ASSESSMENT OF
SAFE YIELD FOR THE
INDIAN WELLS VALLEY
GROUNDWATER BASIN

Prepared by:
Indian Wells Valley Technical Working Group

September 4, 2024

TECHNICAL WORKING GROUP:

ASSESSMENT OF SAFE YIELD FOR THE INDIAN WELLS VALLEY GROUNDWATER BASIN

Table of Contents

Figures

Tables

Appendices

Acronyms, Abbreviations, and Initialisms

Abbrev.	Description
%	percent
A	area (acres)
AF	acre-feet
AFY	acre-feet per year
B&C	Brown and Caldwell
BCM	Basin Characterization Model
CY	calendar year
District	Indian Wells Valley Water District
DRI	Desert Research Institute
DWR	California Department of Water Resources
ft	feet
Geoscience	Geoscience Support Services, Inc.
GSP	Groundwater Sustainability Plan
HGZ	Hydrogeologic Zone
in	inch
in/yr	inches per year
IWV	Indian Wells Valley
IWVGA	Indian Wells Valley Groundwater Authority
KCWA	Kern County Water Agency
K&S	Krieger & Stewart Engineering Consultants
LSCE	Luhdorff & Scalmanini Consulting Engineers
msl	mean sea level
NAF	Naval Air Force
No.	number
Q_{in}	groundwater recharge (AFY)
Q_{out}	groundwater discharge (AFY)
RAM	Ramboll
ΔS	change in groundwater storage (AFY)
SGMA	Sustainable Groundwater Management Act
Sy	specific yield
TP	Thiessen polygon
TWG	Technical Working Group
USGS	United States Geological Survey
WDL	Water Data Library

ΔWL	change in water level
WY	Water Year (October 1 through September 30)
WRCC	Western Regional Climate Center

TECHNICAL WORKING GROUP:

ASSESSMENT OF SAFE YIELD FOR THE INDIAN WELLS VALLEY GROUNDWATER BASIN

1.0 Executive Summary

A Technical Working Group (TWG) composed of qualified groundwater professionals designated by parties representing more than 80 percent of the total groundwater production in Water Year (WY) 2022 from the Indian Wells Valley Groundwater Basin (IWV Basin) was formed to assess the safe yield of the IWV Basin.

Safe yield as defined by the California Supreme Court is “the maximum amount of water that can be withdrawn annually, from a groundwater supply under a given set of conditions, without causing an undesirable result.” (City of Los Angeles v. City of San Fernando (1975) 14 Cal.3d 199, 278). A groundwater basin is in a state of surplus when the amount of water being extracted from it is less than the maximum that could be withdrawn without adverse impacts on the basin’s long-term water supply. (City of Los Angeles v. City of San Fernando (1975) 14 Cal. 3d 199, 277).

The TWG collaboratively determined a scope of analyses and agreed on a process to develop a reasonable estimate of the IWV Basin safe yield using best scientific practices and best available data. This paper presents the TWG initial estimates of safe yield for the IWV Basin. The TWG also recognizes that estimating safe yield is a dynamic process that periodically incorporates new data and frequently utilizes new tools, such as a new groundwater flow model (e.g., Ramboll, in progress). The initial safe yield assessment is based entirely upon analyses of historical data and does not consider the potential effects of management (augmentation and mitigation) measures that might be applied under a physical solution to further maximize the amount of groundwater that might be safely and reasonably withdrawn.

The TWG’s efforts started with a review of existing studies and published literature, and conducting initial analyses with data currently being relied upon for basin management.

The TWG then developed a comprehensive and rigorous evaluation of safe yield based on change in groundwater storage across the entire IWV Basin. This approach was considered technically superior to other estimation methodologies because it 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 element of the water budget (i.e., groundwater inflows and outflows).

To reduce uncertainty, the TWG evaluation also focused on utilizing the most up-to-date and reliable data available, including measured water levels, groundwater pumping information from IWV Basin pumpers legally-required initial disclosures, and aquifer parameters appropriate for the IWV Basin. The TWG identified the period from 2014 through 2023 as the base period for the analysis because it is representative of long-term average hydrologic conditions in the IWV Basin and incorporates the most accurate water level and pumping datasets, for which availability and resolution has increased significantly since the passage of the Sustainable Groundwater Management Act (SGMA) in 2014.

The TWG employed two separate approaches to assess safe yield, both of which utilize the change-in-storage calculation methodology but differ in their assumptions regarding the distribution of calculation areas and the application of available groundwater data and specific yield values. These variations in approach offer insights into the sensitivity of safe yield estimates to different parameters and assumptions. The results from the two methodologies are very similar and collectively present a higher degree of certainty in the estimate of safe yield. The average safe yield for the period from 2014 through 2023, calculated for the two approaches as the average annual groundwater pumping during that period adjusted for changes in groundwater storage, ranged from 14,300 acre-feet per year (AFY) to 17,000 AFY. Based on review of the two approaches, the TWG estimates the safe yield for the IWV Basin to be approximately **14,300 AFY**.

In accordance with best practices, comprehensive monitoring, ongoing data collection and assessment, modeling, and advances in scientific methods may cause adjustments in this estimate to be made over time. The TWG and its members reserve the opportunity to update this analysis based upon development and review of new data.

2.0 Introduction

The IWV Basin is an alluvium-filled groundwater basin[1] in the Mojave Desert region of Southern California (**Figure 1**). Primary groundwater recharge in this arid environment is through percolation of precipitation in surrounding mountain areas, which primarily enters the basin through recharge from streambed percolation coming from the surrounding mountain ranges (i.e., mountain front recharge). According to data and estimates maintained by the Indian Wells Valley Water District (District), historical pumping between 1975 and 2015 in the IWV Basin ranged between 15,980 AFY (1975) and 29,730 AFY (1985). Recent (2019 through 2023) groundwater pumping in the IWV Basin is on the order of 21,000 AFY (Indian Wells Valley Groundwater Authority (IWVGA), 2024).

Beneficial users of groundwater in the IWV Basin have a common interest in assessing the accuracy of safe yield[2]. The determination of safe yield is necessary to adjudicate water rights and to develop economically feasible mitigation measures for the sustainable management of the IWV Basin for the benefits of communities that rely upon its water supply. For these reasons, the TWG determined safe yield and studied related hydrologic issues. The TWG consists of technical representatives of beneficial

---

[1] Early studies have characterized the basin as a two-aquifer system, with a shallow aquifer of alluvium and lacustrine deposits underlain by a deep aquifer of lacustrine, playa, and dune sand deposits. These two aquifers are separated by lower permeability sediments. More recent conceptual frameworks consider three discrete geologic and hydrogeological water-bearing zones, referred to as Hydrogeologic Zones, in the IWV Basin. Additional discussion on basin hydrostratigraphy is provided in a separate 2024 TWG report on IWV Basin groundwater storage estimates, "Assessment of Groundwater Storage for the Indian Wells Valley Groundwater Basin."

[2] Safe yield is different than "sustainable yield." Sustainable yield is defined by statute in California Water Code section 10721(v) for SGMA implementation purposes. Safe yield is derived from the common law and is used in determining water rights through court adjudication processes.

users of groundwater who collectively represent more than 80 percent of the total groundwater production in WY 2022 in the IWV Basin. These parties include the District represented by Krieger & Stewart Engineering Consultants (K&S), Parker Groundwater, and Ramboll, Meadowbrook Dairy represented by Luhdorff & Scalmanini Consulting Engineers (LSCE), Mojave Pistachios represented by aquilogic, and Searles Valley Minerals represented by Geoscience Support Services, Inc. (Geoscience). **Appendix D**[3] will contain the resumes of the various consultants who have collaborated on this safe yield paper.

---

[3] Appendices referenced here will be produced separately.

