Wagner & Bonsignore
Consulting Civil Engineers, A Corporation

Nicholas F. Bonsignore, P.E.
Robert C. Wagner, P.E.
Paula J. Whealen

Martin Berber, P.E.
Patrick W. Ervin, P.E.
David P. Lounsbury, P.E.
Vincent Maples, P.E.
Leah Orloff, Ph.D, P.E.
David H. Peterson, C.E.G., C.H.G.
Ryan E. Stolfus

TECHNICAL MEMORANDUM

To: Mojave Basin Area Watermaster

From: Robert C. Wagner, P.E. Watermaster Engineer
A. Leonardo Urrego-Vallowe, P.E. Project Engineer

Date: June 22, 2026

Re: **Plan to improve collection of hydrologic data and consideration of Golden State Water Company's recommendations**

This memorandum addresses the Court's Order dated October 23, 2024, for Watermaster:

To recommend a plan to improve the collection of hydrologic data that would be relevant to calculations of PSY in the future. In doing so, to consider the recommendations contained in Section 6.0 of the report of Anthony Brown which marked Exhibit 1 to Golden State's motion filed 9-5-24, except that paragraph 4 on page 32 (GSWC 34) is modified to read: "Based on results from the above, Watermaster should determine whether Producers in Alto have met, are currently meeting, and in the future are likely to continue to meet their obligations under the Judgment."

Recommended Plan to Improve the Collection of Hydrologic Data

Watermaster through the Mojave Water Agency (MWA) has been and continues to improve the collection of hydrologic data with the implementation of the following items:

1. **Installation and monitoring of new stream flow gages.** MWA has installed new stream flow gages at the Mojave River System and tributary streams. These new gages are continuously monitored by the MWA's monitoring program.
    - Mojave River at Daggett CA (USGS gage 10262700): Records Mojave River flows at Daggett in the Baja Subarea, downstream of the Waterman Fault. Installed in approximately August 2022, based on the start of available record.
    - Sheep Creek Wash (MWA gage) captures mountain front recharge from Sheep Creek Wash in Oeste Subarea. Total of 3 stations for surface flow and climate monitoring. Installed in February of 2024.

2379 Gateway Oaks Drive • Suite 100 • Sacramento, CA 95833-4239
Ph: (916) 441-4850 • Fax: (916) 603-3154

- Arrastre Canyon Spring (MWA gage): measures inflow at Arrastre Canyon in the Fifteen-Mile Valley in Este Subarea. There are two Arrastre Canyon gages. Arrastre Canyon, AC01, was installed on September 30, 2025, to replace one that burned down in the 2025 Ranch Fire. The other one, Arrastre Canyon, AC02, was installed on December 3, 2024.
- Kane Wash (MWA gage) records the flow from the Newberry Mountains and Rodman mountains in Baja Subarea. Kane Wash has three gages. KW01 was installed on February 10, 2024. KW02 and KW03 were installed on December 5, 2024.

Additionally, two USGS gages have been re-activated:

- Cushenbury Canyon C NR Lucerne Valley CA (USGS gage 10260400): Measures stream flow at the Cushenbury Wash in Este Subarea. Re-activated in approximately August 2023, based on the start of available record. Previous period of record was 1957 – 1971.
- Mojave River near Hodge CA (USGS gage 10262000): This USGS gage records stream flow at the Mojave River near the Hodge in Centro Subarea. Re-activated in approximately October 2022. Previous period of record was 1930 – 1932, and 1970-1993.

The location of these new gages is shown on **Attachment A**. The newly collected data will support improved understanding and quantification of water budgets for individual groundwater basins within the Mojave Basin Area (MBA). Current evaluations of existing datasets and groundwater models indicate a substantial uncertainty regarding the role of ungaged inflow and mountain front recharge in contributing to groundwater supplies across the MBA. However, the newly collected data will help generate high-quality estimates of potential additional recharge, supporting proactive, science-based decision-making for sustainable groundwater basin management.

2. **Installation of weather stations.** A total of eleven weather stations have been installed by MWA. These weather stations provide continuous time series of climatological parameters including but not limited to air temperature, wind speed, solar radiation, precipitation, relative humidity, and reference evapotranspiration. The data collected is being used and analyzed to improve the understanding of hydrogeologic features of the MBA in connection with the surface and groundwater processes. Real time access to this data is provided via the Western Weather Group at the website: https://mojave.westernweathergroup.com/.

   In addition, the MWA website provides real time data (15-minute interval) showing precipitation and stream flow relationships at critical locations in the MBA: Deep Creek, West Fork, Lower Narrows, Hodge, Barstow, Daggett, and Afton Canyon. Access to the real time data is provided via MWA website at https://www.mojavewater.org/real-time-data/.

3. **Continuing monitoring of the water levels.** MWA continues its monitoring program of water levels with an extensive and robust network of monitoring wells throughout the MBA.

As noted above, Watermaster is already collecting hydrologic data relating to the MBA. Watermaster's plan to improve collection of hydrologic data includes: (a) study and utilization of the Regional Mojave Basin Model when completed and calibrated; (b) further analysis of the network of monitoring wells; (c) identification of any data gaps, and providing a strategy to fill the data gaps; (d) studying riparian vegetation using satellite-based remote sensing tools to update consumptive use values for phreatophytes; and (e) developing and implementing a program to identify, monitor and quantify production by Minimal Producers. Watermaster's plan is being implemented in the current Water Year 2025-26 and will continue to be implemented throughout the following years.

Watermaster's Consideration of Recommendations from Section 6.0 of Expert Report of Anthony Brown

Per the October 23, 2024, Court's Order, Watermaster considered the recommendations contained in Section 6.0 of the Expert Report of Anthony Brown, Exhibit 1 to Golden State Water Company's motion filed on September 5, 2024. This section describes Watermaster's consideration of each of the recommendations in Section 6.0 of Mr. Brown's report.

Recommendation 1. *Watermaster should re-evaluate the water budgets for Alto, the TZ, and Centro. This should include improved quantification of the following:*

- *Consumptive Use by agriculture and phreatophytes*
- *Storage losses in the TZ*
- *Subsurface flow between Alto and the TZ and thence to Centro*
- *Surface water flows between the TZ and Centro*

In April of 2026, the Court ordered Watermaster to re-evaluate the Production Safe Yield calculation for each subarea using the initial hydrologic base period of the Judgment (1931-1990). Pursuant to the direction of the Court, Watermaster prepared recommendations for PSY and FPA for Water Year 2026-27 using the long-term water supply, as directed by the Court, from the initial base period 1931-1990. Estimates of water supply and subsurface flows between subareas derive from the USGS Water Resources Investigation Report 01-4002, "Simulation of Ground-Water Flow in the Mojave River Basin, California" (Stamos et al. 2001). The USGS model by Stamos et al. (2001) was used by Watermaster in the PSY determination because:

1. It captures the base period 1931-1990. By comparison, the Upper Mojave Basin Model (UMBM) was developed for the modeling period 1951-2020 and thus, it does not capture the full base period.

2. The USGS model by Stamos et al. (2001) captures the five subareas of the MBA. By comparison, the UMBM only covers the Alto Subarea above the Lower Narrows, portions of the Este and portions of the Oeste subareas.
3. The USGS model by Stamos et al. (2001) can be used for model-to-model comparison. The Stamos et al. (2001) model will allow for comparison with the elements of water supply, use and disposal when MWA finalizes the Regional Mojave Basin Model.

Pursuant to the Court's Order dated April 21, 2026, Watermaster updated the water budgets for Alto (including the TZ), Centro, Baja, Este and Oeste based on the hydrologic base period of 1931-1990 and recent Consumptive Uses, Imports and Outflows. Watermaster presented this analysis in the Technical Memorandum titled *Production Safe Yield Update and Recommendation for Free Production Allowance for Water Year 2026-27*, available via the following link https://www.mojavewater.org/20260605_psy_fpa_2026-2027/

Consumptive Use by Agriculture in Alto, the Transition Zone, and Centro. Recent pumping data compiled by Watermaster is based on flow meter records, or other Watermaster approved methods for measuring and reporting. Watermaster's Technical Memorandum *Production Safe Yield re-calculation per Court's Order* dated May 30, 2025 (available via the link https://www.mojavewater.org/tm_psy_reevaluation_20250530/), provides the different methods and percentages for measuring pumping in each subarea. Overall, about 99% of water pumped is metered/measured since at least 2012. Thus, the amount of production is reliably verified. Consumptive use by an agricultural crop is determined using the evapotranspiration rates of applied water and the irrigated acreages. The difference between the potential consumptive use and the applied water (pumping) corresponds to return flow to the system. The estimates of consumptive use by agriculture and return flows utilize accepted methodologies that are aligned with the scientific recommendations.

Consumptive use by phreatophytes for Alto, the TZ, and Centro. In 2024, Watermaster re-evaluated riparian habitat water use in Alto, the TZ and Centro. Watermaster analysis using remote sensing techniques indicates an average consumptive use of 3,776 AFY in Alto upstream of the Lower Narrows, 6,178 AFY in the TZ, and 2,146 acre-feet in Centro. The USGS report by Lines and Bilhorn (1996) indicated that the long-term consumptive uses by riparian vegetation of 5,000 AFY in Alto upstream of the Lower Narrows, 6,000 AFY in the TZ, and 3,000 AFY in Centro. The values reported by Lines and Bilhorn represent the average riparian vegetation use during the 1931-1990 period. The California Department of Fish and Wildlife (CDFW) is currently investigating the consumptive uses by the riparian habitat. The results of this study will be used to provide more recent and updated values of the consumptive uses by riparian habitat. Our recommendation is to continue to use the Lines and Bilhorn (1996) values until CDFW has completed its riparian habitat study and the results can be evaluated and if appropriate, incorporated into the water budget calculations and the RMBM (when complete).

Subsurface flow between Alto and the TZ and thence to Centro. Watermaster estimates of subsurface flows were established by the parties to the Judgment. Watermaster considered and adopted a recommendation, presented to the Court in April 2006, to establish subsurface flow obligation for Alto to Centro of 2,000 acre-feet per year.

The USGS model by Stamos et al. (2001) provides estimates of subsurface flows from Alto to the TZ of 3,501 AFY and from the TZ into Centro of 1,566 AFY during the 1931-1990 base period.

In April of 2025, Watermaster prepared updated estimates of the subsurface flows near the Helendale Fault to update a 2006 study of flow across the TZ to Centro boundary (see **Attachment B**). MWA well hydrographs for water levels measured after 2016 indicate that levels in wells upstream of the fault (Alto TZ) have remained relatively constant. This update indicates that the estimated subsurface flow ranges from 2,300 to 3,400 AFY based on water levels for nine years between 2006 and 2024. Based upon this more recent analysis, the Judgment's assumption of 2,000 acre-feet Subsurface Flow through the TZ appears to be conservative and, accordingly, Centro actually is receiving more than 2,000 acre-feet per year of subsurface flow.

Surface water flows between the TZ and Centro. In 2025, Watermaster prepared a Technical Memorandum titled *Responses to Court's questions to be addressed in the next motion to adjust FPA* available via the following link:
https://www.mojavewater.org/tm_addressing_court_questions_20250530/

This Technical Memorandum provided an analysis of monitoring wells in the TZ showing stable long-term water levels. Watermaster carefully reviews water levels within the TZ to confirm that the long-term average storage losses in the TZ are nearly zero. The network of monitoring wells in the TZ supports this conclusion. The TZ monitoring wells show stable long-term water levels throughout the TZ, including the area near and downgradient (within Centro) of the Helendale Fault.

