	4.0	1.2	-141	-2,814	-70	2,814	865	654
TP-13	26S/39E-31R03	SW	0.08	2,500	5,119	5	355.6	356.0	356.5	357.7	359.1		-0.4	-0.5	-1.2	-1.4	-0.9	-164	-205	-491	-573	-369	-1,802
TP-14	27S/39E-08P02	SW	0.08	2,581	3,760		431.3	432.1	432.3	433.8	434.8	435.7	-0.8	-0.2	-1.5	-1.0	-0.9	-241	-60	-451	-301	-271	-1,324
TP-15	27S/39E-28L01	SW	0.08	2,820	10,847		289.4	289.4	288.8	288.8	288.2	288.6	0.0	0.6	0.0	0.6	-0.4	0	521	0	521	-347	694
TP-16	27S/39E-19E01	SW	0.08	2,639	3,474		203.8	204.0	203.9	204.3	204.1	204.0	-0.2	0.1	-0.4	0.2	0.1	-56	28	-111	56	28	-56
TP-35	26S/39E-26A03	SE	0.18	2,377	2,690		251.0	252.2	251.4	252.5	252.4	253.8	-1.2	0.8	-1.1	0.1	-1.4	-581	387	-533	48	-678	-1,356
TP-36	26S/39E-34C01	SE	0.08	2,451	3,713	6	294.3	294.8	295.1	297.3	298.0		-0.5	-0.3	-2.2	-0.7	-0.7	-149	-89	-654	-208	-214	-1,313
TP-37	27S/39E-11D01	SE	0.08	2,510	7,907		354.7	358.9	358.7	359.7	360.0	358.1	-4.2	0.2	-1.0	-0.3	1.9	-2,657	127	-633	-190	1,202	-2,151
TP-38	27S/40E-06F01	SE	0.08	2,407	8,376	6	324.7	322.6	323.5	322.4	322.1		2.1	-0.9	1.1	0.3	0.8	1,407	-603	737	201	563	2,305
TP-40	26S/40E-28J01	SE	0.21	2,291	4,048		134.0	133.9	134.6	134.7	135.3	133.3	0.1	-0.7	-0.1	-0.6	2.0	85	-595	-85	-510	1,700	595
TP-41	27S/40E-01K02	SE	0.21	2,323	10,631		160.5	160.3	160.5	161.4	162.1	161.6	0.2	-0.2	-0.9	-0.7	0.5	447	-447	-2,009	-1,563	1,116	-2,456
TP-9	26S/39E-08F	NVY	0.21	2,319	3,721		160.0	161.3	162.0	163.4	164.5	165.5	-1.3	-0.7	-1.4	-1.1	-1.0	-1,016	-547	-1,094	-860	-781	-4,298
TP-22	24S/40E-21K02	NVY	0.21		36,916	2					52.3	52.0					0.3	-1,551	-1,551	-1,551	-2,326	2,326	-4,652
TP-23	24S/39E-34D01	NVY	0.21	2,227	13,194	3				46.6	46.9	46.9				-0.3	0.0	-554	-554	-554	-831	0	-2,494
TP-24	25S/39E-12R01	NVY	0.21	2,202	10,162		23.3	23.5	23.7	23.9	24.2	24.5	-0.2	-0.2	-0.2	-0.3	-0.3	-427	-427	-427	-640	-640	-2,561
TP-25	25S/41E-18R01	NVY	0.21	2,003	13,523		22.1	22.0	21.9	22.2	22.1	21.5	0.1	0.1	-0.3	0.1	0.6	284	284	-852	284	1,704	1,704
TP-26	25S/40E-30E01	NVY	0.21	2,191	5,445		13.6	13.7	13.7	14.0	14.2	14.4	-0.1	0.0	-0.3	-0.2	-0.2	-114	0	-343	-229	-229	-915
TP-27	25S/39E-28P01	NVY	0.21	2,229	7,615		47.7	45.5	40.5	40.7	39.4	50.2	2.2	5.0	-0.2	1.3	-10.8	3,518	7,995	-320	2,079	-17,270	-3,998
TP-28	26S/39E-11E01	NVY	0.21	2,307	4,642		131.8	132.6	133.0	133.8	134.4	135.6	-0.8	-0.4	-0.8	-0.6	-1.2	-780	-390	-780	-585	-1,170	-3,704
TP-29	26S/39E-01A01	NVY	0.21	2,218	3,308		47.2	47.7	47.7	48.1	48.2	44.0	-0.5	0.0	-0.4	-0.1	4.2	-347	0	-278	-70	2,918	2,223
TP-30	25S/40E-31P	NVY	0.21	2,192	3,581		20.3	20.3	20.0	20.5	20.5	19.5	0.0	0.3	-0.5	0.0	1.0	0	226	-376	0	752	602
TP-31	26S/40E-12C	NVY	0.21	2,166	9,875		4.3	4.6	4.1	4.7	4.3	5.7	-0.3	0.5	-0.6	0.4	-1.4	-622	1,037	-1,244	830	-2,903	-2,903
TP-32	26S/40E-22H03	NVY	0.21	2,228	4,338		31.2	31.8	32.1	32.8	33.2	33.3	-0.6	-0.3	-0.7	-0.4	-0.1	-547	-273	-638	-364	-91	-1,913
TP-33	26S/40E-21K03	NVY	0.21	2,267	3,065		102.8	101.7	101.2	103.1	101.9	100.0	1.1	0.5	-1.9	1.2	1.9	708	322	-1,223	772	1,223	1,802
TP-34	26S/39E-13R03	NVY	0.21	2,319	2,662		149.7	150.0	150.5	150.8	151.2	151.9	-0.3	-0.5	-0.3	-0.4	-0.7	-168	-280	-168	-224	-391	-1,230
TP-39	26S/40E-17Q01	NVY	0.21	2,278	6,769	4			145.9	146.1	146.0	143.3			-0.2	0.1	2.7	-426	-711	-284	142	3,838	2,559
TP-12	27S/38E-02C01	EP	0.21	2,655	4,116		282.2	282.4	281.9	282.9	282.9	281.9	-0.2	0.5	-1.0	0.0	1.0	-173	432	-864	0	864	259
TP-17	27S/38E-23F01	EP	0.21	2,851	3,475		183.4	183.4	183.3	183.3	182.8	182.8	0.0	0.1	0.0	0.5	0.0	0	73	0	365	0	438
TP-18	27S/38E-09C01	EP	0.21	3,070	4,533		381.2	380.8	380.7	381.3	381.1	381.3	0.4	0.1	-0.6	0.2	-0.2	381	95	-571	190	-190	-95
TP-19	27S/38E-21L01	EP	0.21	3,024	10,409		361.3	361.5	360.9	360.9	358.4	357.9	-0.2	0.6	0.0	2.5	0.5	-437	1,312	0	5,465	1,093	7,432
TP-20	28S/38E-18F01	EP	0.21	3,027	31,788		212.3	211.6	211.3	211.7	210.9	210.9	0.7	0.3	-0.4	0.8	0.0	4,673	2,003	-2,670	5,340	0	9,346
TP-21	28S/38E-18R	EP	0.21	3,017	12,317		197.3	197.2	197.0	196.4	196.8	196.8	0.1	0.2	0.6	-0.4	0.0	259	517	1,552	-1,035	0	1,293