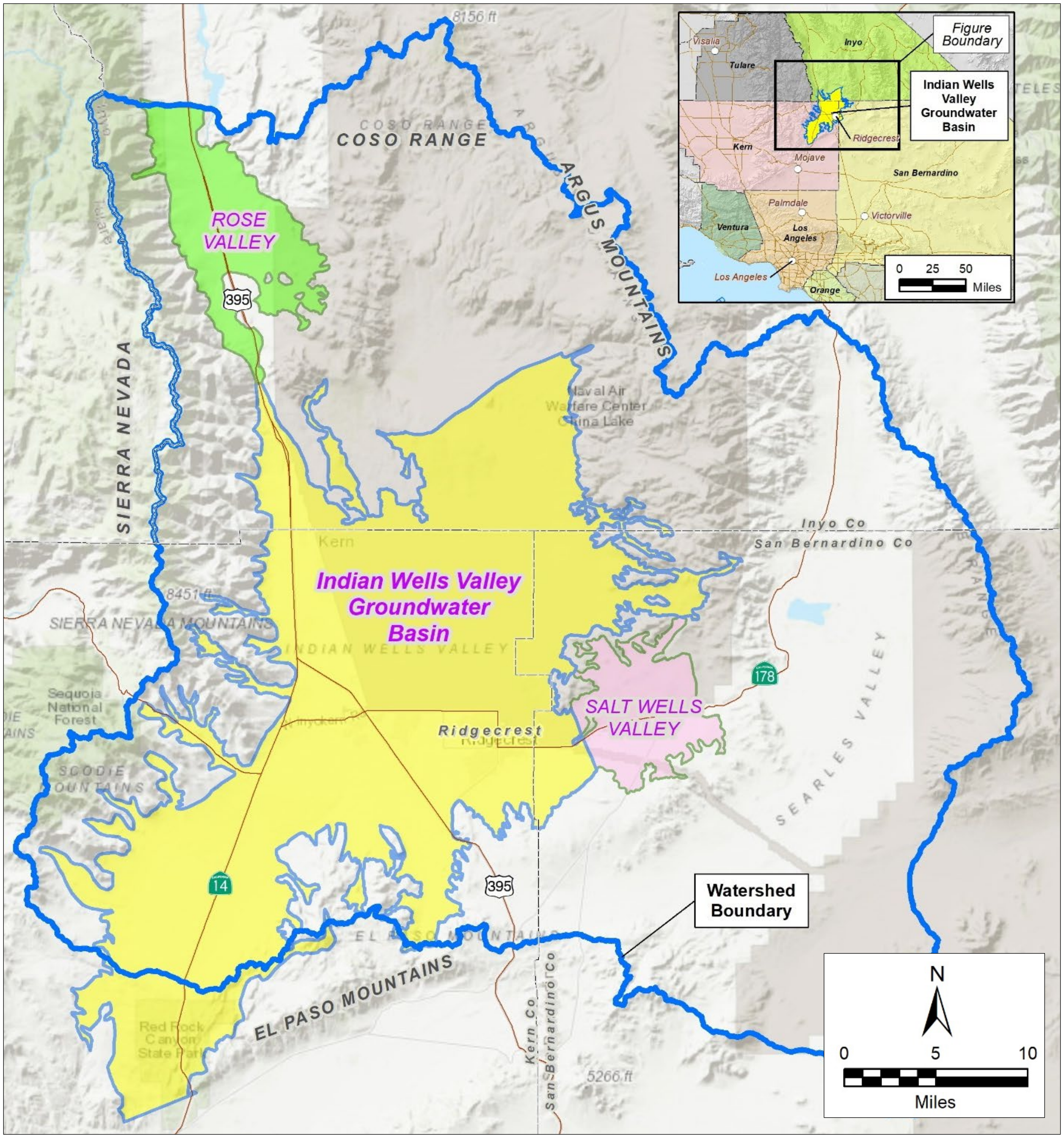


Figure 1. Indian Wells Valley Groundwater Basin

2.1 Background

Safe yield has been defined by the California Supreme Court as “the maximum amount of water that can be withdrawn annually, from a groundwater supply under a given set of conditions, without causing an undesirable result” (City of Los Angeles v. City of San Fernando(1975), 14 Cal.3d 199, 278). Understanding the safe yield of the IWV Basin is at the core of determining water rights and developing sustainable groundwater management.

Since its formation in 2022, the TWG has met regularly, roughly every other week over the last two years, to develop a thorough approach to evaluate the safe yield of the IWV Basin utilizing the best available information. The TWG started with a review of existing studies and published literature with previous estimates of basin water supplies and conducting initial analyses with data currently being relied upon for basin management. Specifically, and consistent with best practices, the TWG's initial evaluation of safe yield for the IWV Basin included the following:

- Literature review of previous studies;
- Estimation of natural recharge and runoff from the existing United States Geological Survey (USGS) Basin Characterization Model (BCM) (Flint et al., 2021; USGS, 2020); and
- Review of sustainable yield established in the IWV Groundwater Sustainability Plan (GSP) and data presented in GSP annual reports (IWVGA, 2020a, 2021, and 2022).

Results of these initial evaluations, to be provided in **Appendix A**, conclude that previous estimates of groundwater recharge had significant limitations that would affect the credibility of their safe yield estimates for the IWV Basin. These limitations include: omitting additional sources of recharge that, while small compared to the main mountain front recharge mechanism, collectively represent an important source of groundwater recharge; relying on methodologies that are inherently uncertain due to the inability to directly measure sources of groundwater recharge and discharge; and ignoring observed physical data, such as water level measurements and recorded groundwater pumping.

The TWG then developed a comprehensive and rigorous evaluation of safe yield based on change in groundwater storage from measured water levels, recently updated groundwater pumping information provided by basin pumpers (as required under the pending comprehensive IWV Basin water rights adjudication), aquifer parameters appropriate for the IWV Basin, and a representative base period.

2.2 Purpose

This paper presents an overview of the collective work completed to date by members of the TWG related to the evaluation of safe yield for the IWV Basin. Preliminary evaluations of safe yield through the TWG process based upon previous studies or limited data have been updated through this more comprehensive evaluation and to correct the observed deficiencies in accordance with best practices.

3.0 Approach

This section provides an overview of safe yield calculation methodology, selection of the safe yield base period, and safe yield analysis sources of data (pumping, groundwater elevations, and basin-wide specific yield (Sy) distribution). Safe yield, in the absence of applied management measures, including, for example, conjunctive use and controlled withdrawal of temporary surplus, represents the amount of groundwater pumping that causes no change in groundwater storage and can be expressed as:

Safe Yield = Pumping +/- Change in Storage... (Eqn. 1)

One of the benefits of estimating 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. The most representative base period can also be considered with this approach –a period that characterizes average hydrology, includes both wet and dry years, and has a record of reliable groundwater level and groundwater pumping data.

3.1 Calculation Methodology

The safe yield of a groundwater basin also can be determined using a water balance method, which relates groundwater inflow, outflow, and change in storage over an average hydrologic base period. This is known as the Equation of Hydrologic Equilibrium. Quantitatively, the Equation of Hydrologic Equilibrium may be expressed as:

$$\Delta S = Q_{in} - Q_{out} \quad \text{(Eqn. 2)}$$

Where:

Q_{in} = Groundwater Recharge [AFY]
Q_{out} = Groundwater Discharge [AFY]
ΔS = Change in Groundwater Storage [AFY]

Using this water balance approach, inflows (recharge) and outflows (pumping and evapotranspiration) need to be accurately estimated to determine the change in storage.

Change in storage over a given area can also be calculated separately as:

$$\Delta S = A \times Sy \times \Delta WL \quad \text{(Eqn. 3)}$$

Where:

ΔS = Annual Change in Groundwater Storage [acre-feet (AF)]
A = Area [acres]
Sy = Specific Yield[4] [unitless]
ΔWL = Annual Change in Water Level [feet (ft)]

Therefore, where adequate data are available to calculate the change in storage and pumping data are available for the same period of time, the safe yield can be estimated on an average annual basis using Equation No. 1.

The change in groundwater storage can be calculated spatially over a groundwater basin using Thiessen polygons. 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

---

[4] Sy is an aquifer parameter referred to as the storage coefficient.

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.

By combining Equation Nos. 1 and 3, safe yield over a given base period can be calculated using a defined set of Thiessen polygons as:

$$\text{Safe Yield} = \text{Average Pumping} \pm \text{Average} \sum_{i=1}^{n}(A\ x\ Sy\ x\ \Delta WL) \text{ .... (Eqn. 4)}$$

Where:

Average = Average annual value over base period
n = total number of Thiessen polygons
$\sum_{i=1}^{n}(A\ x\ Sy\ x\ \Delta WL)$ = the annual total change in groundwater storage, calculated as the sum of annual storage change for each Thiessen polygon

The TWG applied Equation No. 4 to estimate safe yield for the IWV Basin. As discussed above, the TWG's evaluation of safe yield was deemed to be necessary after completing a systematic and progressive evaluation of previous studies and recharge estimates (to be presented in **Appendix A**). That review ultimately led the TWG to select the calculation methodologies described here. Specifically, the TWG applied two similar but different approaches to further validate the results. TWG Approach #1 was developed through review and subsequent improvement of the storage change methodology utilized by the IWVGA for GSP annual reporting. TWG Approach #2 was a redesign of the storage change and Thiessen polygon approach to offer approximate safe yield using carefully selected and representative data and calculation areas. While the two TWG approaches rely on the same base period and pumping assumptions, they employed different distributions of Thiessen polygons and applications of available groundwater data and Sy values, discussed in the following subsections.

3.1.1 Thiessen Polygon Areas

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 Thiessen Polygons (41 Polygons), and selected 41 representative wells. The Thiessen Polygons were updated in the WY 2022 GSP Annual Report (IWVGA, 2023). In addition to expanding the number of polygons to 77, 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 (Updated 77 Polygons) cover 188,970 acres, approximately 62 percent of the 304,700 acres covered by the 41 original polygons. The selected key monitoring wells also increased from 41 to 77.

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 41 original polygons can cause significant differences in groundwater storage changes. The TWG evaluated these differences by developing a set of extended polygons, which uses the updated 77 polygon areas and includes 8 additional polygons, for a total of 85 polygons, to extend coverage out to the edge of the basin – creating a footprint consistent with that of the 41 original polygons (Extended 85 Polygons [TWG Approach #1]; see **Figure 2**).