Storage losses in the TZ. Because water levels and pumping are the best available data at this time, Watermaster continues to rely on these parameters to evaluate changes in storage and to re-evaluate PSY recommendations. Based on the water levels in the TZ, Watermaster concluded that the long-term average change in storage within the TZ is nearly zero. Once complete, the Regional Mojave Basin Model will provide more information about the storage changes and outflow in the TZ.

Recommendation 2. *Watermaster should update the current UMRB model to include the entire adjudicated area subject to the Judgment, and then use the updated (and calibrated) model to reevaluate water budgets.*

MWA is in the process of finalizing the Regional Groundwater Model which will include the Alto (Transition Zone), Centro, Baja, Oeste and the Fifteen-Mile Valley in Este Subarea initially, and ultimately the Lucerne Valley portion. The USGS model by Stamos et al. (2001) includes the entire Este Subarea, which is the basis for the current PSY determination. Once the RMBM is complete and calibrated, the model will be used to evaluate water budgets.

Recommendation 3. *Watermaster should perform statistical analyses to correlate groundwater levels in Alto, the TZ, and Centro (three areas) with: (i) time; (ii) with combined surface and subsurface inflows; and with (iii) groundwater production (three variables). These analyses should consider the following three periods of time: (i) prior to the Judgment (pre-1994); (ii) during the period of production ramp-down (1994-2004); and (iii) the period after the ramp-downs (2005-2024).*

In 2025, Watermaster conducted an analysis of the groundwater levels in the Transition Zone and in the Centro Subarea near the Helendale Fault. Watermaster analyzed hydrographs showing the relationship between depth to water at different wells and total historical production in the Transition Zone. The hydrographs and results of this analysis were presented in the Technical Memorandum titled *Responses to Court's questions to be addressed in the next motion to adjust FPA* dated March 30, 2025.

As described in this Technical Memorandum, "the average depth to water from the pre-development conditions (1930 - 1950) was 15.56 feet, which is the same as the average depth to water with and after the implementation of the Judgment (1996-2024) of 15.57 feet."

In addition, Mr. Brown recommended a Mann-Kendall (MK) statistical test to establish groundwater level trends for all wells located in the Transition Zone to determine whether there is a trend of water levels over time. Based upon Mr. Brown's recommendation, MWA performed an MK statistical test in 2025, and determined therefrom that about 70% (during 1996-2024) to 80% (during 1990-2024) of the shallow wells in the Transition Zone show either a rise, or no change in groundwater levels. These results *do not indicate* that 20%-30% of the wells show a declining water level. The results *do indicate* the following: For the period 1996 to 2024 (since entry of Judgment) 33 of 40 wells analyzed (82.5%) had trends that were significant at the 95% confidence level ($p\text{-value} < 0.05$). Of these 33, 29 (88%) wells showed an upward water level trend. 7 of the wells showed no significant trend. The number of wells in the categories Very Strong, Strong, Moderate, Weak, or Negligible were respectively 5, 5, 16, 3, 0. Only 4 wells of 40 analyzed show moderate to strong downward trend for water levels.

We conclude from this analysis that there is water level stability within the TZ as was envisioned by Section F. 2 of the 1996 Amended Statement of Decision.

The results of this analysis are provided in **Attachment C**.

Recommendation 4. *Based on results from the above, Watermaster should determine whether Producers in Alto have met, are currently meeting, and in the future are likely to continue to meet their obligations under the Judgment.*

Exhibit G of the Judgment defines the Alto Subarea obligation as "an average Annual combined Subsurface Flow and Base Flow of 23,000 acre-feet per Year to the Transition Zone." The subsurface flow component was deemed to be 2,000 acre-feet per year.

The results of Watermaster's analysis indicated that the Alto producers have met their subarea obligation, are continuing to meet and are likely to continue to meet their obligation in the future. This was demonstrated through the analysis of the hydrographs presented in Watermaster's Technical Memorandum *Responses to Court's questions to be addressed in the next motion to adjust FPA*, as well as the calculation of subsurface flows between Alto and the Centro Subarea (see **Attachment B**).

As noted, in April of 2025, Watermaster developed updated estimates of subsurface flows near the Helendale Fault to revise the 2006 analysis of flow across the Transition Zone–Centro boundary. The updated analysis, based on groundwater levels from nine years between 2006 and 2024, estimates subsurface flow to range between approximately 2,300 and 3,400 acre-feet per year (see **Attachment B**). Based on this analysis, Watermaster indicates that the Judgment's assumed subsurface flow of 2,000 acre-feet per year through the TZ is conservative.

The Makeup Obligation from Alto to Centro is determined by the base flow at Lower Narrows, subsurface flow deemed by the Judgment, and the treated wastewater discharge from Victor Valley Wastewater Reclamation Authority (VVWRA) in the TZ. Table 4-3 from the Thirty-Second Annual Report of the Mojave Basin Area Watermaster shows the yearly Makeup Obligations from Alto to Centro during the Water Years 2015-16 through 2024-25. It demonstrates that the producers in Alto have met their subarea obligation. Each year Watermaster reports the preceding ten (10) years; however, the compilation is available in the Annual Reports since Water Year 1993-1994. It is important to note that there are only two inputs to determining the Makeup Obligation: (1) base flow and the assumed subsurface flow at Lower Narrows; and (2) VVWRA discharges.

Recommendation 5. *If Watermaster determines the obligation has not been, is not being, and will not be met, Watermaster should develop a plan to ensure they are met in the future and then implement such a plan, and develop an approach to address past shortfalls in water delivery.*

As mentioned above, Alto producers have met and continue to meet their subarea obligation. Importantly, the Makeup Obligation calculation is designed to ensure that the obligation of 21,000 acre-feet of surface water flow and 2,000 acre-feet of subsurface flow to the TZ is always met per the Judgment. Therefore, no additional action is needed at this time.

Recommendation 6. *If Watermaster determines the obligation has been, is being, and will be met, Watermaster should recommend and implement additional analyses that would evaluate why chronic water levels declines are being observed at Golden State's production wells in Centro.*

As mentioned above, the Alto producers have been and will continue to meet their Subarea obligations to Centro. The most likely reason for the water level decline observed at Golden State's production wells in Centro is the below average water supply to the MBA experienced from 2012 to 2022, coupled with Golden State's pumping in a concentrated small area in Centro. **Attachment D** provides graphics showing total and cumulative production by sublocation in Centro Subarea for the 1993-2025 period. About 79% of total groundwater production occurs within the area of concentrated pumping in which the Golden State wells are located (between Hodge and Barstow gage). **Attachment E** is the aerial imagery showing the spatial distribution of groundwater pumping within Centro Subarea, the location of production wells by Golden State and other producers between Hinkley and Barstow (Focus Area), as well as the average groundwater production between Water Years 2016-17 and 2022-23.

Watermaster has previously explained and demonstrated the reason for the groundwater level declines near Golden State's wells, and that the Alto Producers have met their Subarea Obligation, and that there are no unaccounted water losses in the TZ. The *Watermaster's Amended Opposition to Golden State Water Company's Motion to Enforce Judgment* dated October 9, 2024 provides the reasons for and analysis of this issue, and is summarized herein as follows:

The historical dry period 2012-2022 was about 40-percent of long-term average supply 1931-2025. **Attachment F** is the hydrograph showing the historical dry periods at the Forks. According to the flow at the Forks, the average water supply to the Basin Area during the period 2012-2022 was 27,614 AFY, which is 60-percent drier than the 95-year (1931-2025) long-term average of 68,635 AFY. In other words, the inflow to the MBA, including the Centro Subarea, received only a small portion of the long-term average potential recharge. Therefore, the issues at Golden State wells are related to the drought conditions and the lack of storm flow during the 2012 to 2022 period, and the concentrated pumping that occurs within the relatively small area in which Golden State wells are located. This conclusion is further confirmed by the fact that the monitoring wells located upstream of the "Focus Area" (between the TZ and Hodge) show relatively stable water levels. See Centro Subarea hydrographs in **Attachment G**. For example, monitoring well 08N04W12Q01 located upstream of Hodge has a long period of record and indicates that water level measurements around 1931 were at elevation 2,322 feet msl, and the most recent water level in 2026 was also at 2,322 feet msl.

The foregoing constitutes a complete consideration of the recommendations contained in Section 6.0 of the Expert Report by Anthony Brown. However, in subsequent paragraphs of Mr. Brown's report he suggests certain other methodologies for data collection, which we also discuss briefly below.

Section 6.1 Additional Statistical Analyses

See response to **Recommendation 3** above.

Section 6.2 Improved Measurement of Surface Water Flow into Centro

Watermaster has stated previously that the Alto Subarea obligation to Centro is "an average Annual combined Subsurface Flow and Base Flow of 23,000 acre-feet per year to the Transition Zone" (paragraph 1.e of Exhibit G to the Judgment). Per the 1996 Amended Statement of Decisions, the surface water requirement from Alto to Centro is 21,000 acre-feet average annually and is measured at the Lower Narrows, not at Helendale Fault (HF).

Watermaster acknowledges remote sensing techniques are available for estimation of surface water flow in desert environments. However, the ability of remote sensing to accurately quantify river flows is limited under the environmental conditions existing at the HF, compounded by the relative infrequency of significant storm events that produce detectable storm flows at the HF.

Implementing remote sensing, as proposed by Golden State Water Company (GSWC) is not a requirement under the Judgment. Nonetheless, Watermaster has considered the recommendation of using remote sensing to determine surface water flow into Centro. In the *Watermaster's Reply Brief in response to Motion to Adjust Free Production Allowance for Water Year 2025-2026*, dated July 28, 2025, Watermaster observed that:

- GSWC proposes using Upstream Tech's AI modeling to estimate water flow through the Helendale Fault, but Watermaster views it as another model—not a direct measurement—similar to the RMBM being developed by MWA.
- Watermaster considered Upstream Tech's presentation, "but was not persuaded its modeling services would be useful at this time."
- Watermaster suggests that if GSWC strongly supports Upstream Tech, GSWC should fund and conduct the modeling itself and share the results with Watermaster.
- Watermaster budget is limited and relies on MWA for the costly modeling work being performed, including the RMBM.

Watermaster's Technical Memorandum titled *Responses to Court's questions to be addressed in the next motion to adjust FPA* dated May 30, 2025, included hydrographs of the Mojave River surface flows measured by the USGS at the Lower Narrows (USGS gage #10261500) and near Hodge (USGS gage #10262000). The hydrographs include Sentinel-2 NDWI imagery near HF during two different times. As noted on the imageries, "the normalized difference water index is most appropriate for water body mapping". The two images show the location of surface water along the Mojave River from the TZ into Centro during the times when Hodge gage was recording Mojave River discharge values. This demonstrates how Watermaster has incorporated remote sensing techniques as a visual check for storm flows passing into the Centro Subarea. However, Watermaster continues to use recorded surface flow measurements from the USGS gages, measurements of discharges from VVWRA, measured groundwater pumping and groundwater levels in the TZ, measurement of precipitation and estimates of consumptive uses within the TZ to calculate the surface and subsurface flows from the TZ into Centro at the HF. These measurements are considered the best available data at this time.