red: field measurement not available, estimated from hydrograph through Oct 2020

red: calculated using nearby well's dtw change

Totals:

IWV Main Basin	-3,316	-5,927	-19,382	-10,459	-18,274	-57,358
El Paso Sub-area	4,702	4,432	-2,554	10,326	1,767	18,673
Total	1,387	-1,495	-21,936	-133	-16,508	-38,685

4.1.2.2 Consideration of Hydrologic Conditions

Precipitation data can be used to categorize hydrologic conditions such as wet, above normal, normal, below normal, and dry. These conditions directly correlate with the amount of groundwater recharge an area will experience. In general, higher rates of precipitation generate greater amounts of groundwater recharge.

The WY 2020 Annual Report provided historical annual precipitation at the Western Regional Climate Center (WRCC) Station 041733 (China Lake Naval Air Force [NAF]), as summarized below in **Table 10**. Long-term average annual precipitation (from 1945 through 2023) is approximately 3.42 inches per year (in/yr).

Table 10. Annual Precipitation at China Lake NAF Station

Water Year	Type	Annual Precipitation [in/yr]
2016	Below Normal	1.38
2017	Above Normal	4.61
2018	Below Normal	1.43
2019	Wet	6.13
2020	Above Normal	5.57
Annual Average (2016 – 2020)	**-**	**3.82**
Long-Term Average (1945 – 2023)	**-**	**3.42**

Annual precipitation and WY type from Table 4-2 of the WY 2020 GSP Annual Report (IWVGA, 2021).
Long-term average precipitation from Figure 4 of main TWG safe yield paper.

As shown, the average annual precipitation for WYs from 2016 through 2020 (the period which coincides with the safe yield calculations in **Table 8**) was 3.82 in/yr at the China Lake NAF Station, according to the WY 2020 Annual Report, which is approximately 12% higher than the long-term average precipitation of 3.42 in/yr. Safe yield should be estimated over a representative hydrologic base period, as differences in base period hydrology from long-term average hydrology can impact the appropriateness of a safe yield estimate.