Comparison of the resulting calculations indicate that the safe yield value calculated with the updated 77 polygon area is higher than the safe yield calculated using the original 41 or extended 85 polygon areas. Considering the entire basin area in these calculations may slightly overestimate the change in groundwater storage because it assumes the same change in water level to the edges of the basin and it is unlikely there are changes in water levels at the edges of the basin. However, 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 polygon areas that cover the entire extent of alluvium in the IWV Basin.

TWG Approach #1 utilized the Extended 85 Polygons described above and shown in **Figure 2**. TWG Approach #2 departed from the previous GSP polygon areas and involved a complete redesign of Thiessen Polygons based on a separate evaluation of available water level data and reselection of key wells. As described further in Section 3.2.2, key wells were selected to provide suitable spatial coverage across the IWV Basin while utilizing wells with the most complete dataset of high spring water levels for 2013 to present. The resulting redesign created a completely new set of 81 Thiessen Polygons (81 Polygons), as shown in **Figure 3**. The entire 81 polygon area was also designed to coincide with a new groundwater flow model domain (Ramboll, in progress) for future comparative analysis.

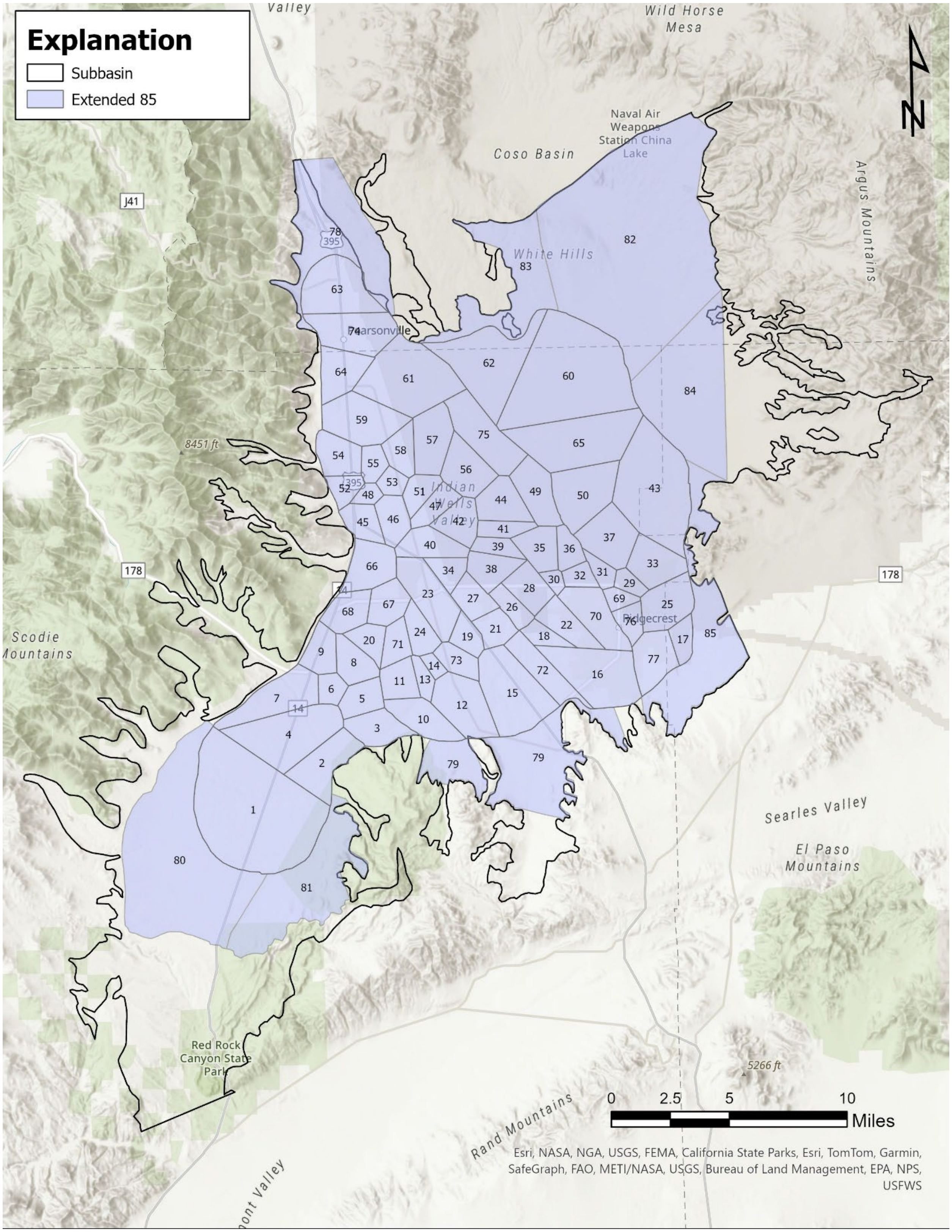
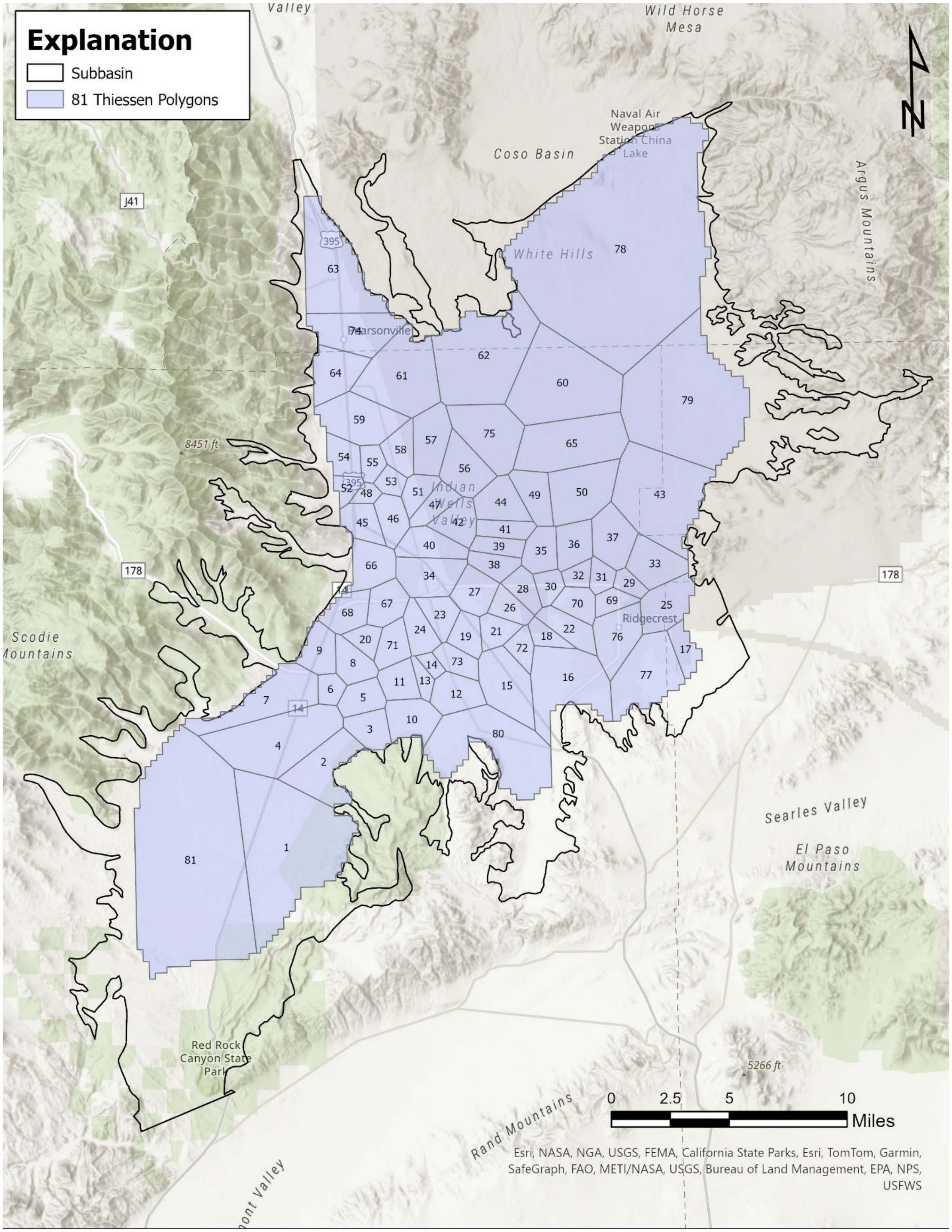


Figure 2. Extended 85 Thiessen Polygons (TWG Approach #1)



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

Figure 3. 81 Thiessen Polygons (TWG Approach #2)

3.1.2 Hydrologic Base Period

The hydrologic base period is a sufficiently long period of time, considered to be representative, over which pumping and the change in groundwater storage was evaluated to develop an estimate of safe yield. Selection of an appropriate hydrologic base period includes an evaluation of annual precipitation representative of the study area, which has a long-term period of record with adequate monthly or annual resolution, and the characterization of long-term precipitation. A precipitation record for the IWV Basin was developed using precipitation data from the Western Regional Climate Center (WRCC) Station 041733 (China Lake Naval Air Force [NAF]). Annual precipitation at this location is shown in **Figure 4** for the period from 1945 through 2023. The average annual precipitation during this period was 3.42 inches. The annual precipitation varies from a high of 9.92 inches in 1965 to a low of 0.16 inches in 1953.