Section 6.3 Remote Sensing of Riparian and Agricultural Evapotranspiration

Consumptive uses of water by riparian habitat are adopted by Watermaster from the U.S. Geological Survey Water-Resources Investigations Report 96-4241 titled "Riparian Vegetation and Its Water Use During 1995 Along the Mojave River, Southern California" by Lines and Bilhorn. For Alto, including the Transition Zone, Lines and Bilhorn (1996) indicated an average water use of 11,000 acre-feet per year. This number was previously adopted as part of the Alto/Transition Zone water budget and PSY calculation.

Watermaster is not opposed to use of remote sensing technologies to improve and/or update estimates of consumptive use by agriculture and phreatophytes. In fact, Watermaster has worked on studying the riparian vegetation using satellite-based remote sensing tools to update consumptive use values for phreatophytes.

The total consumptive use for an agricultural crop is determined using the evapotranspiration rates of applied water and the irrigated acreages. Current estimates of agricultural evapotranspiration rates are calculated by Watermaster as the evapotranspiration of applied water (ETaw) from CUP+. CUP+ is a tool developed by DWR and the University of California, Davis to estimate ETaw values specific for each crop type. The CUP+ program incorporates climatological conditions, obtained from the CIMIS (California Irrigation Management Information System) stations, and which are specific for each subarea and vary from year to year. The CUP+ program also incorporates the crop coefficients, which are specific for each type of ag cultivation. Therefore, this methodology has been widely used and considered acceptable for calculation of ETaw (FAO 56).

In 2024, Watermaster presented an analysis of the riparian water use using remote sensing techniques. Watermaster analysis indicates an average annual consumptive use of 3,776 acre-feet per year for Alto upstream from the Lower Narrows, and 6,178 acre-feet per year for the Transition Zone, totaling 9,954 acre-feet per year. The table below summarizes and compares the estimates of riparian habitat water use.

Subarea	Lines and Bilhorn (1996)		OpenET eeMETRIC analysis		Difference
	Total Area, including hydrophytes	Estimated CU of groundwater and surface water by riparian vegetation	Total Area, including hydrophytes	Total Average ET from 2008-2023	
	(acres)	(acre-feet)	(acres)	(acre-feet)	
Alto upstream from the Lower Narrows	1,399	5,000	1,430	3,776	-24%
Alto Transition Zone	2,605	6,000	2,882	6,178	3%
Centro	2,828	3,000	3,179	2,146	-28%
Baja	2,790	2,000	4,319	1,581	-21%

CDFW has commissioned a multi-year study to update the estimates by Lines and Bilhorn (1996) and will be updated in Watermaster records when completed.

6.4 Transition Zone Water Budget

Watermaster has previously demonstrated that the Transition Zone Water balance provides an adequate calculation of the surface and subsurface flows entering the TZ at the Lower Narrows. This represents the total flow entering Centro at or near the Helendale Fault. In the Watermaster's

Technical Memorandum *Responses to Court's questions to be addressed in the next motion to adjust FPA*, Watermaster presented a complete hydrologic inventory for the TZ for the Water Years 2023 and 2024 (i.e., the complete years when we have full record of flows at the Hodge gage). Watermaster also demonstrated the relationship between the total surface flows at the Lower Narrows and the total flows near Hodge.

Watermaster analysis concluded that "this demonstrates that the Transition Zone generally allows for surface, subsurface and storm flows to pass into the Centro subarea."

Watermaster concurs that a groundwater model could provide an improved water budget calculation, and the Regional Groundwater Model that is being developed by MWA will provide estimates of groundwater flow rates between the Transition Zone and Centro, estimates of change of groundwater storage over time, etc.

Enclosures:

Attachment A – Map showing location of stream flow gages in MBA

Attachment B – Subsurface Flow at the Alto-Centro Subarea Boundary

Attachment C – MWA Statistical analysis memorandum

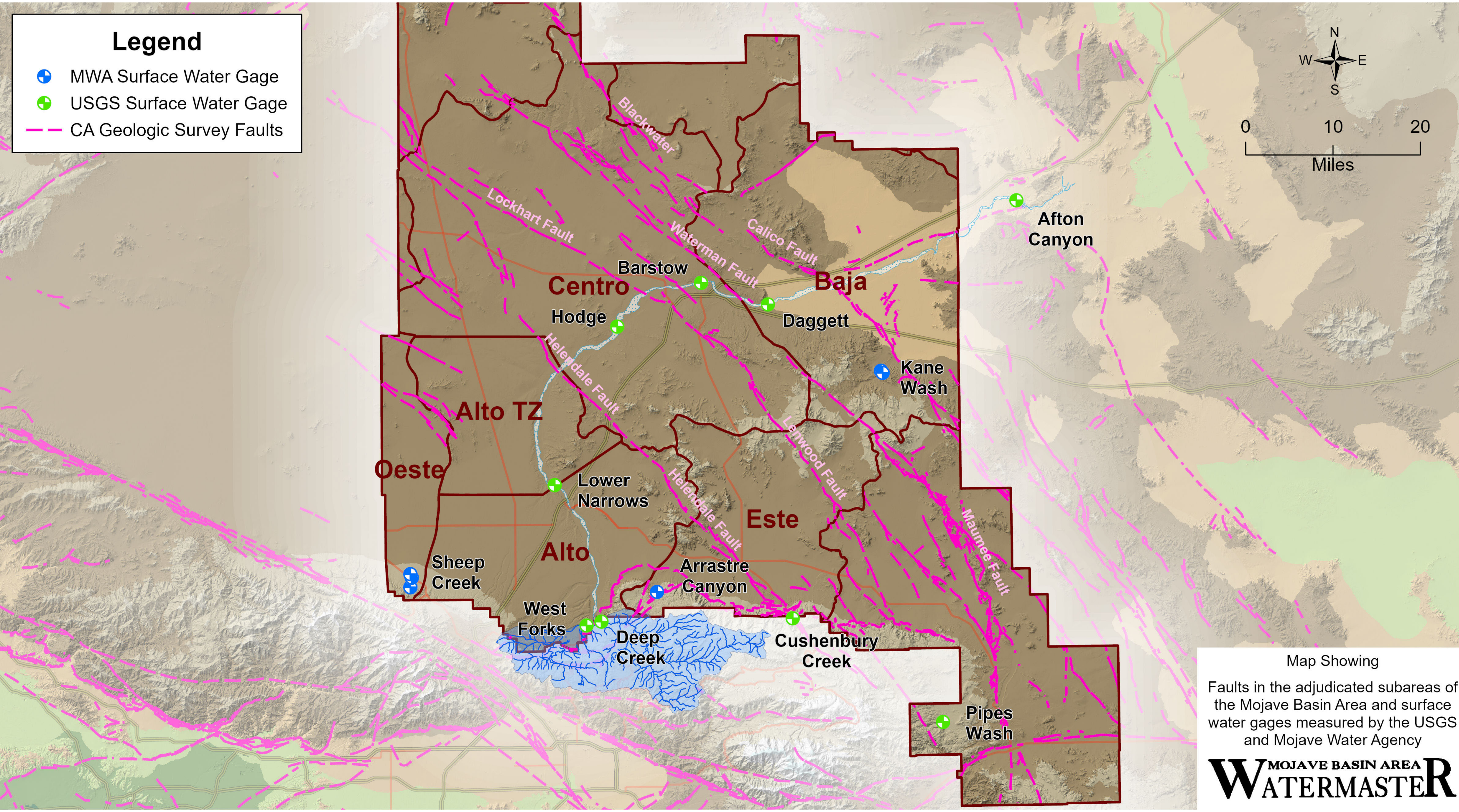
Attachment D – Centro Production by Sub Location

Attachment E – Map showing Average Production in Centro Subarea

Attachment F – Historical dry periods at the Forks

Attachment G – Centro Subarea Hydrographs 2026

Attachment A



Map Showing

Faults in the adjudicated subareas of the Mojave Basin Area and surface water gages measured by the USGS and Mojave Water Agency

MOJAVE BASIN AREA WATERMASTER

Attachment B

Wagner&Bonsignore
Consulting Civil Engineers, A Corporation

Nicholas F. Bonsignore, P.E.
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MEMORANDUM

To: Mojave Basin Area Watermaster

From: Robert C. Wagner, P.E. and David H. Peterson, C.Hg

Date: April 16, 2025

Re: **Review of Subsurface Flow at the Alto-Centro Subarea Boundary Mojave Basin Area**

This memorandum presents a review of previous studies performed to estimate the annual subsurface flow across the Alto-Centro Subarea boundary. In addition, groundwater data reviewed were used to calculate the annual flow across the Helendale fault, which generally defines the subarea boundary. This review relied on existing maps and data; field investigation or well testing were not performed. The sources reviewed are listed in the References.

<u>Hydrogeologic Setting of the Alto Transition Zone - Centro Boundary (Helendale Fault)</u>

The setting of the area reviewed is shown on the attached geologic map from a study of the Helendale fault by the U.S. Geological Survey (USGS; Stamos and others, 2003, Figure 2). Groundwater flow through the shallow (Floodplain) and deeper alluvial (Regional) aquifers has been evaluated at the Alto Transition Zone (TZ) - Centro Subarea boundary in several prior studies. These prior studies have generally concluded that the Helendale fault, which generally defines the Alto-Centro subarea boundary, does not impede groundwater flow in the shallow Floodplain aquifer. In California Department of Water Resources Bulletin 84 (DWR; 1967), analysis of groundwater levels concluded that the Helendale fault impedes groundwater flow in the deeper, older alluvium (i.e., Regional aquifer), but not within the recent channel deposits of the Mojave River. The study also noted that upstream of the fault, rising water (i.e., an upward gradient) contributes to the Mojave River, while downstream, this condition is reversed.

A 1971 study by Hardt (USGS) also noted that water levels in wells adjacent to the Mojave River near the Helendale fault indicated that the fault impeded flow in the deeper, older alluvium (Regional aquifer), but not within the overlying Mojave River deposits (Floodplain aquifer). Since most pumping and development is from the shallow river deposits of the Floodplain aquifer, Hardt concluded that ground-water movement was little affected by the Helendale fault. Hardt also noted that the fault acts as a barrier in the older alluvium (Regional aquifer) and causes water to move upward to the land surface on the south (upstream) side of the fault, which in part accounts for the abundance of phreatophytes upstream of the fault.

Review of well hydrographs prepared by Mojave Water Agency and U.S. Geological Survey for various years generally indicate that water levels in most wells through the Alto TZ remained stable or rose slightly since the early 1990s, indicating that groundwater storage within the Transition Zone has remained relatively stable or has increased slightly. Hydrographs show a period from about 2000 to 2005 when water levels in wells upstream and south of the fault steadily declined up to about seven feet, but rebounded after a large storm event in 2005. Overall, gradients have remained relatively constant.

In the electric analog model of the Mojave basin, Hardt (1971) developed values for transmissivity (the flow through a vertical strip through the aquifer one foot wide) of the Floodplain aquifer, based on an empirical relationship between specific capacity of a well (the pumping yield per foot of drawdown) and transmissivity. This was obtained mainly by estimating transmissivity of the materials from information on well drillers reports. Hardt notes that the values of transmissivity developed by this method are approximate, and dependent on factors such as the accuracy of the drillers descriptions and estimates of well yield, in addition to construction (efficiency) of the well. Transmissivity developed by this method was about 100,000 gallons per day (gpd) per foot in the channel deposits (i.e., Floodplain aquifer), and much lower, about 5,000 to 25,000 gpd per foot in the adjacent and underlying older alluvium (Regional aquifer). The transmissivity estimates developed by Hardt (1971) have subsequently been used or cited in subsequent studies by USGS and by private consultants.