4.1.2.3 Updated 77 Thiessen Polygons

The WY 2022 GSP Annual Report presents updated Thiessen polygon areas based on feedback from previous analyses. The overall area encompassed by the polygons was reduced to more closely reflect the area where groundwater level data are available to interpret changes in groundwater storage. The updated 77 polygons cover 188,970 acres, approximately 62 percent of the 304,700 acres covered by the 41 original polygons. In addition, the number of selected key monitoring wells increased from 41 to 77. The updated 77 Thiessen Polygons are shown in **Figure 14**. As a preliminary evaluation of the impact of changing the polygon areas and selected key wells, the safe yield was calculated using Equation No. 5 with groundwater storage change and groundwater pumping presented in the WY 2022 GSP Annual Report. The results are summarized in **Table 11**.

Table 11. Derived Yield using Groundwater Pumping
and Change in Groundwater Storage from the WY 2022 GSP Annual Report

Water Year	Annual Groundwater Pumping[1] [AFY]	Change in Groundwater Storage [AFY]	Derived Yield [AFY]
2016	24,314	-4,380	19,934
2017	23,813	-10,482	13,331
2018	23,311	-16,105	7,206
2019	22,810	-9,338	13,462
2020	21,994	-13,492	8,498
2021	20,800	-13,492	7,308
2022	21,160	-13,492	7,668
Average (2016 - 2022)	**22,840**	**-11,215**	**11,623**

[1] Refer to **Table 7** for sources of 2016-2020 GSP-estimated pumping. 2021-2022 pumping came from the 2022 GSP Annual Report (IWVGA, 2023).

The average safe yield derived for 2016 through 2022 based on the updated 77 polygons would be approximately 11,600 AFY, nearly 4,000 AFY lower than that obtained for the 2016 through 2020 period based on the original 41 polygons (**Tables 8 and 11**). The average from the updated calculation, however, includes two additional years (2021 and 2022) characterized as dry and below normal. These drier-than-average precipitation years cause the period from 2016 through 2022 to be lower than the long-term average (3.08 inches compared to 3.42 inches).