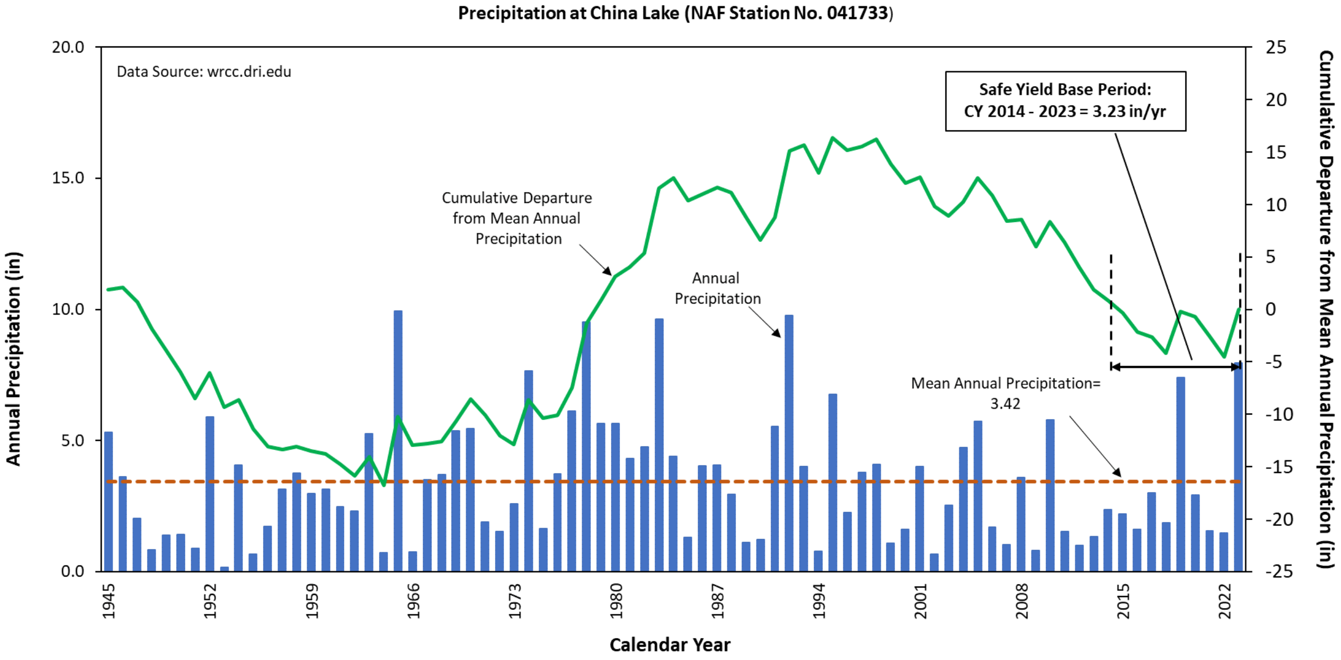


Figure 4. Cumulative Departure from Mean Annual Precipitation 1945-2023 – China Lake NAF Station

Characterization of long-term trends in precipitation typically analyzes a cumulative departure from mean. This type of chart shows the difference between a specific year's precipitation and the mean precipitation value. The cumulative departure from the mean charts the sum of these departures over time, beginning with the first year of departure and adding each subsequent year's departure. The cumulative departure based on data from China Lake NAF station is also shown on **Figure 4**. On this cumulative departure chart, a positive slope on the cumulative departure from mean annual precipitation curve indicates a wetter-than-average period (i.e., wet hydrologic conditions) while a negative, or downward, slope indicates a drier-than-average period (i.e., dry hydrologic conditions). The IWV Basin has experienced a long, generally wet period from 1960 through 1990, followed by a generally dry period since the mid-1990s.

Selection of a base period for the IWV Basin is informed by the availability of reliable data. Historical pumping data are generally only available for a handful, but the most significant, of basin pumpers comprising mor than 80 percent of total groundwater production in WY 2022, though pumping data are considered more reliable after the passage of SGMA in 2014 and the required reporting of pumping of non-de minimis wells in the IWV Basin. Water level measurements also generally increase in resolution through time, with additional monitoring beginning in response to SGMA monitoring requirements.

For the purposes of this analysis, the base period from January 2014 through December 2023 was used for both TWG approaches for the following reasons:

- It is representative of long-term hydrologic conditions. The average annual precipitation during the base period is 3.23 inches (3.25 inches for WY 2014-2023), compared to the long-term average annual precipitation (1945-2023) of 3.42 inches (3.44 inches for WY 1945-2023) at the China Lake NAF station (see **Figure 4**)[5].
- It includes wet, dry, and average years of precipitation, including some of the wettest and driest years on record in the state.
- It spans at least ten years, as recommended by the California Department of Water Resources (DWR, 2016).
- It includes recent cultural conditions, as also recommended by DWR (2002 and 2016).
- It considers more accurate water level and pumping data. Water level measurements and metering of groundwater pumping significantly increased in resolution after SGMA was approved in 2014. In addition, recently submitted (May 2024) pumping records through the legally-required initial disclosure process for the groundwater basin adjudication, which covers the period from 2011 through 2020, represents the most updated and comprehensive accounting of groundwater pumping to date.
- The parties reporting production over the base period accounted for more than 80 percent of the cumulative groundwater production in WY 2022.

3.2 Sources of Data

3.2.1 Groundwater Pumping

Both approaches to the TWG safe yield analysis utilized the same groundwater pumping data from two primary sources: the initial disclosures[6] filed by parties in the pending comprehensive groundwater basin adjudication and the GSP annual reports. The TWG utilized initial disclosure pumping data for the years 2011 through 2020 and utilized the GSP annual reports covering the years 2021 to 2023, which are years in which flowmeter data must be recorded and administratively reported by "non-de minimis" pumpers. Within the initial disclosure data, the TWG identified some missing pumping. Of note, pumping was not

---

[5] Note: hydrogeologic investigations traditionally consider WY, which represents the period of time from October of one year through September of the next (e.g., WY 2011 covers the period from October 1, 2010, through September 30, 2011). However, because the best available pumping data are reported in terms of calendar year (CY; see Section 3.2.1), the hydrology presented here is also shown in terms of calendar year. Averages for both time classifications have been provided here to confirm representativeness of the selected base period.

[6] 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.

reported for the City of Ridgecrest or Inyokern Community Services District for several years within the selected base period. Based on previous reported pumping from the 2020 Pumping Verification Report (IWVGA, 2020), pumping for these two entities reportedly averaged nearly 500 AFY. Reported pumping values from the Verification Report were therefore substituted for missing initial disclosures data for these two entities. Any remaining years of missing data during the initial disclosures reporting period were assumed to be the same as the next available reported annual pumping value.

In addition, the initial disclosures data included multiple submissions from domestic pumpers that indicated the occurrence of pumping but were unable to provide a pumped value (i.e., pumping unmetered and/or unknown). The TWG therefore conducted an estimate of unmetered domestic water demand to account for unreported pumping. The results of this analysis, which identified approximately 1,500 improved parcels relying on supply from domestic wells, will be provided in **Appendix B**. Unreported domestic pumping for these parcels was estimated to be approximately 1,350 AFY (0.90 AFY per parcel). For the safe yield analysis, this additional pumping was added to the total initial disclosures pumping for each year to account for missing or unknown domestic pumping. The domestic well pumping analysis is considered by the TWG to be the most current and complete analysis of its kind for the IWV Basin, to date.

Groundwater pumping provided in GSP annual reports largely represents reported pumping from major pumping entities in the IWV Basin. The IWVGA has made its own assessment of unreported domestic pumping, which has already been included in the annual pumping volumes presented in each annual report. It is important to note that the GSP annual report pumping values represent WY pumping (October 1 through September 30). Since monthly resolution of groundwater pumping is not available from the GSP annual reports, the pumping was unable to be converted to CY. However, differences between WY and CY are typically only a couple of hundred AF and often average out over multiple years. Given uncertainties inherent in estimated pumping and the TWG's decision to round to the nearest hundred AF in recognition of this, these slight differences in time reference are unlikely to have a significant effect on estimates of safe yield.

The pumping data for the base period are provided in **Table 1**. On average, the pumping rate of this 10-year span was 23,900 AFY. A gradual decline in pumping was observed, with the highest level recorded in 2014 at 29,600 AF, and the lowest in 2023 at 19,100 AF.