In 2003, the USGS released a report of the geohydrologic study of the Helendale fault (Stamos and others, 2003). In that study, multi-point wells (piezometers) were installed in four locations near the fault. The USGS performed a well pumping test in one of the wells (8N/4W-20Q12) and monitored the response in the piezometers. The USGS also performed single well (slug) tests to estimate aquifer transmissivity. The pumping test yielded a calculated transmissivity 1,346 gpd per foot for the Floodplain aquifer, much lower than the transmissivities estimated by Hardt (1971) or Stamos and others (2001). However, the USGS concluded that the tested well may have been located in less permeable materials that were not representative of the overall Floodplain aquifer. The single well (slug) test data also did not agree well with prior studies or well test and so were used only as a relative comparison between the wells for the study.

In a 2013 study of the Centro and Baja subareas, Todd Engineers also used the relationship between specific capacity and transmissivity to estimate transmissivities from well logs. They assumed unconfined aquifer conditions and used a conversion factor of 1,500 to estimate a range of 50,000 to 100,000 gpd/ft for the Floodplain aquifer. The estimates assumed an aquifer thickness of 150 feet, similar to the conditions at the subarea boundary.

Prior Estimates of Subsurface Flow Across the Alto-Centro Subarea Boundary

Early investigations of the Mojave River Groundwater Basin by Department of Water Resources, (DWR; Weber, 1967) estimated groundwater flow from the upper Mojave Basin (Alto, Este, Oeste) to the middle Mojave at 2,000 acre-feet per year (AFY). The subsurface flows across the subarea boundary were calculated using a form of Darcy's equation. In this equation, the flow across the boundary in gallons per day Q = TIW; where W is the width of aquifer at the basin boundary in feet; T (transmissivity) is the hydraulic conductivity of the aquifer material times the saturated thickness of the aquifer, expressed in gallons per day per foot of aquifer width; and I is the slope of the groundwater surface (i.e., the gradient).

In a 2001 groundwater model by USGS (Stamos and others), Hardt's 1971 transmissivity data were used as initial input to the model and subsequently adjusted during model calibration. From the 2001 USGS groundwater model simulation, flow across the Helendale fault was calculated to range from 2,444 AFY in 1930 to 720 AFY in 1994, with an average of 1,566 AFY over that period. However, the same report cites an estimate by Gregory Mendez of the USGS that as much as 5,000 to 6,000 AFY of groundwater may actually flow through the Floodplain aquifer across the fault, with an additional 1,200 AFY in the deeper Regional Aquifer.

In a 2003 study of the Transition Zone hydrogeology by URS Corporation, the prior estimates of flow by Weber (1987) at 2,000 AFY and USGS (2001) of 1,556 AFY were presented, as well as an independent calculation of flow across the Helendale fault, using previously developed transmissivity values. In their study, URS estimated that average flow across the Helendale fault, using 1998 water levels, was about 3,358 AFY in the Floodplain Aquifer and about 1,220 in the deeper Regional Aquifer across the Helendale fault.

Updated Estimate of Flow Across Alto TZ-Centro Boundary

As part of the current review, we also performed an estimate of groundwater flow across the Helendale fault. Our analysis used water levels and gradients calculated from USGS regional water table maps and MWA hydrographs (see attached 2025 hydrograph map) for the period from 2006 to 2016, and the cross-sectional area of the Floodplain aquifer measured from Cross Section A-A' (see attached) in the 2003 USGS Helendale fault study (Stamos and others, 2003). In addition, we used MWA monitoring data from 2024 to evaluate recent conditions. We compared Floodplain aquifer thickness shown on the USGS cross section (denoted by symbols Qra and Qya) to unpublished cross sections we prepared (Wagner & Bonsignore, 2024) as part of MWA's groundwater model update and found good agreement. Additionally, a transmissivity of 100,000 gpd per foot was used, based on information presented in Hardt (1971) and was divided by an aquifer thickness of 150 feet to obtain a hydraulic conductivity (k) of 666 gallons/day or equivalently, 89 ft/day.

Gradients were estimated from measurements taken from relatively small-scale USGS regional water table maps and so are considered approximate. From the period of 2006 to 2016, water levels near the cross section varied from about 2,391 to 2,396 feet and gradients in the vicinity of the USGS cross section generally ranged from about 0.0024 to 0.0043. The results of our analysis are shown in the following table:

Subsurface Flows at USGS Cross Section A-A' (Stamos and others, 2003; see attachments)

Year	Groundwater Elevation Near Fault (Well Number)	Measurement Date	Average Gradient	Wells and Elevations Used for Gradient Calculation/Distance	Flow through Section, AFY
2006	2,395 (20Q11)	4/21/2006	0.0043	6N1(2,463) – 29E6(2,401) 2.69 mi.	3,411
2010	2,394 (19G4)	3/29/2010	0.0041	6N1(2,459) - 29E6 (2,401)/ 2.69 mi.	3,253
2012	2,396 (19G4)	3/13/2012	0.0029	6N1(2,444) - 29E6 (2,402)/ 2.69 mi.	2,301
2014	2,392 (20Q13)	3/3/2014	0.0030	6F7 (2,438) – 29E6 (2,402)/ 2.27 mi.	2,380
2016	2,391 (20Q13)	3/8/2016	0.0031	6F7 (2,438)- 29E6 (2,401)/ 2.27 mi.	2,459
2018	2,390 (20Q11)	Annual Averages	0.0041	6F7 (2,434) - 29E6 (2,385) / 2.27 mi.	3,253
2020	2,391 (20Q11)		0.0042	6F7 (2,436)- 29E6 (2,386) / 2.27 mi.	3,332
2022	2,390 (20Q11)		0.0042	6F7(2,436) - 29E6 (2,386) / 2.27 mi.	3,332
2024	2,392 (20Q11)		0.0041	6F7 (2,437) - 29E6 (2,388)/ 2.27 mi.	3,253
Averages	2,393		0.0038		2,997

Note: Water level data from 2006 – 2016 from USGS; data from 2018 – 2024 are from MWA. Gradient calculations for 2018 to 2024 were based on average water levels for the year.

The subsurface flow analysis performed above indicates that flow through the Helendale fault has exceeded 2,000 AFY for the period reviewed. While our analysis relied primarily on water-table maps by USGS published through 2016 and MWA well monitoring data from 2018 to 2024, water levels in wells south and upstream of the fault (Alto TZ) have only changed slightly over time. Since water levels and gradients have been small over time, changes in flow through the subarea boundary are also expected to be small.

Discussion and Conclusions

As previously discussed, calculation of flow using Darcy's Law requires three inputs; cross sectional area, gradient, and permeability/transmissivity. Of these, cross sectional area and gradient can be determined or calculated from well data and water levels. In the analysis, we calculated the area of the saturated Floodplain aquifer using the USGS cross section and an average groundwater elevation of about 2,393 feet. This was the approximate average water level during the period analyzed, although variations in water levels might introduce a few percent of error into the calculations.

Somewhat more difficult to measure is transmissivity, which was obtained from the references reviewed and was based on the approximate relationship between the pumping yield and drawdown observed in newly completed wells, often during initial development. Ideally, transmissivity data would be obtained by controlled, constant-rate pumping tests in several locations, in wells that fully penetrate the aquifer (i.e., at least 150 feet deep in this area). However, without these types of tests, the use of specific capacity data to estimate transmissivity is a broadly accepted method in hydrogeologic studies and is a typical method used in development of groundwater models.

As shown above, the calculated subsurface flow has averaged about 2,997 acre feet per year at Helendale Fault and has been as high as 3,411 acre feet and as low as 2,301 acre feet. The average is at nearly 3,000 acre feet per year, which is about 50% higher than the 2,000 acre feet per year assumed for the Judgement. Additionally, MWA monitoring data for well 08N04W20Q11, located just upstream of the Helendale fault indicates that water levels are little changed since 2018.

Attachments

Geologic Map and Explanation Sheet from Stamos and others, USGS, 2003 (Figure 2)
Cross Section A-A' from Stamos and others, USGS, 2003 (Figure 3)
Alto Subarea Transition Zone Hydrographs 2025 – MWA

References

Albert A. Webb Associates, 2000, Consumptive Water Use Study and Update of Production Safe Yield Calculations for the Mojave Basin Area: Unpublished report to the Mojave Basin Area Watermaster, dated February 16, 2000, 234p.

Hardt, W.F., 1971, Hydrologic Analysis of Mojave River Basin, California, Using Electric Analog Model: U.S. Geological Survey Open File Report 72-157, 91p.

Mojave Water Agency, 2025, Alto Subarea Transition Zone Hydrographs 2025: unpublished well hydrograph maps prepared by Mojave Water Agency staff.

Richard C. Slade & Associates LLC, 2011, Review of Subsurface Data for Northern Transition Zone, Mojave Water Agency: Unpublished Technical Memorandum to Mojave Water Agency, dated May 31, 2011, 44p.

Stamos, C.L., Martin, P., Nishikawa, T., and Cox, B.F., 2001, Simulation of Ground-Water Flow in the Mojave River Basin, California: U.S. Geological Survey Water-Resources Investigations Report 01-4002, Version 3, 137p., with illustrations.

Stamos, C.L., Cox, B.F., Izbicki, J.A., and Mendez, G.O., 2003, Geologic Setting, Geohydrology and Ground-Water Quality near the Helendale Fault in the Mojave River Basin, San Bernardino County, California: U.S. Geological Survey Water-Resources Investigations Report 03-4069, 53p.

Todd Engineers with Kennedy/Jenks Consultants, 2013, Final Report, Conceptual Hydrogeological Model and Assessment of Water Supply and Demand for the Centro and Baja Management Subareas, Mojave River Groundwater Basin: Unpublished report to the Mojave Water Agency, dated July 2013, 291p. with Appendices.

URS Corporation, 2003, Mojave River Transition Zone Recharge Project, Phase I Report, Transition Zone Hydrogeology: Unpublished report to the Mojave Water Agency, dated March 13, 2003, 112 p., with tables and illustrations.

U.S. Geological Survey, 1996-2016, Regional Water Table in the Mojave River and Morongo Groundwater Basins, Southwestern Mojave Desert, California: Scientific Investigations Maps/Reports prepared by various authors, scale 1:170,000.

Wagner & Bonsignore Consulting Engineers, 2024, Draft geologic cross sections and explanatory text for the Baja and Centro Subareas, Mojave River Groundwater Basin: unpublished consultants report to Mojave Water Agency, 18 sheets (cross sections) and 18p (text).

Weber, E.M. (Supervising Geologist), 1967, Mojave River Groundwater Basins Investigation: California Department of Water Resources, Bulletin 84, 196p, with figures and tables.