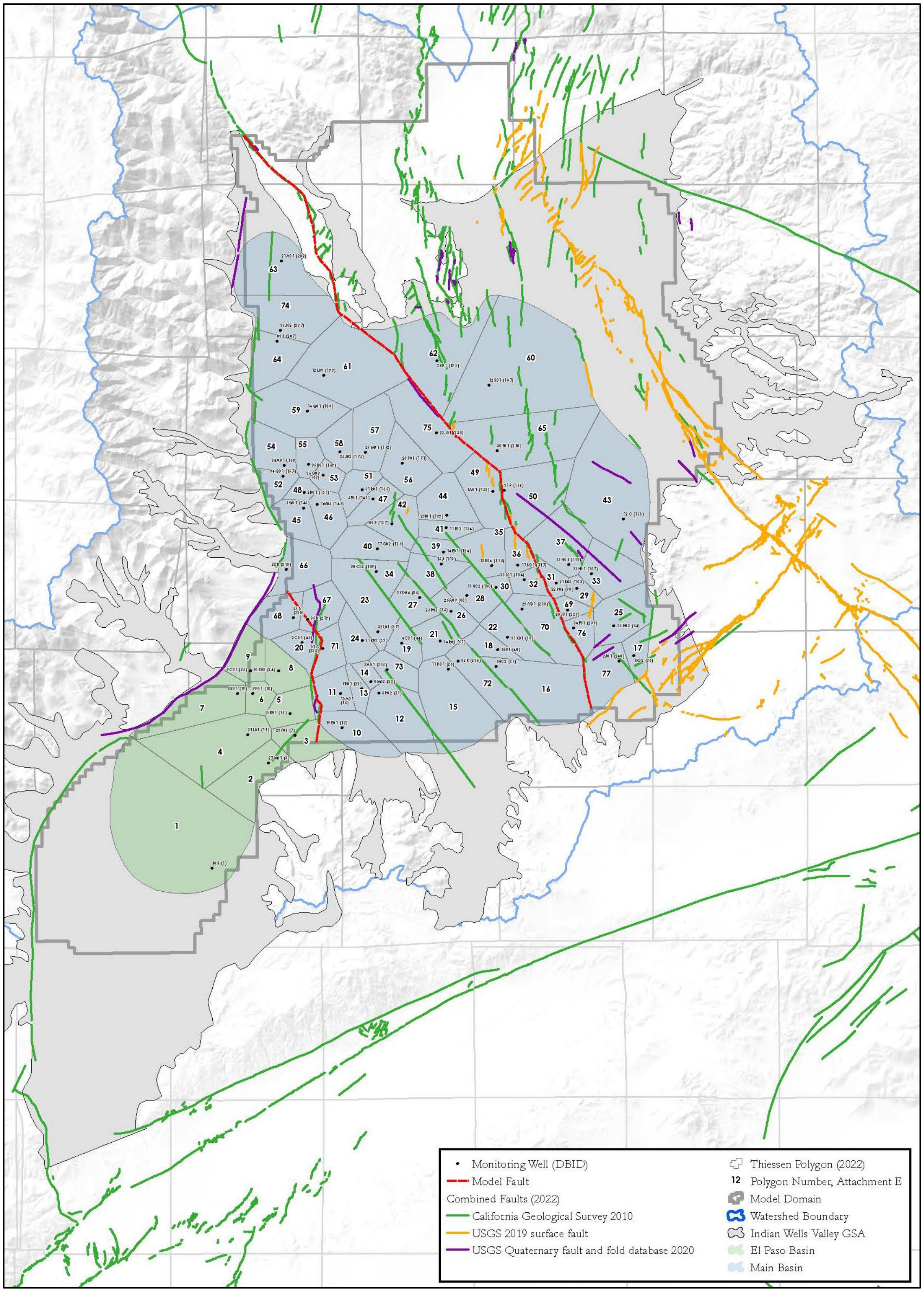


Figure 14. 77 Thiessen Polygons Used for Change in Storage Calculations
(Source: Figure 5-7 in IWVGA, 2023)

4.2 Limitations and Considerations

The management of groundwater outlined in the GSP relies on the 7,650 AFY value as the maximum allowable volume of groundwater that can be removed annually to maintain sustainability in the IWV Basin. However, the TWG notes the following key limitations/considerations:

- The GSP's estimate of a sustainable yield of 7,650 AFY matches the DRI estimates originally developed for NAWS China Lake (McGraw et al., 2016). According to the 2016 report, the mountain front recharge and underflow from Rose Valley values were estimated using a combination of an empirical and limited, two-dimensional groundwater flow model. The empirical model, the bootstrap brute-force recharge model (BBRM; Epstein et al., 2010), developed for Nevada state hydrology application, estimated a "range in calculated recharge is 9,300 afy to 29,000 afy, depending on the assumptions used" (McGraw et al., 2016). The two-dimensional flow model was used to further assess the total groundwater recharge into IWV Basin and refine its spatial distribution to adjust the magnitude and spatial distribution of recharge until there was a general agreement between the simulated and measured predevelopment (1920 to 1921) water levels. Mountain front recharge estimates were then adjusted slightly to produce a "best estimate", though the report does not provide detailed information or a justification for this adjustment. The mountain front recharge value of 5,250 AFY, though within the range of previous estimates of natural recharge (3,000 to 15,000 AFY – see **Table 2**), is lower than the average from these studies (8,700 AFY), and lower than the estimate in the BBRM empirical recharge prediction model. It is also lower than the recent USGS estimate of mountain front recharge developed using the USGS BCM (8,680 AFY or higher – see **Section 3.2**).
- Recharge in the GSP is based on the DRI analysis (McGraw et al., 2016) does not consider recharge contributions from precipitation areas receiving less than 8 inches of precipitation per year. Model output from the BCM confirms that these lower precipitation areas can still contribute significant recharge, particularly in wetter years (see **Figure 11**). By excluding these areas in the water budget analysis, the GSP misses a significant amount of recharge that contributes to long-term safe yield of the basin.
- The GSP assumes that other sources of recharge, such as geothermal upwelling, subsurface inter-basin flow through fractures in the Sierra Nevada bedrock, infiltration of precipitation falling on the IWV Basin, leakage from the Los Angeles Aqueduct, and percolation from wastewater treatment spreading ponds are insignificant (refer to Appendix 3-H of IWVGW, 2020b). McGraw et al. (2016) mention leakage from distribution systems and irrigation return flow (likely close to 20% of applied water), but this recharge does not appear in the modeled IWV Basin water budget, nor is it considered in the GSP's estimate of sustainable yield.
- The GSP three-dimensional DRI groundwater flow model (McGraw et al, 2016), was subsequently developed using the total estimated recharge of 7,650 AFY (5,250 AFY natural recharge and 2,400 AFY basin interflow from Rose Valley) as a constraint to calibrate the model and adjust the Sy values. As a result, the Sy values used in the DRI model based on the recharge estimate are too