Table 1. IWV Basin Groundwater Pumping (2014 – 2023)

Year	Total Estimated Pumping [AFY]
2014	29,600
2015	27,400
2016	27,200
2017	24,600
2018	23,900
2019	22,400
2020	22,800
2021	20,800
2022	21,200
2023	19,100
Average Annual Pumping (2014 - 2023)	**23,900**

3.2.2 Groundwater Elevation

To determine the change in storage from year-to-year, groundwater level data were evaluated to determine change in groundwater elevation. For both TWG approaches, the safe yield analysis focuses on spring groundwater levels, which represent the seasonal high conditions. However, as described below, the two TWG approaches use slightly different applications of available water level data.

TWG Approach #1 utilized groundwater level data from approximately 150 wells across the IWV Basin; all wells with adequate water level data were considered in each polygon area. Water level data were obtained from the DWR Water Data Library (WDL)[7] for the years 2013 through 2024. Over this period, groundwater level data were typically recorded on a monthly to quarterly basis. Then, for each year of the base period, a raster surface representing the seasonal high conditions was created by spatially interpolating (kriging) between all available data points, excluding outliers. These raster surfaces were used to determine the difference in groundwater elevation from year to year. For each year, an average groundwater level was then assigned to each of the 85 polygon areas using zonal statistics. Change in groundwater storage was then calculated by taking the difference between the seasonal high groundwater levels from year-to-year and multiplying by the Sy value applied to each corresponding polygon (discussed in the next section). The change in groundwater elevation and change in storage for each polygon during the base period using TWG Approach #1 will be presented in **Appendix C**.

TWG Approach #2 leveraged multiple sources of groundwater level data collected through the considerable work Ramboll has completed to date in their development of a new groundwater flow model

---

[7] The WDL provides public access to groundwater level, groundwater quality, and automated continuous measurement datasets maintained by DWR. https://wdl.water.ca.gov/Map.aspx

for the IWV Basin. These sources included the IWV Basin GSP for years 2013 through 2014 (IWVGA, 2020b), the GSP Annual Report Water Year 2023 for years 2015 through 2023 (IWVGA, 2024), and DWR WDL for 2024. Over this period, groundwater level data were typically recorded on a monthly to quarterly basis. For each year of the base period, the spring high groundwater levels for each of the 81 selected wells were used to calculate change in groundwater storage. This process is the same as that described above for Approach #1, namely taking the difference between the seasonal high groundwater levels from year-to-year and multiplying by the Sy value applied to each corresponding polygon (discussed in the next section). Where groundwater levels were missing or anomalous, simple linear trend or interpolation was used to fill in the data gaps. The change in groundwater elevation and change in storage for each polygon during the base period using TWG Approach #2 will be presented in **Appendix C**.

3.2.3 Specific Yield

Specific yield (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). Earlier investigations have estimated hydraulic parameters within the IWV Basin, and nearly all of these are from the China Lake Area. Analysis methods used to estimate hydraulic properties have included reviewing geologic logs from various studies, drillers logs from water wells drilled throughout the Basin, aquifer tests, specific capacity tests, and literature values from studying IWV Basin and Range lithologies (Kunkel and Chase, 1969; Dutcher and Moyle, 1973; USBR, 1993; Anderson et al., 1992; Schwartz and Zhang, 2003). Hydraulic properties resulting from these studies are summarized in a separate TWG paper, “Assessment of Groundwater Storage for the Indian Wells Valley Groundwater Basin,” published in February 2024.

The two TWG Approaches to calculating safe yield rely on refined distributions and ranges of Sy, as explained below.

TWG Approach #1 looked at three main sources of spatially distributed Sy estimates for the IWV Basin: the Brown and Caldwell (B&C) Model, developed in 2009; the Desert Research Institute (DRI) Model, used for the GSP (McGraw et al., 2016)[8]; and an updated Hydrogeological Conceptual Framework (HCF) developed by Ramboll in 2024. **Figure 5** shows the spatial distribution of Sy obtained from different sources for each of the 85 Thiessen Polygons, and **Figure 6** illustrates the same data in a graph for the comparison of magnitudes of Sy. These figures present the Sy value that best characterizes each polygon area (i.e., greatest spatial coverage). The values also represent the average weighted value for the top three model layers from each source. The top two model layers correspond to Hydrogeologic Zone (HGZ) 1 (Ramboll Model, in progress). While the majority of basin pumping occurs from HGZ 1, the third model layer was included in Approach #1 to consider the effect of Sy from deeper pumping.

Notably, the value of Sy is significantly higher and much more homogenously distributed in the DRI Model. In contrast, the B&C (2009) and Ramboll (2024) distributions exhibit more realistic heterogeneity and are similar in magnitude. Based on IWV Basin hydrogeology, typical associated Sy values, and TWG review of

---

[8] The DRI Model refers only to model summary documentation and not the actual DRI Model or DRI Model Files, which have not been publicly released by DRI or the IWVGA. Information on refined Sy distributions was not provided by DRI in their 2017 updated model technical memorandum (DRI, 2017).

available Sy information in the IWV Basin (see Appendix A (forthcoming) for more detail), the distributions and value ranges developed by B&C and Ramboll are more representative. Therefore, the B&C and Ramboll HCF Sy values were selected for the TWG safe yield analysis Approach #1.

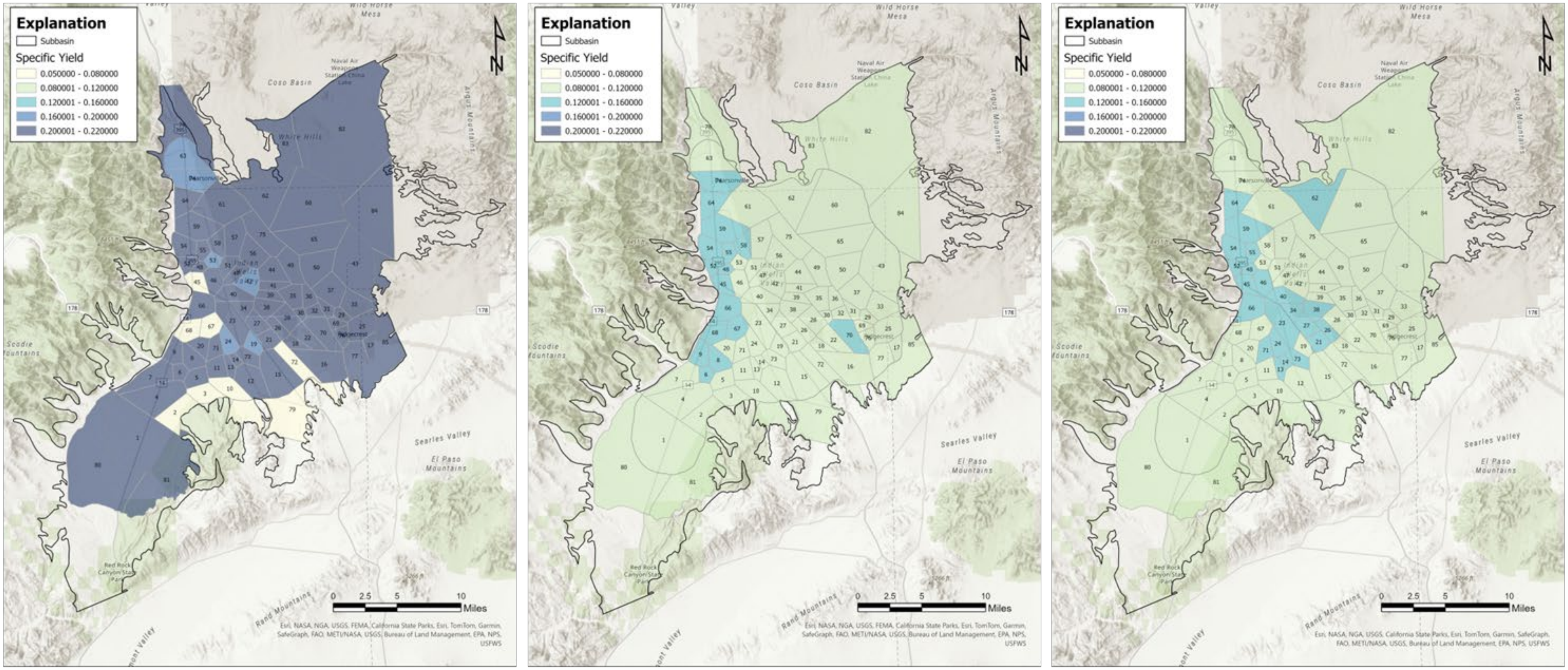


Figure 5. Specific Yield from (Left to Right) DRI Model, B&C Model, Ramboll HCF – Extended 85 Polygons