Figures from Stamos and others, 2003, USGS Water-Resources Investigations Report 03-4069

Geologic Setting, Geohydrology, and Ground-Water Quality near the Helendale Fault in the Mojave River Basin, San Bernardino County, California

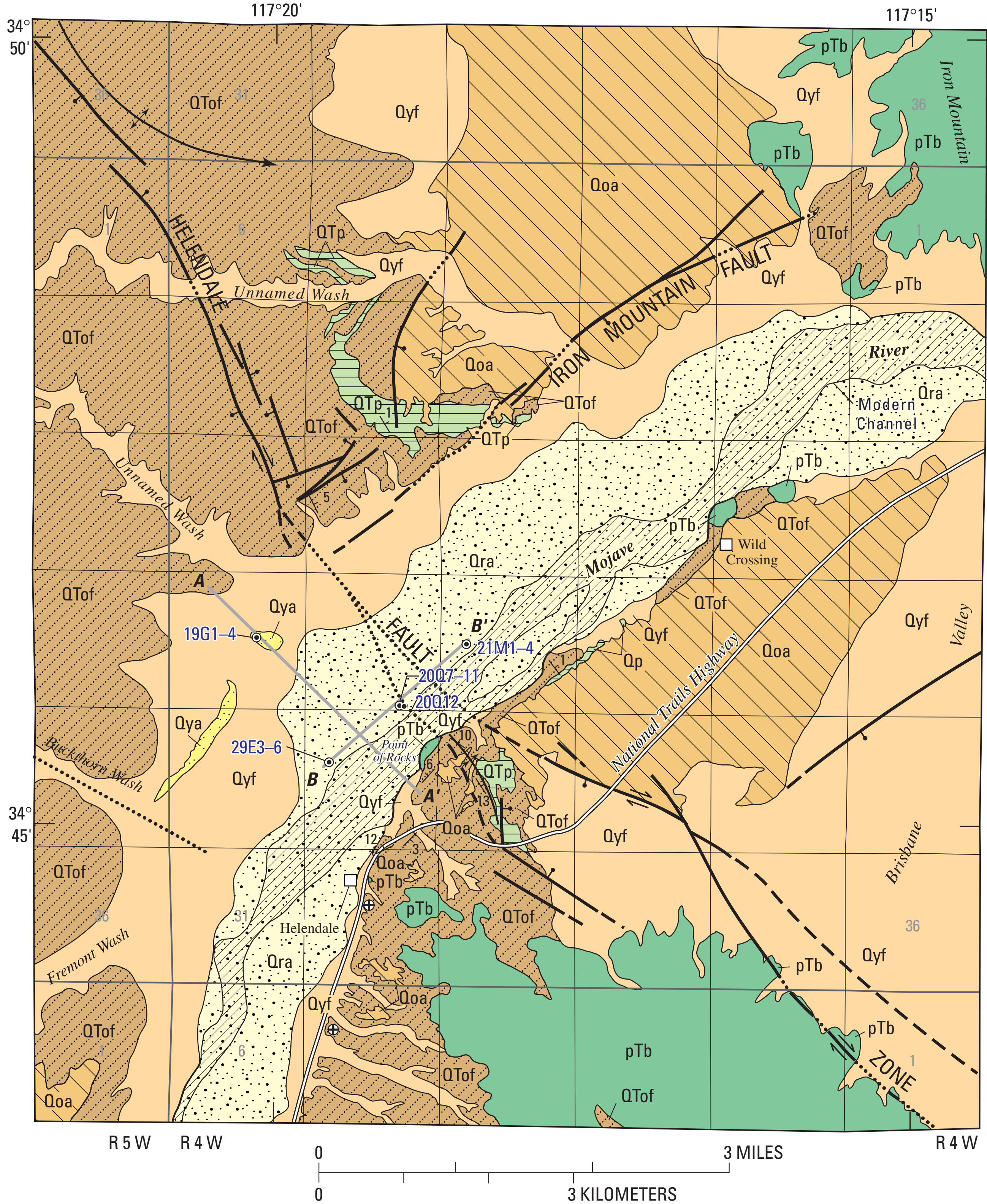


Figure 2. Surface geology, line of cross sections *A–A'* and *B–B'*, and location of the multiple-well monitoring sites near Helendale, San Bernardino County, California.

Reference: Stamos and others, USGS, 2003

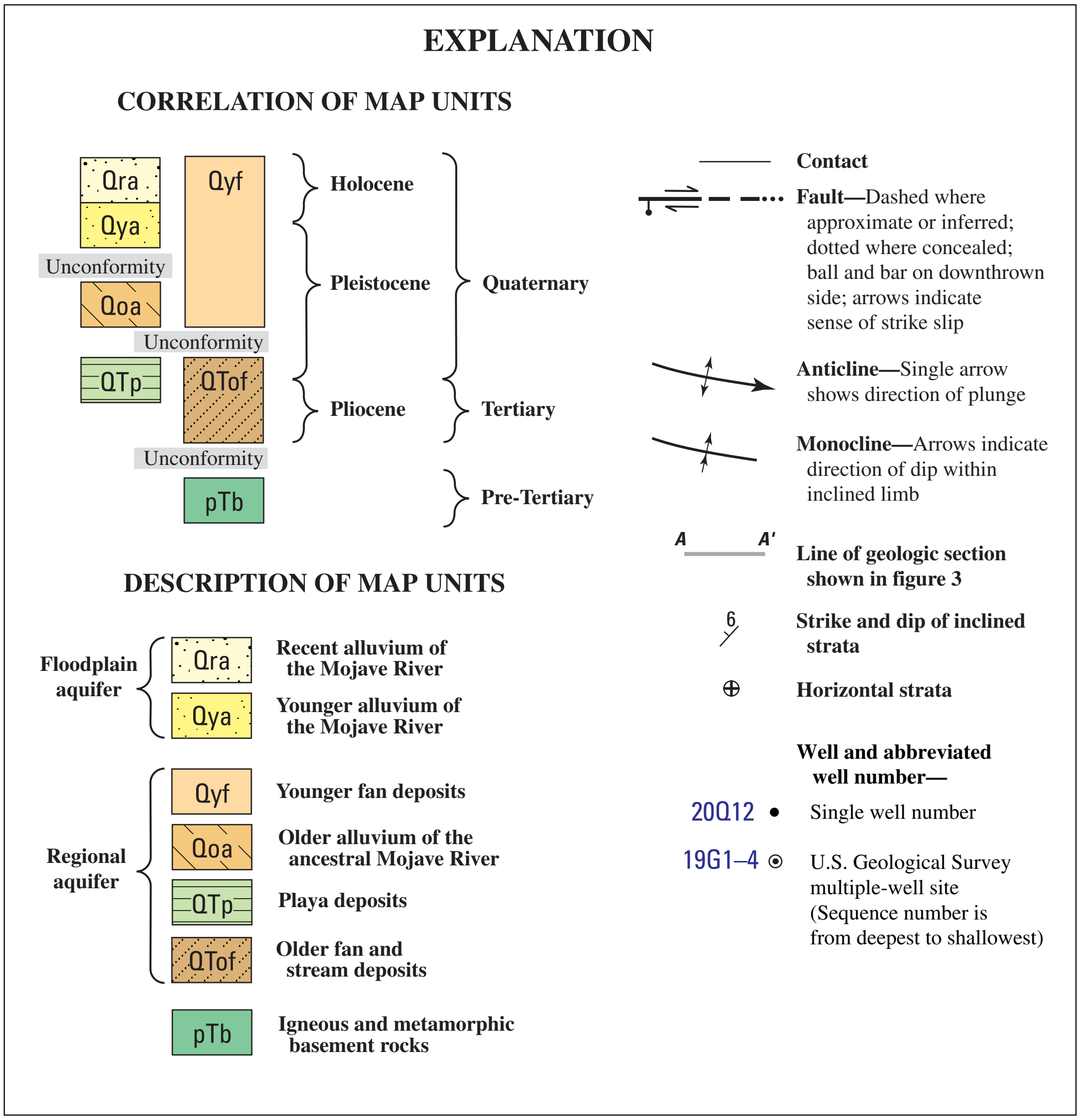


Figure 2.—Continued.