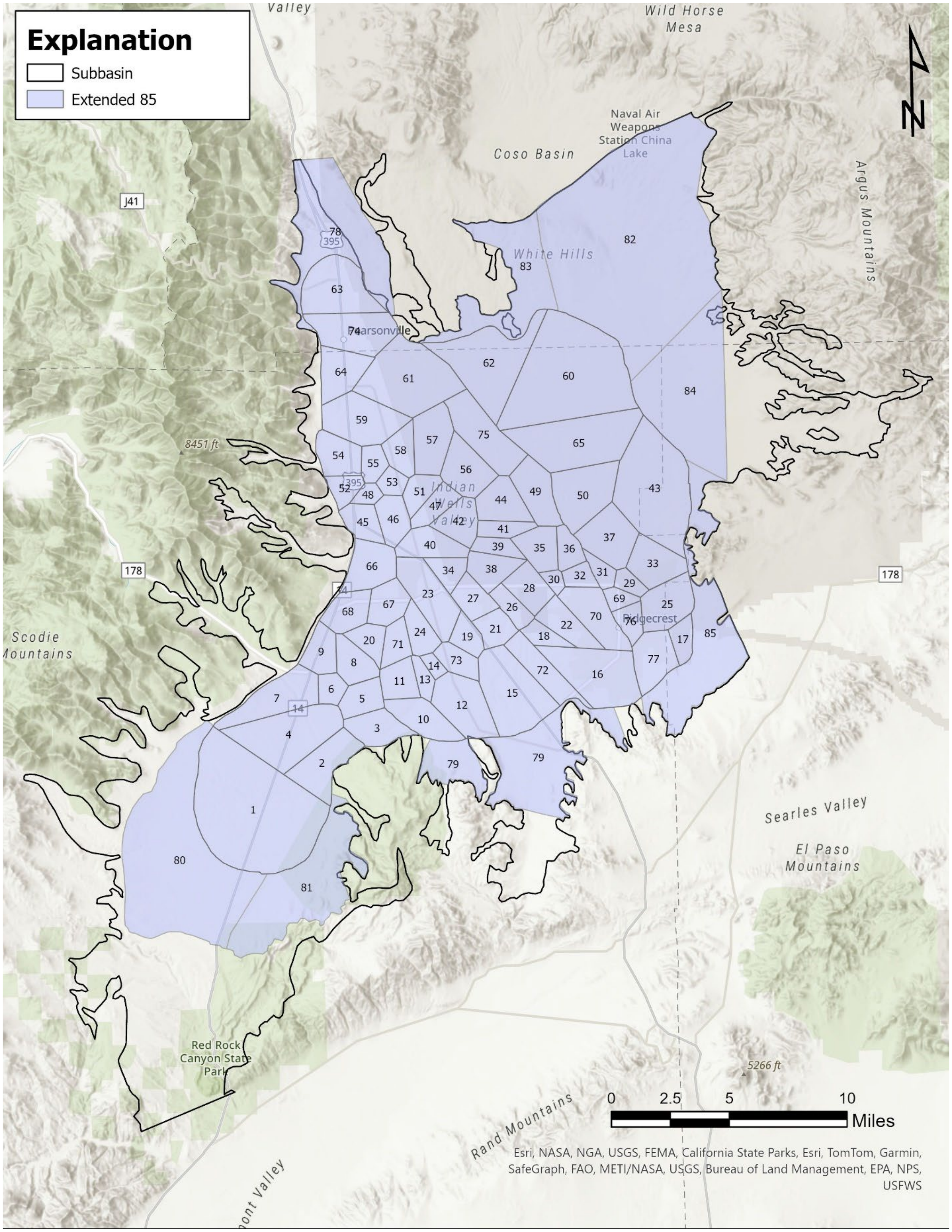
high and not considered representative of the aquifer sediments in the IWV Basin. The use of more representative values of Sy would dramatically increase the estimate of recharge.

- Water level, change in groundwater storage, and pumping data provided largely from GSP annual reporting are inconsistent with the sustainable yield presented in the GSP and indicate a safe yield for the IWV Basin greater than 7,650 AFY.

5.0 Calculation Areas for Independent Estimates of Safe Yield Utilizing Change in Groundwater Storage

As discussed in the previous sections, change in groundwater storage calculations have been conducted to evaluate GSP implementation using two different Thiessen polygon configurations: an original 41 polygon area covering the entirety of IWV Basin, and an updated 77 polygon area with a smaller footprint. The TWG reviewed both of these Thiessen polygon configurations and believes that more polygon areas will generally provide more reliable results due to increased water level and change in groundwater storage resolution throughout the Basin. However, differences between the total areas encompassed by the updated 77 polygons and the original 41 polygons can cause significant differences in groundwater storage changes. Therefore, storage changes estimated using these two sets of polygons cannot be directly compared.

Differences in estimated safe yield due to modifications in the area considered for change in groundwater storage calculations were evaluated by the TWG during their independent analysis of safe yield. This independent analysis considered additional water level measurements, more representative Sy values, and the best available, most up-to-date pumping records from initial disclosures consistent with TWG Approach #1 presented in the main report. In order to evaluate differences caused by calculational area, the TWG added 8 additional polygons to the updated 77 polygons to encompass previously excluded areas consistent with the footprint of the 41 original polygons, creating the set of extended 85 polygons (**Figure 15**). Groundwater storage changes estimated using the extended polygons can be reasonably compared with changes estimated using the 41 original polygons because of their consistent spatial coverage. However, the use of extended polygons can introduce some uncertainties to results due to data resolution and basin geometry. Results of this analysis are summarized in **Table 12**.