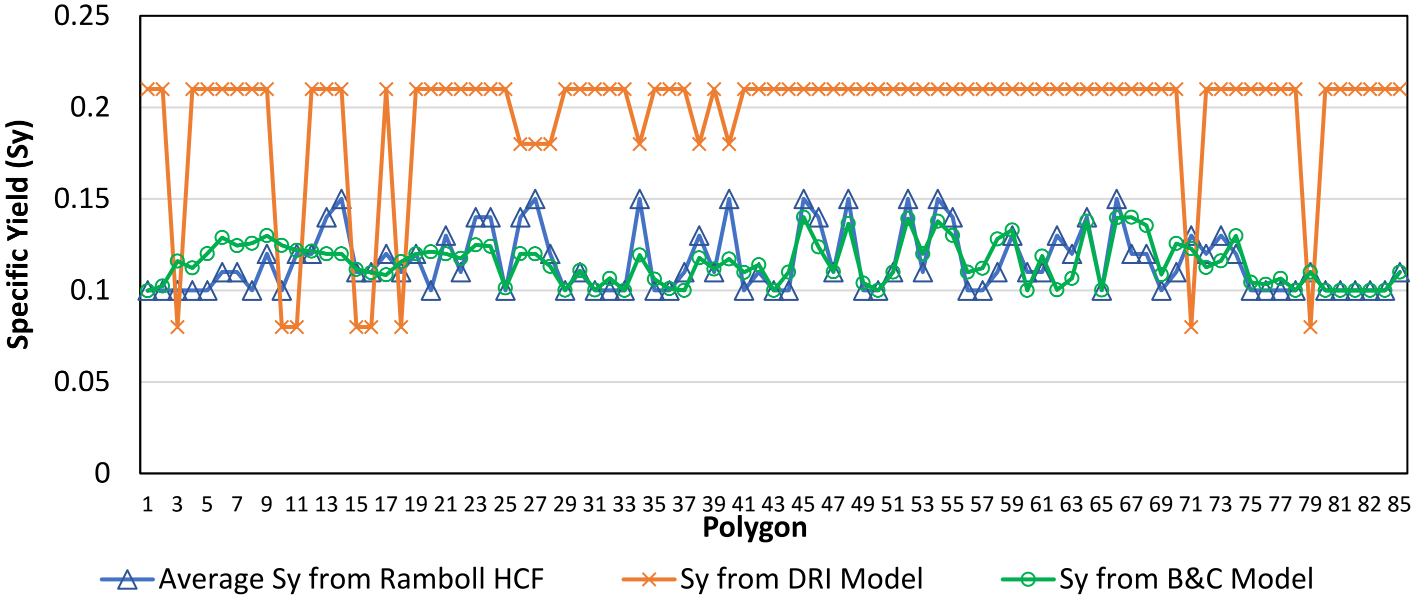
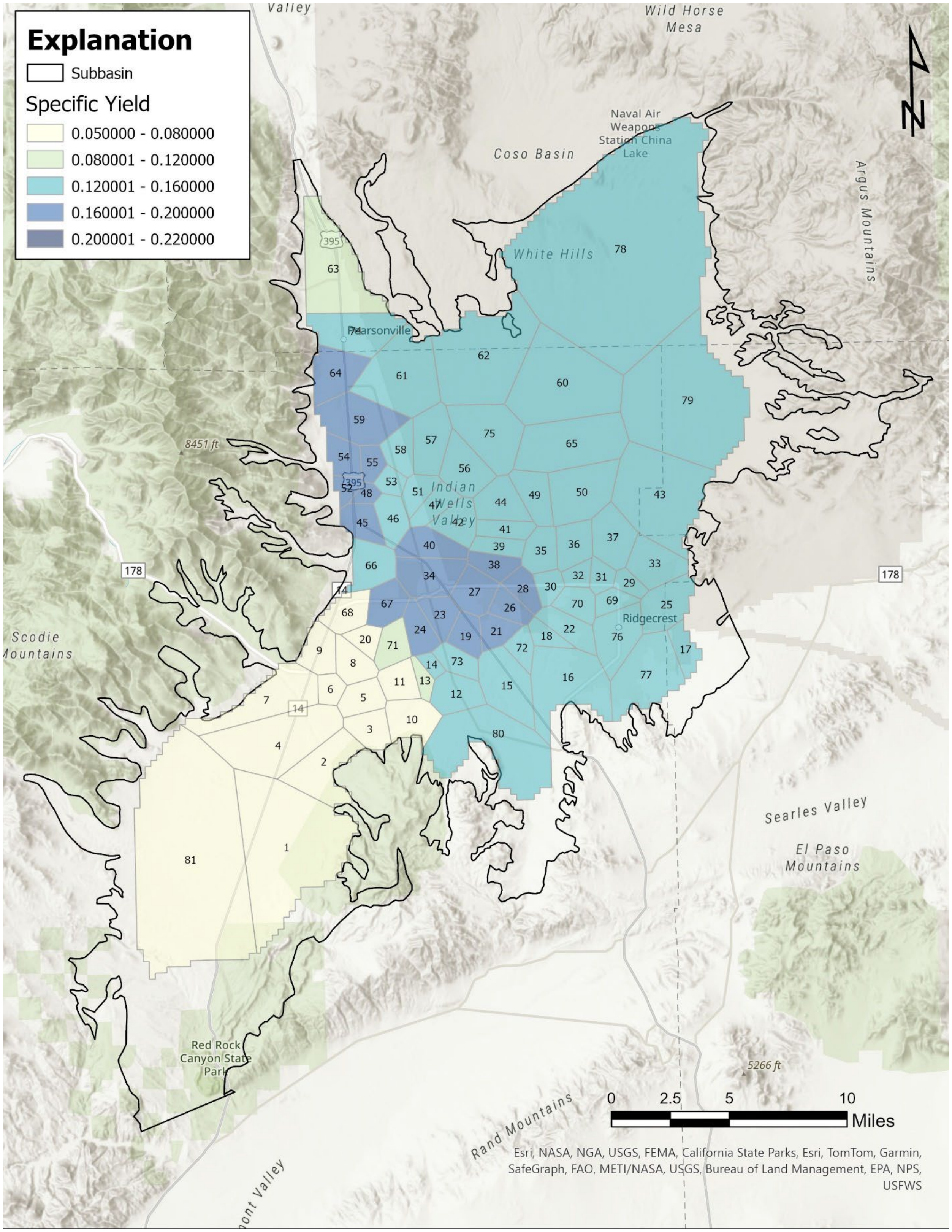


Figure 6. Specific Yield (Sy) by Thiessen Polygon (Extended 85 Polygons)

Estimates of Sy continue to be refined through ongoing studies and data collection within the IWV Basin. The updated groundwater flow model currently under development by Ramboll can provide an improved understanding of Sy, both spatially and at depth. Due to this increased resolution, TWG Approach #2 utilizes Sy values and distribution obtained from preliminary calibration runs on the Ramboll groundwater model (in progress). These values are similar to the Ramboll Sy values used for Approach #1 since they originate from the same conceptual framework but represent a more refined approximation based on calibration to observed water levels across the IWV Basin. The values used for TWG Approach #2 also represent the average weighted value for only the top two model layers (i.e., HGZ 1). The spatial distribution of Sy values assigned to each of the 81 Thiessen Polygons utilized in TWG Approach #2 are presented in **Figure 7**. Sy values for both approaches will also be summarized in **Appendix C**. The B&C Sy distribution was also evaluated under TWG Approach #2 to provide a comparison point to B&C results from TWG Approach #1.



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

Figure 7. Specific Yield from Ramboll Groundwater Model (In Progress) – 81 Polygons

4.0 Calculation of Safe Yield

For each approach, a yield value was determined annually by subtracting the annual pumping from the calculated change in storage. The safe yield was then calculated by averaging the annual yield values over the base period. For the purpose of this analysis, a spring-to-spring change was assumed to best represent pumping from the starting year. For example, the change in storage from seasonal high conditions in 2014 to seasonal high conditions in 2015 is reflective of the total pumping for calendar year 2014 (i.e., 2014 Calculated Yield = 2014 Pumping +/- Change in Storage from Spring 2014 to Spring 2015). Change in storage was determined for each individual polygon area (85 for Approach #1 or 81 for Approach #2). Results for the two different TWG approaches are summarized in the following subsections.

4.1 TWG Approach #1 (Extended 85 Polygons)

The total change in storage using spatially interpolated changes in groundwater levels across 85 Thiessen Polygon areas, Sy values from the Ramboll HCF (2024) and the B&C model (2009), and best estimates of groundwater pumping is presented in **Figure 8,** with the safe yield estimates shown in **Figure 9**. Safe yield estimates for the 2014 through 2023 base period using TWG Approach #1 are summarized in **Table 2**.