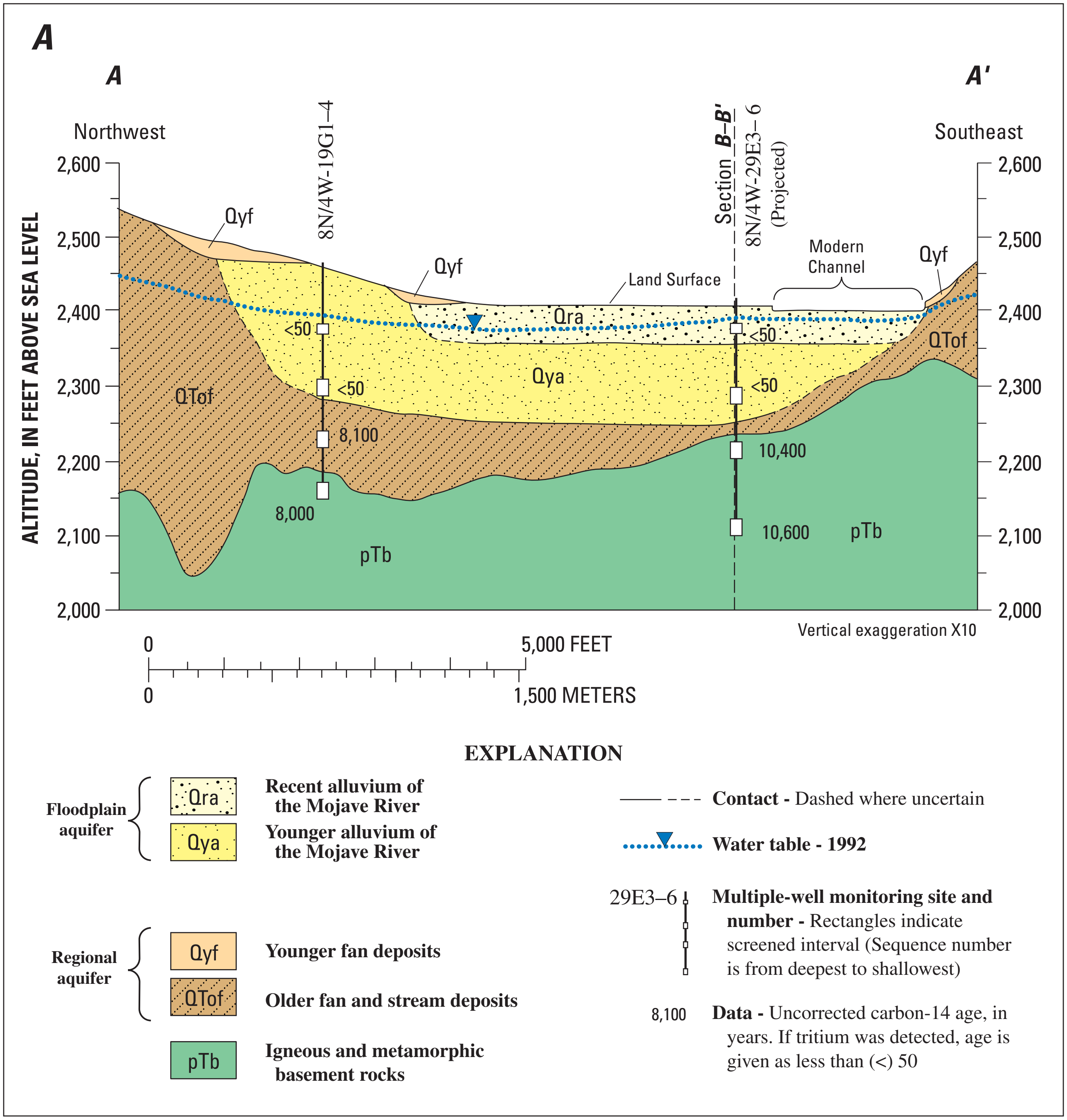
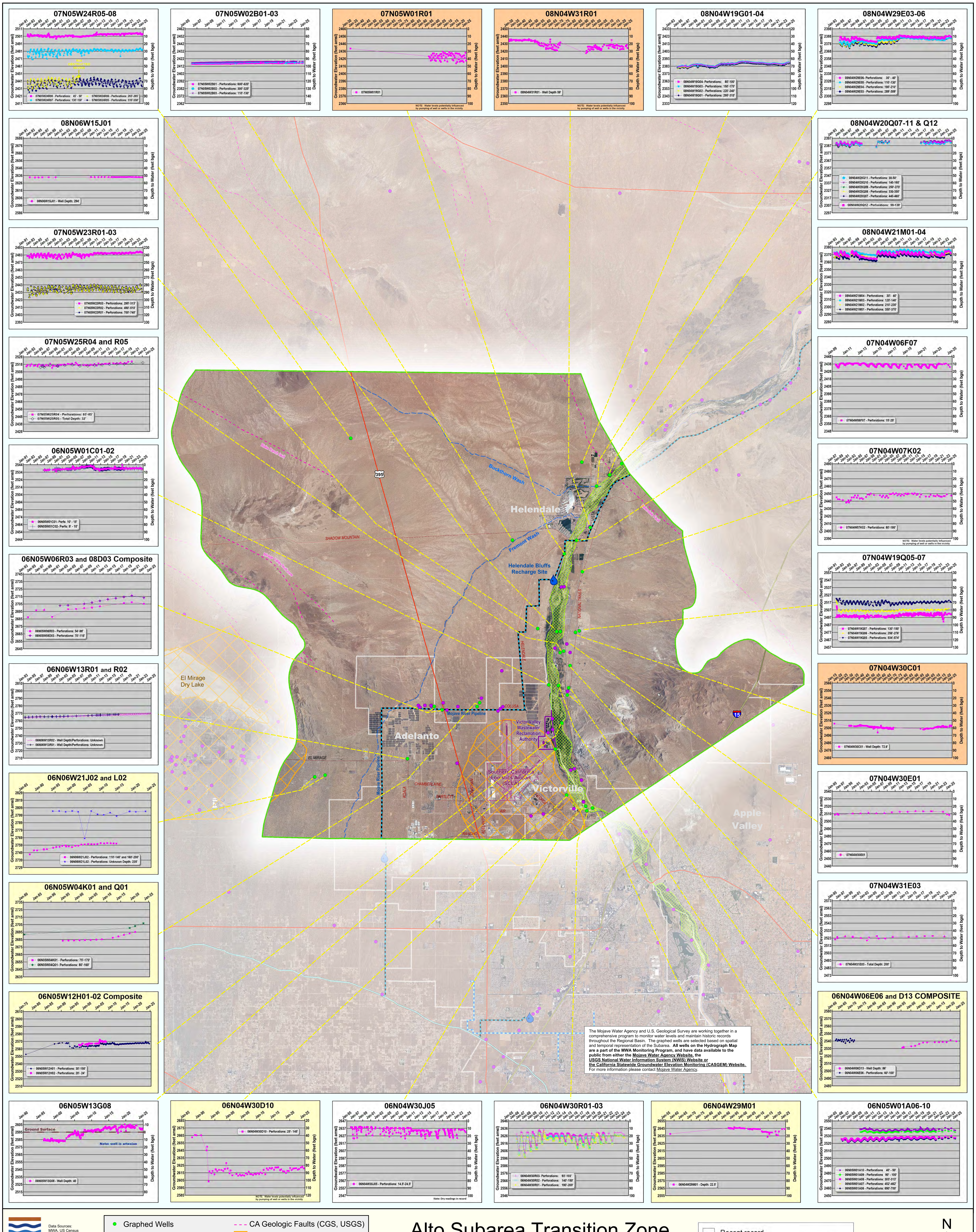


Figure 3. Geologic cross sections near Helendale, San Bernardino County, California, (*A*) cross section *A–A′*, and (*B*) cross section *B–B′*.

Mojave Water Agency, 2025

Alto Subarea Transition Zone Hydrographs 2025



The Mojave Water Agency and U.S. Geological Survey are working together in a comprehensive program to monitor water levels and maintain historic records throughout the Regional Basin. The graphed wells are selected based on spatial and temporal representation of the Subarea. **All wells on the Hydrograph Map are a part of the MWA Monitoring Program, and have data available to the public from either the Mojave Water Agency Website, the USGS National Water Information System (NWIS) Website or the California Statewide Groundwater Elevation Monitoring (CASGEM) Website.** For more information please contact Mojave Water Agency.

Mojave Water Agency

Data Sources:
MWA, US Census
USGS/NWIS,
DWR Bulletin 84 1967
Date: January 2024
Mojave Water Agency
Water Resources Department

- Graphed Wells
- MWA Monitoring Program Wells
- MWA Potable Pipeline
- MWA Recharge Pipeline
- CA Geologic Faults (CGS, USGS)
- USGS Perched Water Table

Alto Subarea Transition Zone Hydrographs 2025

- Recent record
- Long-term record (begins ~1950 to ~ 1980)
- Very long-term record (begins ~1920)

0 0.5 1 2
Miles

N

Attachment C

TECHNICAL MEMORANDUM

To: Mojave Basin Area Watermaster

From: Kapo Coulibaly, PhD, P.G

Date: May 30, 2025

Re: **Statistical Analysis of Groundwater Levels in The Transition Zone**

In October 2024, the Superior Court of California, County of Riverside ordered the Watermaster to provide a statistical analysis of the groundwater levels in the Transition Zone. The goal being to establish the trends in groundwater level changes.

1. Approach

The Mann-Kendall (MK) statistical test was used to establish groundwater level trends. This approach was chosen for two reasons:

- The purpose of the MK test is to statistically assess if there is a monotonic upward or downward trend of the variable of interest over time.
- Unlike linear regression it does not require that the data or the residual be normally distributed

The MK test was applied to the depth to water of 39 shallow wells from 1990 to 2024, 40 wells from 1996 to 2024 and 7 wells from 1931 to 1990.

2. Results

a. Period from 1990 to 2024

Of the 39 wells analyzed 34 wells had trends that were significant at the 95% confidence level (pvalue < 0.05). Of these wells 31 (80%) exhibit a negative correlation with time, meaning the depth to water got smaller over time, in other words the groundwater levels have been rising between 1990 and 2024.
The correlation derived from the MK test can be classified as Very Strong, Strong, Moderate, Weak, or Negligible. The number of wells in each category was respectively: 5, 8, 13, 5, and 0 for the rising water level trend.

b. Period from 1996 to 2024

Of the 40 wells analyzed 33 wells had trends that were significant at the 95% confidence level (pvalue < 0.05). Of these, 29 showed an upward water level trend.
The number of wells in the categories Very Strong, Strong, Moderate, Weak, or Negligible were respectively 5, 5, 16, 3,0. Only 4 wells show moderate to strong downward trend for water levels.