Esri, NASA, NGA, USGS, FEMA, California State Parks, Esri, TomTom, Garmin, SafeGraph, FAO, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USFWS

Figure 15. Extended 85 Polygon Area

Table 12. TWG Independent Estimates of Safe Yield using Various Calculation Areas for Change in Groundwater Storage (2014-2023)

Thiessen Polygon Area	Base Period [Calendar Year]	Safe Yield[1] [AFY]
Original 41	2014 - 2023	15,900
Updated 77	2014 - 2023	17,800
Extended 85	2014 - 2023	16,000

[1] Refer to the TWG's "Assessment of Safe Yield for the IWV Basin" for additional detail on underlying assumptions and sources of data.

Comparison of the calculations presented above indicate similar safe yield values using polygon areas that cover the entire IWV Basin (i.e., original 41 and extended 85 Thiessen Polygon areas). Since the change in groundwater storage is calculated as $\Delta S = A \times Sy \times \Delta WL$ (Equation No. 2), decreasing the area will decrease the change in groundwater storage. Consequently, everything else remaining equal, a lower change in groundwater storage will produce a greater estimate of safe yield (*Safe Yield = Pumping +/- Change in Storage*; Equation No. 5). While considering the entire basin area in these calculations may slightly overestimate the change in groundwater storage since it assumes the same change in water level to the edges of the basin, it is a more conservative approach in terms of estimating safe yield and provides a degree of safety against inherent uncertainty in data sets considered for the analysis. As such, the TWG utilized Thiessen polygons that covered the entire alluvium within the IWV Basin.

6.0 Summary and Conclusions

An initial evaluation of existing recharge estimates for IWV Basin was conducted by the TWG. This review included looking at estimates from over two dozen reports of previous geologic and hydrologic investigations in the IWV Basin and surrounding areas, evaluating estimated recharge from the USGS BCM, and critically assessing the appropriateness of the sustainable yield defined by the GSP by considering the impact of different data assumptions (e.g., Sy, groundwater level measurements, hydrology) and initial safe yield calculations using data presented in the GSP annual reports. The TWG's evaluation of previous estimates of safe yield and similar studies for the IWV Basin is summarized as follows:

- Many previous investigations provide evidence for additional sources of groundwater recharge beyond mountain front recharge and basin underflow. If these additional sources of recharge are considered, the total recharge to the IWV Basin ranges between 6,600 and 22,000 AFY, with an average of 14,000 AFY (**Table 2**). This average is 6,350 AFY more groundwater recharge than the value currently used in the GSP, which is the basis for the sustainable yield value established there and the main driver for prioritizing costly projects and regulatory actions being taken in the IWV.
- An evaluation using the USGS BCM indicates that generated recharge and runoff in the IWV Watershed is typically 0 to 14 % of precipitation totals and averages approximately 18,000 AFY from 2010 to 2020, with an estimated average annual groundwater recharge of 8,700 AF for the period from 1981 to 2010, and 6,000 AFY for the period from 2000 to 2013. These values represent natural recharge and do not reflect safe yield of the basin, which should also consider groundwater underflow (from Rose Valley on the order of 2,000 AFY) and supplemental recharge (potentially on the order of 4,000 AFY).
- Sy values used in the GSP model (McGraw et al., 2016) are generally too high. The use of more representative values of Sy would necessitate an increase in the amount of recharge simulated in the model.
- Estimates of safe yield, derived from WY 2016 through 2020 GSP-calculated change in groundwater storage and groundwater pumping reported in the WY 2020 GSP Annual Report, indicate that safe yield for the IWV Basin would be approximately 15,500 AFY, while data from the WY 2022 GSP Annual Report indicates a safe yield for the period of WY 2016 through 2022 would be 11,600 AFY. The average safe yield of these initial calculations based upon those datasets would be 13,550 AFY (**Tables 8 and 11**).
- Considering the limitations of the methodologies reviewed above, the TWG conducted a thorough and independent evaluation of safe yield. The TWG evaluated safe yield over the entire IWV Basin area based upon a representative hydrologic period, additional data, including supplemental water level information, updated pumping based on recent initial disclosure data, and more representative Sy values. As presented in the TWG paper "Assessment of Safe Yield for the IWV Basin," the TWG finds a safe yield for the IWV Basin of approximately **14,300 AFY**.

7.0 References

Anderson, T.W., G.W. Freethey, and P. Tucci, 1992. Geohydrology and Water Resources of Alluvial Basins in South-Central Arizona and Parts of Adjacent States. US Geological Survey Professional Paper 1406-B.

Bauer, 2002. The Hydrogeology of Rose Valley and Little Lake Ranch, Inyo County, California. Master's Thesis, California State University, Bakersfield, California.

Bean, R.T., 1989. Hydrogeologic Conditions in Indian Wells Valley and Vicinity. Prepared for California Department of Water Resources, dated February.

Beeby, R., T. Durbin, W. Leever, P. Leffler, J.C. Scalmanini, and M. Wildermuth, 2010. Summary Expert Report Phase 3 – Basin Yield and Overdraft, Antelope Valley Area of Adjudication, dated July 2010.