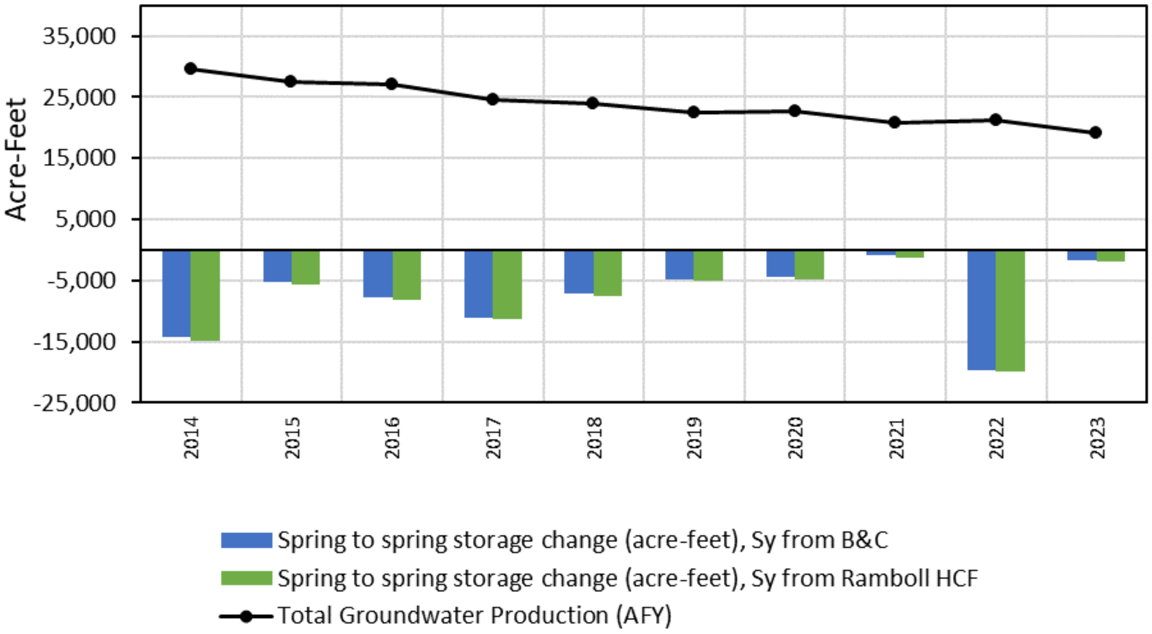


Figure 8. Spring-to-Spring Groundwater Storage Change (TWG Approach #1)

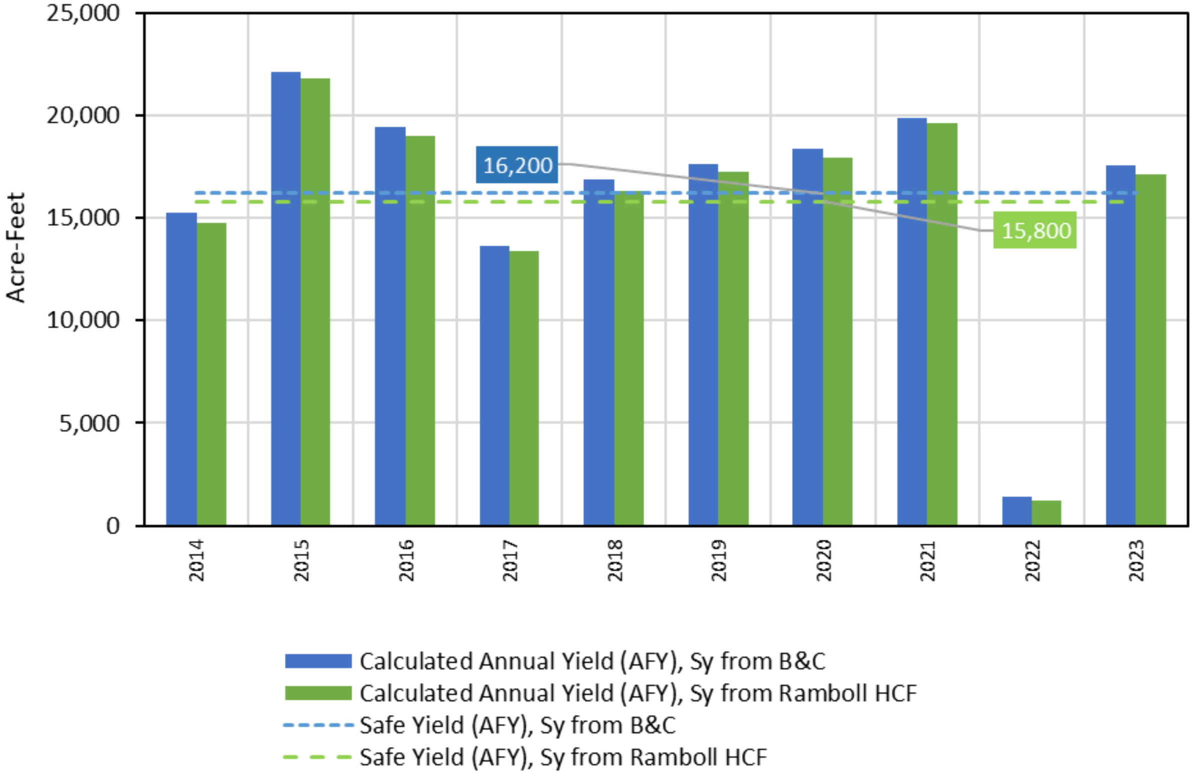


Figure 9. Calculated Yield (TWG Approach #1)

Table 2. IWV Calculated Yield (2014-2023) – TWG Approach #1 (85 Polygon Areas)

Year	B&C Sy [AFY]	Ramboll HCF Sy [AFY]	Average [AFY]
2014	15,200	14,800	15,000
2015	22,100	21,800	21,950
2016	19,400	19,000	19,200
2017	13,600	13,400	13,500
2018	16,900	16,300	16,600
2019	17,600	17,300	17,450
2020	18,400	17,900	18,150
2021	19,900	19,600	19,750
2022	1,400	1,200	1,300
2023	17,500	17,200	17,350
Safe Yield (2014 - 2023)	**16,200**	**15,800**	**16,025**

As illustrated above, average safe yield from 2014 through 2023 was estimated to be 16,200 AFY using Sy values obtained from the B&C model. The estimated safe yield for that same period was 15,800 AFY based on Sy values from the Ramboll HCF study (2024). Therefore, the average value of safe yield using TWG Approach #1 is approximately 16,000 AFY.

4.2 TWG Approach #2 (81 Polygons)

The total change in storage using changes in groundwater levels in 81 key wells and corresponding Thiessen Polygon areas, Sy values from the Ramboll groundwater flow model (in progress), and best estimates of groundwater pumping is presented in **Figure 10,** with the safe yield estimates shown in **Figure 11**. Safe yield estimates for the 2014 through 2023 base period using TWG Approach #2 are summarized in **Table 3**.

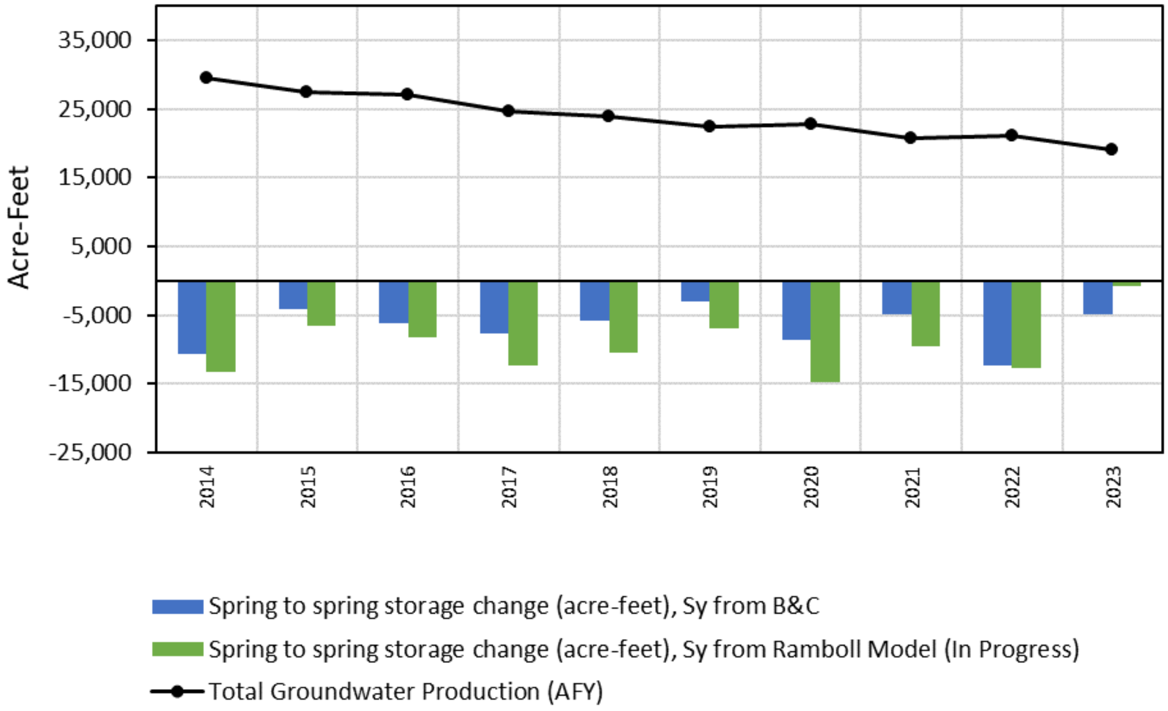


Figure 10. Spring-to-Spring Groundwater Storage Change (TWG Approach #2)