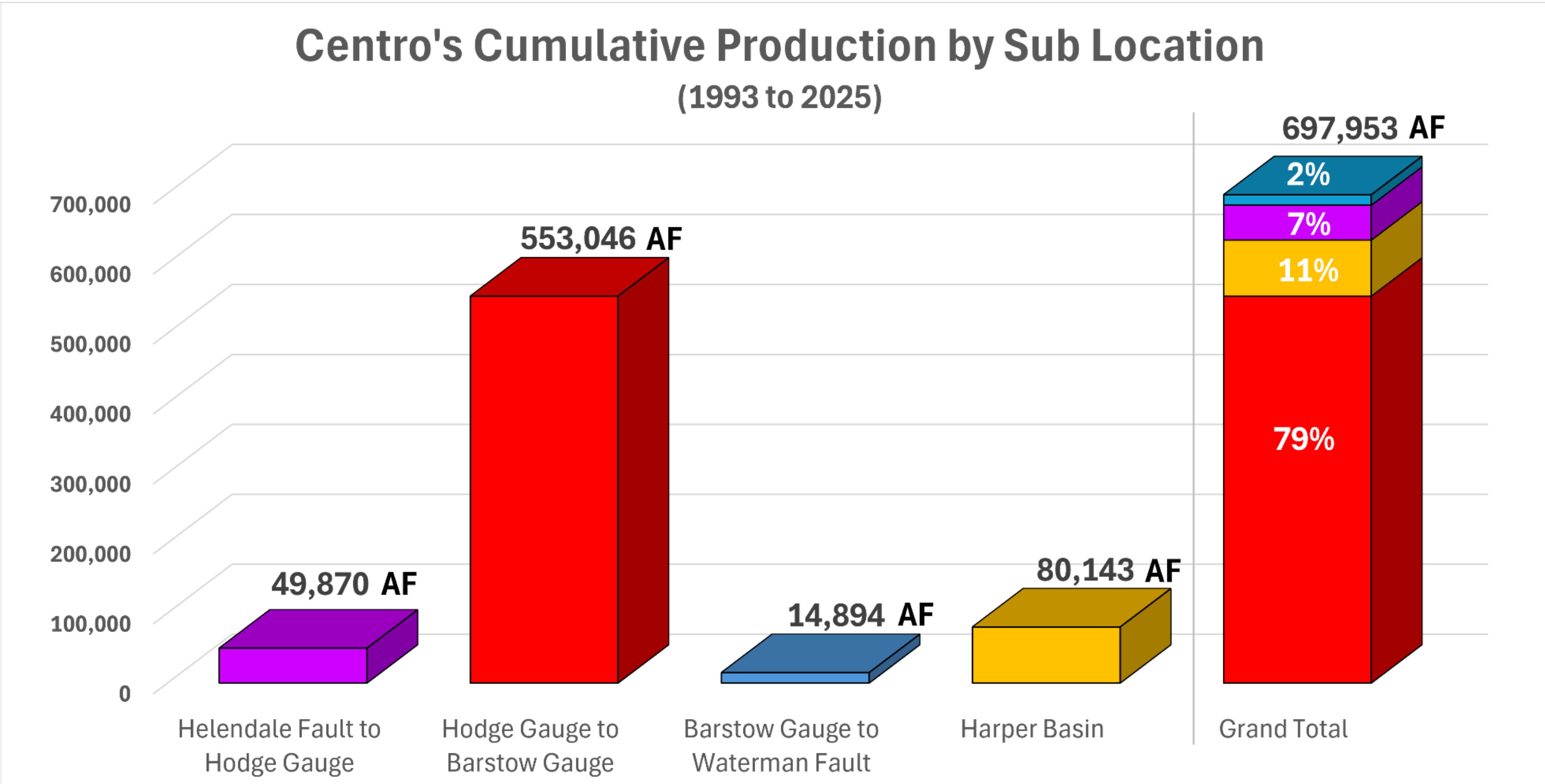
c. Period from 1931 to 1990

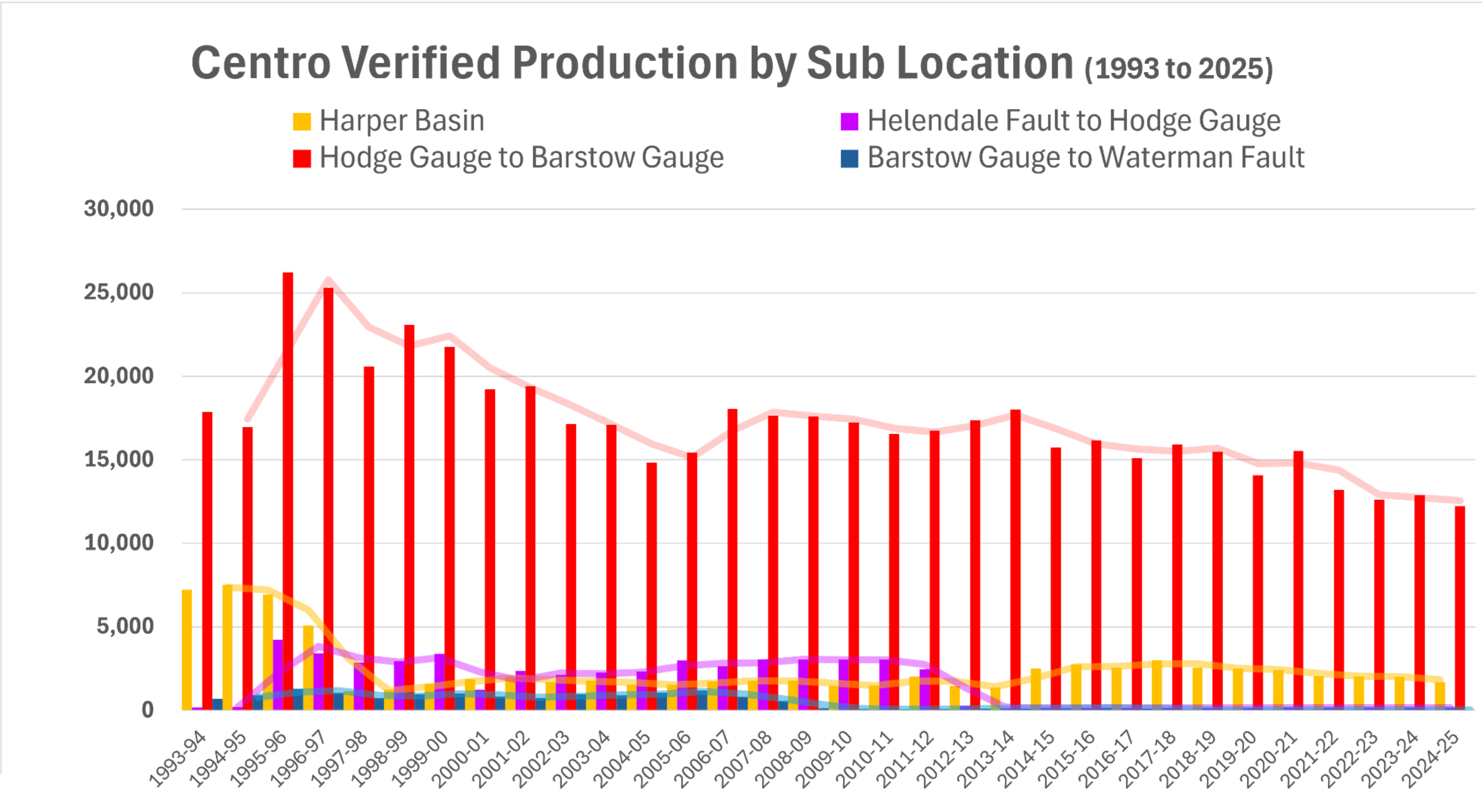
Only 7 wells had data for this period and 4 of them have a lot of missing data making the results of the MK test unreliable. Of the remaining 3 only one showed a significant trend at the 95% confidence level, which was a groundwater level downward trend.

3. Conclusion

The MK test analysis shows that approximately 70% (1996-2024) to 80% (1990-2024) of the shallow wells in the Transition Zone show either a rise of groundwater levels (Moderate to very strong upward trend) or no change (weak to negligible trend) for the periods from 1996 to 2024 and 1990 to 2024.

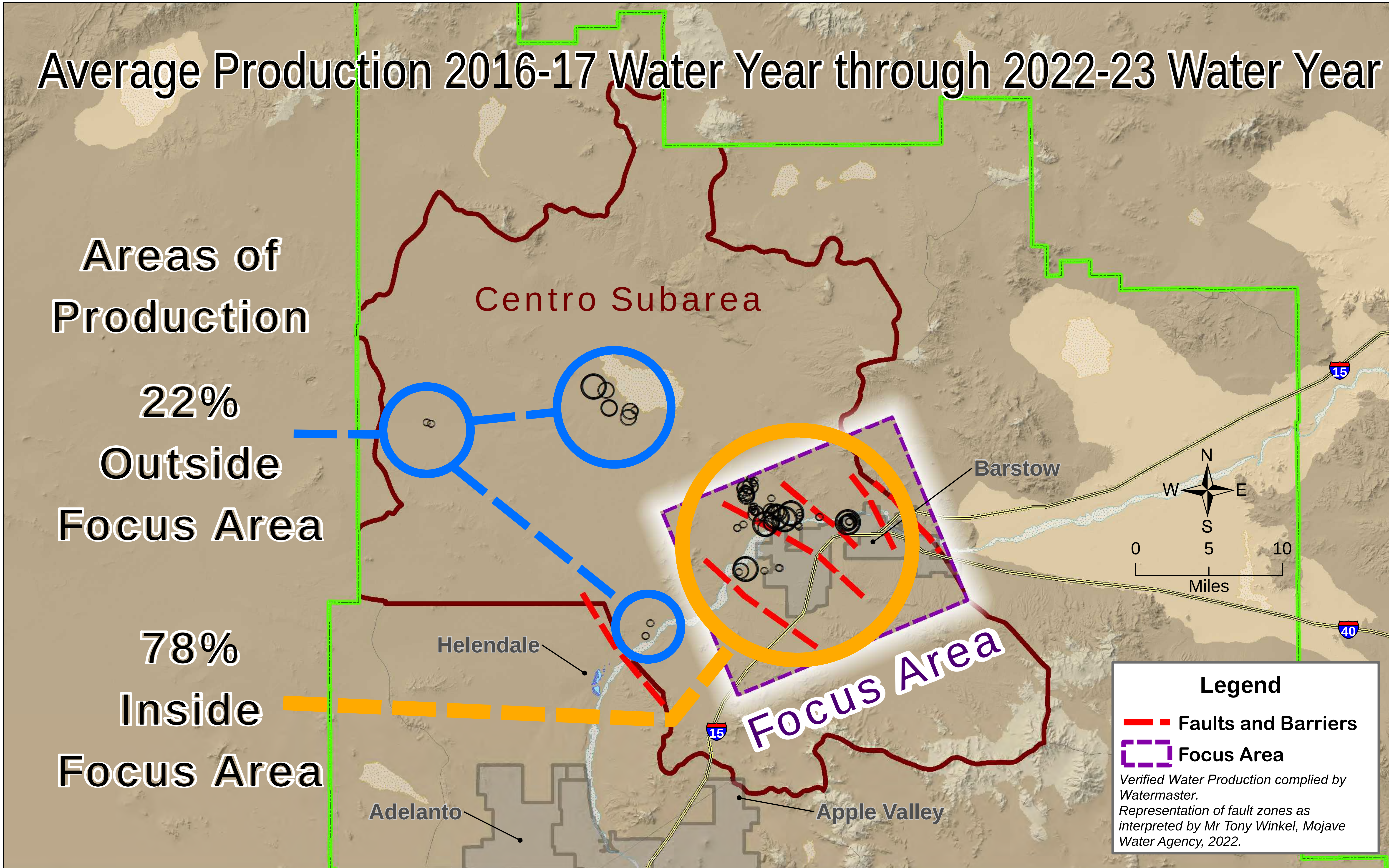
Attachment D


Centro's Cumulative Production by Sub Location
(1993 to 2025)
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
49,870 AF
553,046 AF
14,894 AF
80,143 AF
697,953 AF
2%
7%
11%
79%
Helendale Fault to Hodge Gauge
Hodge Gauge to Barstow Gauge
Barstow Gauge to Waterman Fault
Harper Basin
Grand Total



Centro Verified Production by Sub Location (1993 to 2025)
Harper Basin
Helendale Fault to Hodge Gauge
Hodge Gauge to Barstow Gauge
Barstow Gauge to Waterman Fault
30,000
25,000
20,000
15,000
10,000
5,000
0
1993-94
1994-95
1995-96
1996-97
1997-98
1998-99
1999-00
2000-01
2001-02
2002-03
2003-04
2004-05
2005-06
2006-07
2007-08
2008-09
2009-10
2010-11
2011-12
2012-13
2013-14
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
2024-25

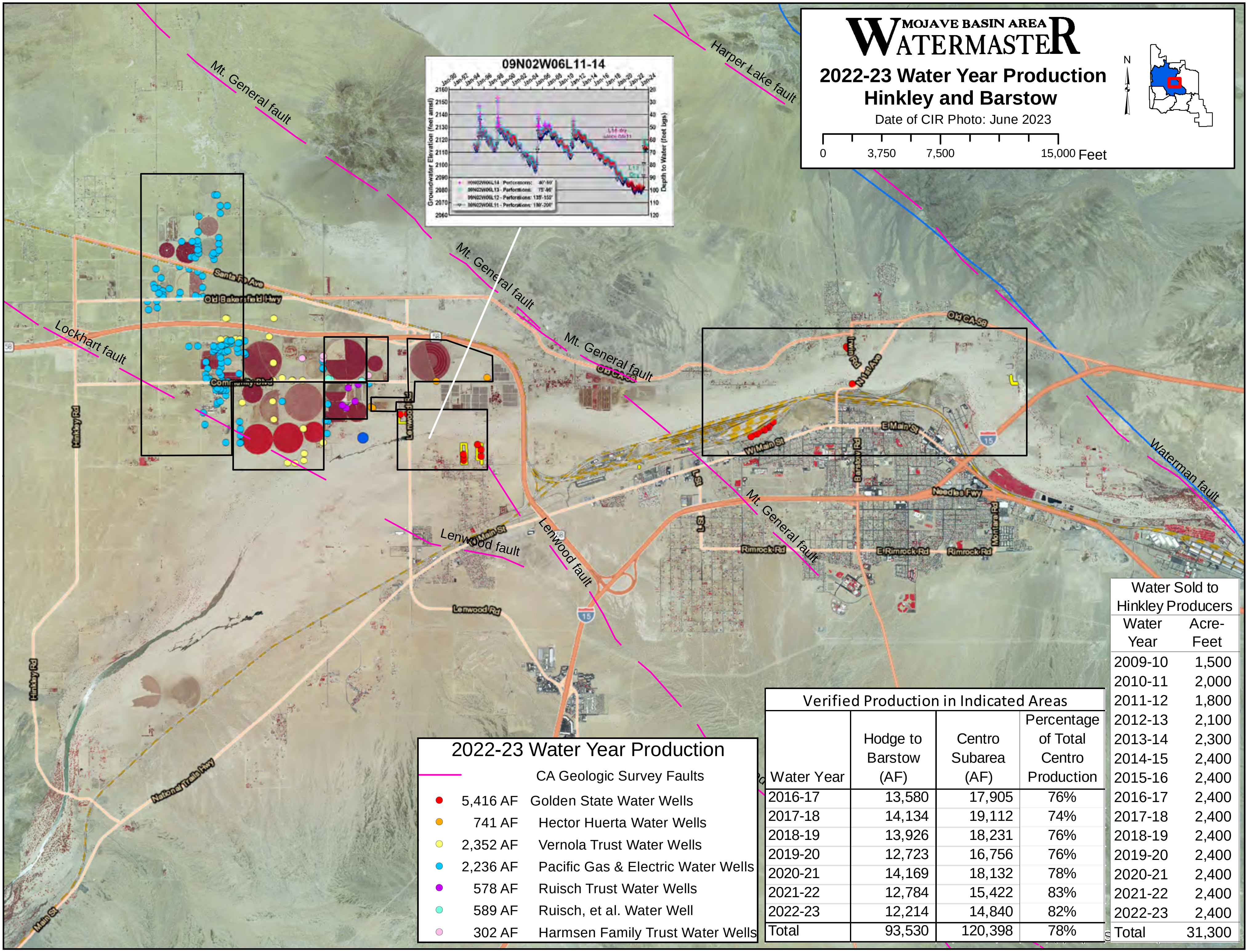
Attachment E


Average Production 2016-17 Water Year through 2022-23 Water Year
Areas of Production
22%
Outside
Focus Area
78%
Inside
Focus Area
Centro Subarea
Barstow
Helendale
Adelanto
Apple Valley
Focus Area
15
40
N
W
E
S
0
5
10
Miles
Legend
Faults and Barriers
Focus Area
Verified Water Production complied by Watermaster.
Representation of fault zones as interpreted by Mr Tony Winkel, Mojave Water Agency, 2022.