Berenbrock, C., and P. Martin, 1991. The Ground-Water Flow Systems in Indian Wells Valley, Kern, Inyo, and San Bernardino Counties, California. US Geological Survey Water-Resources Investigations Report 89-4191. Prepared in cooperation with the Indian Wells Valley Water District and the US Department of the Navy, China Lake Naval Weapons Center.

Bloyd, R.M., and S.G. Robson, 1971. Mathematical Ground-Water Model of the Indian Wells Valley, California. US Geological Survey Open-File Report 72-41. Prepared in cooperation with the Indian Wells Valley County Water District and the Department of the Navy, dated November 12.

Brown, A., 2016. Personal observations of Anthony Brown of aquilogic on visits to Grapevine Canyon and Sand Canyon. April.

B&C (Brown and Caldwell), 2006. Rose Valley Groundwater Model. Prepared for Coso Operating Company, LLC, Rose Valley, California, dated April 10, 2006.

B&C, 2009. Final Report: Indian Wells Valley Basin Groundwater Flow Model and Hydrogeologic Study. Prepared for Indian Wells Valley Water District, dated March 27.

DBSA (Daniel B. Stephens & Associates, Inc.), 2021. Fourth Updated Groundwater Flow Model and Predictive Scenario Results – Coso Operating Company Hay Ranch Water Extraction and Delivery System Conditional Use Permit (CUP) 2007-003. Prepared for County of Inyo, Independence, California, dated May 27, 2021.

Dunne and Leopold, 1978. Water in Environmental Planning. W. H. Freeman Publishing.

Dutcher, L.C., and W.R. Moyle, Jr., 1973. Geologic and Hydrologic Features of Indian Wells Valley, California. US Geological Survey Water-Supply Paper 2007. Prepared in cooperation with the California Department of Water Resources.

ECORP (ECORP Consulting, Inc.), 2012. Final Environmental Impact Report, Water Supply Improvement Project. Prepared for Indian Wells Valley Water District, dated February.

Epstein, B.J., Pohl, G.M., Huntington, J., and R.W.H. Carroll, 2010. Development and Uncertainty Analysis of an Empirical Recharge Prediction Model for Arizona's Desert Basins. Journal of the Nevada Water Resources Association, vol. 5, no.11.

Erskine, M.C., 1989. Review of the Geohydrology of the Indian Wells Valley Region, Kern, Inyo, and San Bernardino Counties, California. Prepared for Eastern Kern County Resource Conservation District, dated June 29.

Flint, A.L., L.E. Flint, J.A. Hevesi, and J.B. Blainey, 2004. Fundamental Concepts of Recharge in the Desert Southwest: a Regional Modeling Perspective. In Groundwater Recharge in a Desert Environment: The Southwestern United States, edited by J.F. Hogan, F.M. Phillips, and B.R. Scanlon, Water Science and Applications Series, vol. 9, American Geophysical Union, Washington, D.C., 159-184.

Flint, L.E., and A.L. Flint, 2007a. Application of the Basin Characterization Model to Estimate In-Place Recharge and Runoff Potential in the Basin and Range Carbonate-Rock Aquifer System, White Pine County, Nevada, and Adjacent Areas in Nevada and Utah. U.S. Geological Survey Scientific Investigations Report 2007-5099.

Flint, L.E., and A.L. Flint, 2007b. Regional Analysis of Ground-Water Recharge. U.S. Geological Survey Professional Paper 1703 – Ground-Water Recharge in the Arid and Semiarid Southwestern United States, Chapter B.

Flint, L.E, A.L. Flint, J.H. Thorne, and R. Boynton, 2013. Fine-Scale Hydrologic Modeling for Regional Landscape Applications: the California Basin Characterization Model Development and Performance. Ecological Processes 2013, 2:25.

Flint, L.E., A.L. Flint, and M.A. Stern, 2021. The Basin Characterization Model – A Regional Water Balance Software Package. U.S. Geological Survey Techniques and Methods 6-H1.

Freeze, R.A., and J.A. Cherry, 1979. Groundwater. Englewood Cliffs, NJ, Prentice-Hall, 604 p.

Gillespie, J., and G. Thyne, 1996. Groundwater Recharge in the Western Indian Wells Valley – Interim Report, dated May 16.

Guidehouse Inc., 2022. Industrial, Economic and Administrative Survey of the Los Angeles Department of Water and Power. Prepared for the City of Los Angeles.

IWVGA (Indian Wells Valley Groundwater Authority), 2023. Indian Wells Valley Groundwater Basin: GSP Annual Report Water Year 2022 (October 1, 2021 to September 30, 2022), dated March.

IWVGA, 2022. Indian Wells Valley Groundwater Basin: GSP Annual Report Water Year 2021 (October 1 2020 to September 30 2021), dated March.