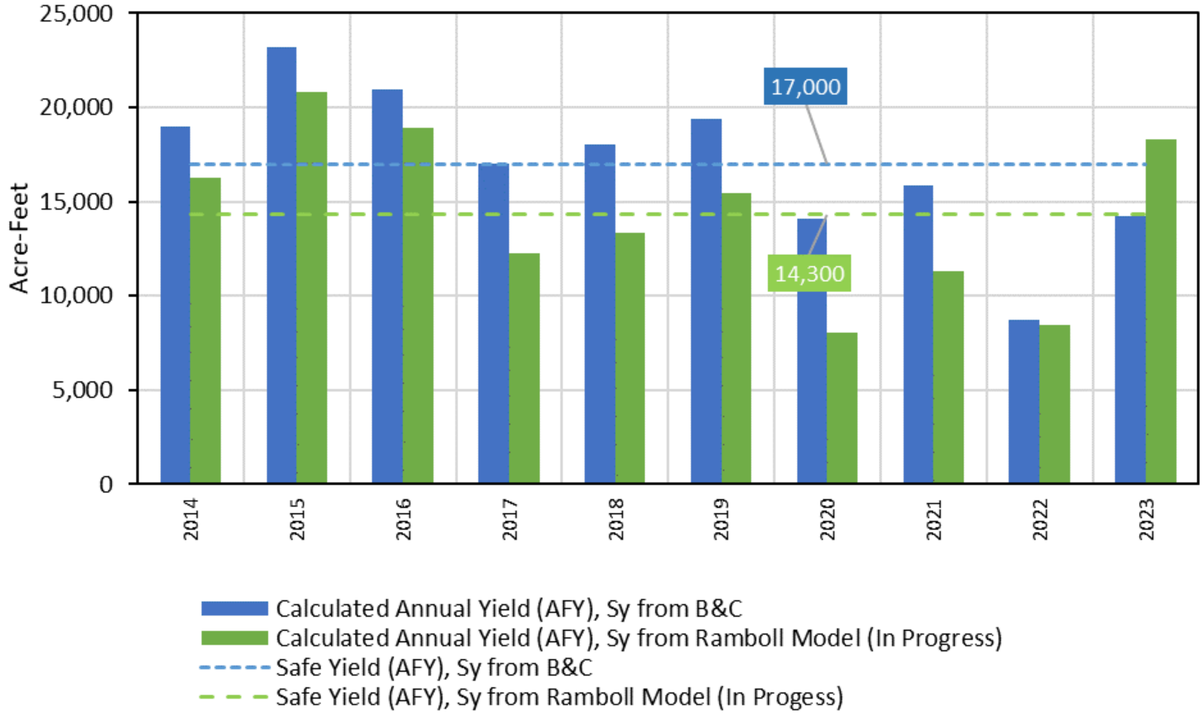


Figure 11. Calculated Yield (TWG Approach #2)

Table 3. IWV Calculated Yield (2014-2023) – TWG Approach #2 (81 Polygon Areas)

Year	B&C Sy [AFY]	Ramboll Model Sy [AFY]	Average [AFY]
2014	18,900	16,200	17,550
2015	23,200	20,800	22,000
2016	20,900	18,900	19,900
2017	17,000	12,300	14,650
2018	18,000	13,300	15,650
2019	19,400	15,400	17,400
2020	14,100	8,000	11,050
2021	15,800	11,300	13,550
2022	8,700	8,400	8,550
2023	14,200	18,300	16,250
Safe Yield (2014 - 2023)	**17,000**	**14,300**	**15,700**

As illustrated above, average safe yield from 2014 through 2023 was estimated to be 17,000 AFY using Sy values obtained from the B&C model. The estimated safe yield for that same period was 14,300 AFY based on Sy values from preliminary calibration runs using the Ramboll groundwater model (in progress). Therefore, the average value of safe yield using TWG Approach #2 is approximately 15,700 AFY.

4.3 Comparison

The two TWG approaches to estimating safe yield produce similar average results, with a value of 16,000 AFY from Approach #1 and 15,700 AFY from Approach #2. The similarity in the results presents a high degree of certainty and confidence in the resulting estimate of safe yield. This comparison provides a good check and indication of the potential effects of different assumptions and sensitivity of resulting estimates of safe yield as compared to a more traditional application of the Thiessen polygon methodology for calculating storage change utilized in TWG Approach #2. The extent of the 81 Polygons used in TWG Approach #2 also coincides with the new groundwater flow model domain (Ramboll, in progress) which will further improve future comparative analyses. Within TWG Approach #2, the TWG considers Sy values from the Ramboll groundwater flow model (in progress) to be more reliable since they are based on both lithologic data (from the Ramboll HCF study) and preliminary model calibration to observed groundwater elevations. Based upon this analysis, the TWG estimates the safe yield for the IWV Basin to be approximately **14,300 AFY.**

5.0 Summary and Conclusions

A TWG of qualified groundwater professionals designated by parties that represent more than 80 percent of the total groundwater production in WY 2022 in the IWV Basin conducted a progressive series of analyses, including review of existing studies and published literature, initial analyses with data currently being relied upon for basin management, and a more rigorous analysis using best available scientific data to develop an initial estimate of safe yield. The methodology and results are summarized as follows:

- The change in groundwater storage methodology for estimating safe yield (i.e., *Safe Yield = Pumping +/- Change in Storage*) was selected as the preferred method since it accounts for known data and comprehensively considers all groundwater inflow and outflow components.
- Two separate approaches were used by the TWG to assess safe yield. Both approaches utilize the change in storage calculation methodology but apply slightly different assumptions regarding the distribution of Thiessen Polygons and application of available groundwater data and Sy values. The highly similar results from these different approaches present a high degree of confidence and certainty in the estimate of safe yield.
- The calculation was performed for the base period from 2014 through 2023, which is representative of average long-term hydrology in the IWV Basin and covers a more recent period of improved data quality and resolution.
- Extended sets of Thiessen polygons were used to calculate change in groundwater storage. The first approach used a set of 85 polygon areas, based on areas defined in recent GSP annual reporting but extended to provide comprehensive coverage of the IWV Basin. The second approach used a set of 81 polygon areas with comprehensive coverage of IWV Basin alluvium, representing a redesign based on an independent review of available water level data.

- Groundwater pumping values from two main sources were utilized, representing the best available, most up-to-date pumping records: 1) recently submitted pumping records through the legally-required initial disclosures process for the groundwater basin adjudication (generally covering the period from 2011 through 2020), and 2) annual metered pumping submitted by pumpers to the IWVGA, summarized in GSP annual reports (2021-2023).
- Under both TWG approaches, all wells with adequate seasonal high water level measurements throughout the IWV Basin were evaluated to determine change in groundwater levels for each polygon area. TWG Approach #1 utilized all the wells within each polygon and spatially interpolated changes in groundwater levels to determine an average annual groundwater level change per polygon. TWG Approach #2 selected one key well per polygon based on data adequacy and used the measured water levels from those key wells for determining the annual groundwater level change per polygon.
- After reviewing previous estimates of Sy, a range of representative Sy values were used for the TWG Approach #1 based on the spatial distributions of Sy provided by B&C (2009) and Ramboll HCF (2024). TWG Approach #2 utilized refined Sy values and distribution from preliminary calibration runs using the Ramboll groundwater model (in progress).
- Using TWG Approach #1, safe yield from 2014 through 2023 was estimated to range from 16,200 AFY to 15,800 AFY based on Sy values from the B&C model and updated Ramboll HCF, respectively.
- TWG Approach #2, which represents a more traditional application of the Thiessen polygon methodology for calculating storage change, produced similar results.
- The TWG and its members reserve the opportunity to update this analysis based upon development and review of new data. Based on the analysis explained above, the TWG estimates the safe yield for the IWV Basin to be approximately **14,300 AFY**.

6.0 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.

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

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.

DWR (California Department of Water Resources), 2023. Groundwater Sustainability Plan Implementation: A Guide to Annual Reports, Periodic Evaluations, & Plan Amendments. Dated October.

DWR, 2016. Bulletin 118 Interim Update 2016: California's Groundwater—Working Toward Sustainability, dated December 22. https://cawaterlibrary.net/wp-content/uploads/2017/05/Bulletin_118_Interim_Update_2016.pdf.

DWR, 2002. Water Resources of the Arroyo Grande – Nipomo Mesa Area. DWR Southern District.

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.

IWVGA (Indian Wells Valley Groundwater Authority), 2024. Indian Wells Valley Groundwater Basin: GSP Annual Report Water Year 2023 (October 1, 2022 to September 30, 2023), dated March.

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

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

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

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.

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.

Schwartz, F., and H. Zhang, 2003. Fundamentals of Ground Water. New York, New York, John Wiley & Sons, Inc., p. 592.

TWG (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. Volume II Technical Report, 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.