MOJAVE BASIN AREA WATERMASTER

2022-23 Water Year Production Hinkley and Barstow

Date of CIR Photo: June 2023



2022-23 Water Year Production

	CA Geologic Survey Faults
5,416 AF	Golden State Water Wells
741 AF	Hector Huerta Water Wells
2,352 AF	Vernola Trust Water Wells
2,236 AF	Pacific Gas & Electric Water Wells
578 AF	Ruisch Trust Water Wells
589 AF	Ruisch, et al. Water Well
302 AF	Harmsen Family Trust Water Wells

Verified Production in Indicated Areas

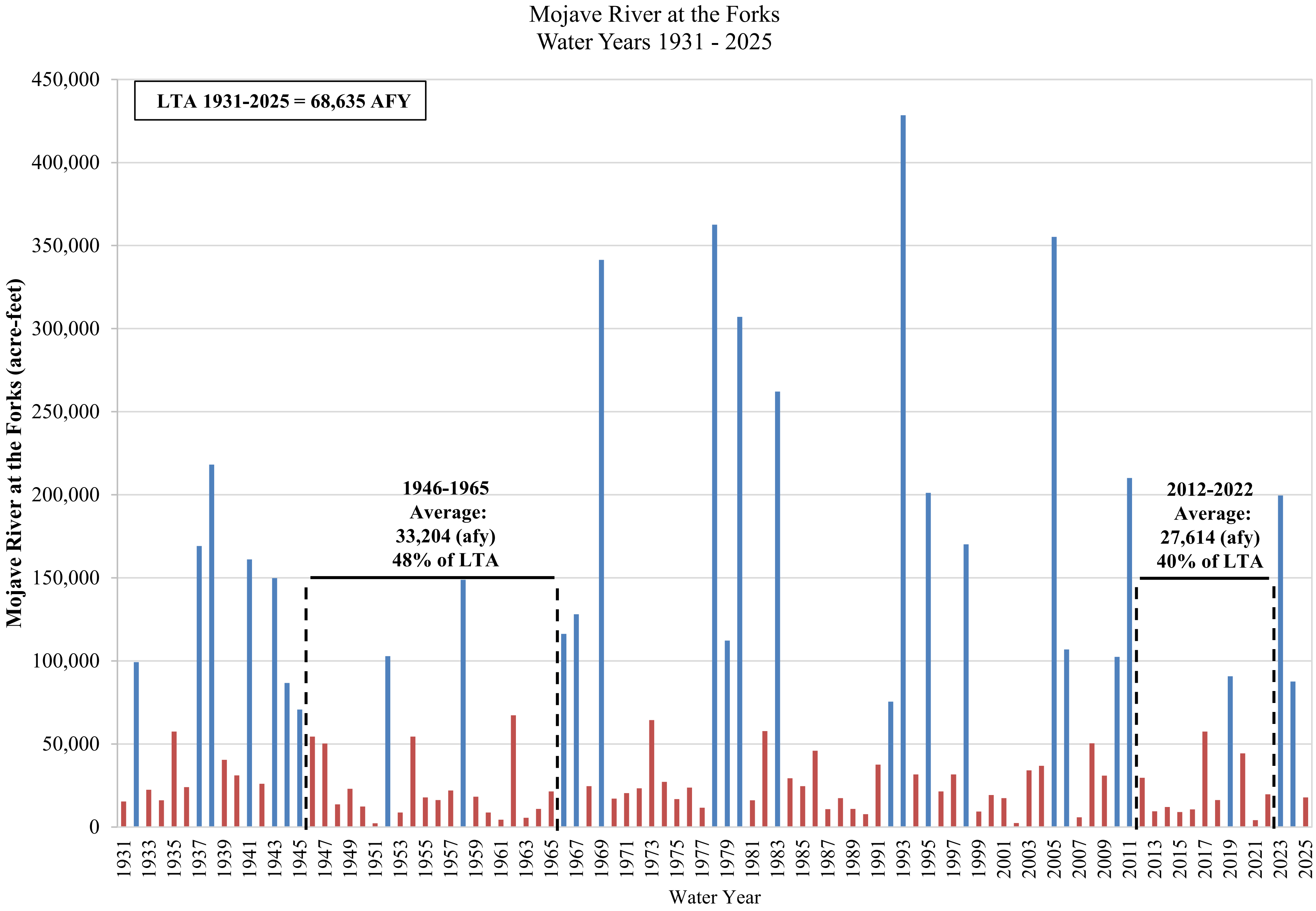
Water Year	Hodge to Barstow (AF)	Centro Subarea (AF)	Percentage of Total Centro Production
2016-17	13,580	17,905	76%
2017-18	14,134	19,112	74%
2018-19	13,926	18,231	76%
2019-20	12,723	16,756	76%
2020-21	14,169	18,132	78%
2021-22	12,784	15,422	83%
2022-23	12,214	14,840	82%
Total	93,530	120,398	78%

Water Sold to Hinkley Producers

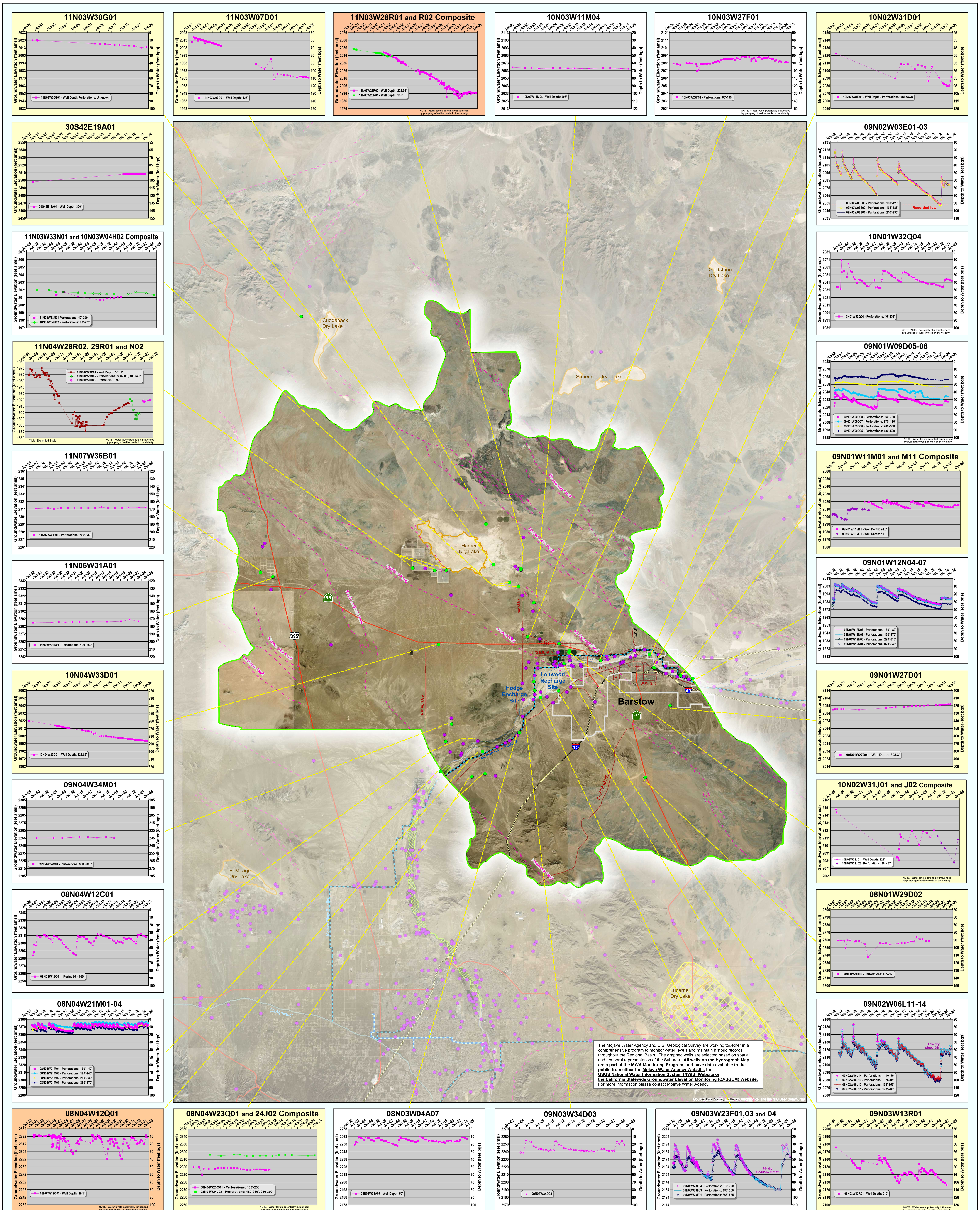
Water Year	Acre-Feet
2009-10	1,500
2010-11	2,000
2011-12	1,800
2012-13	2,100
2013-14	2,300
2014-15	2,400
2015-16	2,400
2016-17	2,400
2017-18	2,400
2018-19	2,400
2019-20	2,400
2020-21	2,400
2021-22	2,400
2022-23	2,400
Total	31,300

Attachment F

Historical dry periods at the Forks



Attachment G



Mojave Water Agency

Data Sources:
MWA, US Census
USGS/NWIS,
DWR Bulletin 84 1967
Date: 02/2026
Mojave Water Agency
Water Resources Department

Legend	
Graphed Wells	MWA Recharge Site
MWA Monitoring Program Wells	MWA Potable Pipeline
CA Geologic Faults (CGS, USGS)	MWA Recharge Pipeline
Exhibit H Riparian Habitat Area	

Centro Subarea Hydrographs 2026

Recent record
Long-term record (begins ~1950 to ~1980)
Very long-term record (begins ~1920)

0 1 2 4
Miles

N