IWVGA, 2021. Indian Wells Valley Groundwater Basin: GSP Annual Report Water Year 2020 (October 2019 to September 2020), dated April.

IWVGA, 2020a. Indian Wells Valley Groundwater Authority Engineer's Report for the Adoption of a Basin Replenishment Fee, dated June 18.

IWVGA, 2020b. Groundwater Sustainability Plan for the Indian Wells Valley Groundwater Basin – Bulletin 118 Basin No. 6-054. Prepared by Stetson Engineers, Inc., dated January.

IWVGA, 2020c. Groundwater Pumping Verification Report. Prepared by Stetson Engineers, Inc., dated August.

IWVGA, 2020d. Indian Wells Valley Groundwater Basin: GSP Annual Report Water Year 2019 (October 2018 to September 2019), dated May.

Izbicki, J.A., Radyk, J., and R.l. Michel, 2000. Water movement through a thick unsaturated zone underlying an intermittent stream in the western Mojave Desert, southern California, USA. Journal of Hydrology, vol. 238, its. 3-4. https://www.sciencedirect.com/science/article/abs/pii/S0022169400003310

Kunkel, F., and G.H. Chase, 1969. Geology and Ground Water in Indian Wells Valley, California. US Geological Survey Open-File Report 69-329. Prepared in cooperation with the Naval Weapons Center China Lake, CA, dated January 23.

Lee, C.H., 1912. Ground-water resources of Indian Wells Valley, California, California State Conservation Commission Report, p. 403-429.

McGraw, D., R. Carroll, G. Pohll, J. Chapman, S. Bacon, and R. Jasoni, 2016. Groundwater Resource Sustainability: Modeling Evaluation for the Naval Air Weapons Station, China Lake, California. Prepared by Desert Research Institute for Naval Air Warfare Center Weapons Division, China Lake, dated September.

Ramboll, 2024. Storage Estimate – Indian Wells Valley. Prepared for Indian Wells Valley Water District. September 2022, Revised June 2023 and February 2024.

Stetson (Stetson Engineers, Inc.), 2016. Water Use Factors and Return Flow Rates Applied to Land Use Coverage within PRMS Model. Prepared for the Santa Margarita River Groundwater Model Working Group, dated October 18, 2016.

Thompson, D.G., 1929. The Mojave Desert Region, California: A Geographic, Geologic, and Hydrologic Reconnaissance. US Geological Survey Water-Supply Paper 578.

Todd (Todd Engineers), 2014. Indian Wells Valley Resource Opportunity Plan – Water Availability and Conservation Report. Prepared for Kern County Planning & Community Development Department, dated January 22.

TriEco Tt, 2012. Technical Justification for Beneficial Use Changes for Groundwater in Salt Wells Valley and Shallow Groundwater in Eastern Indian Wells Valley – Naval Air Weapons Station China Lake, California. Draft. Prepared for the Department of the Navy, Naval Facilities Engineering Command Southwest, San Diego, CA, dated May 25, 2012.

TWG (Indian Wells Valley Technical Working Group), 2024. Assessment of Groundwater Storage for the Indian Wells Valley Groundwater Basin, dated February 23.

USBR (United States Bureau of Reclamation), 1993. Indian Wells Valley Groundwater Project Technical Report. A cooperative effort among the Bureau of Reclamation, the Indian Wells Valley Water

District, the North American Chemical Company, and the Naval Air Weapons Station, dated December.

USGS (United States Geological Survey), 2020. Using the Basin Characterization Model (BCM) to Estimate Natural Recharge in Indian Wells Valley, California. Project summary on California Water Science Center website, available at: https://www.usgs.gov/centers/ca-water/science/using-basin-characterization-model-bcm-estimate-natural-recharge-indian?qt-science_center_objects=0#qt-science_center_objects.

UWCD (United Water Conservation District), 2018. Ventura Regional Groundwater Flow Model and Updated Hydrogeologic Conceptual Model: Oxnard Plain, Oxnard Forebay, Pleasant Valley, West Las Posas, and Mound Groundwater Basins. Open File report 2018-02, dated July.

Watt, D.E., 1993. Estimating Recharge Distribution to Indian Wells Based on Vegetation Distribution in the Recharge Watersheds. Appendix I in "Indian Wells Valley Groundwater Project, Volume II, Technical Report.", dated December.

Whelan, J.A., and R. Baskin, 1989. A Water Geochemistry Study of Indian Wells Valley, Inyo and Kern Counties, California – Volume 1. Geochemistry Study and Appendix A. Prepared for Naval Weapons Center, China Lake, California, dated September.

Williams, David, 2004. Hydrogeologic and Hydrochemical Framework of Indian Wells Valley, California: Evidence for Interbasin Flow in the Southern Sierra Nevada. Master's Thesis, Colorado School of Mines, dated June 24.