Evaluation of "Understanding the source of water for selected springs within Mojave Trails National Monument, California" by Andy Zdon, M. Lee Davisson and Adam H. Love

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This is an external peer review and evaluation of the publication by Andy Zdon, M. Lee Davisson and Adam H. Love (2018), "Understanding the source of water for selected springs within Mojave Trails National Monument, California," published in Environmental Forensics, 19:2, 99-111, DOI: 10.1080/15275922.2018.1448909. Throughout this review the publication will be referred to as Zdon et al. (2018).

In preparing this review and evaluation, information was considered which appears in the references at the end of this report. Further, on June 1, 2018, a field study of Upper and Lower Bonanza Spring, identified in Zdon et al. (2018), and its watershed and surrounding area was conducted.

Generally, Zdon et al. (2018) contains information pertaining to water quality and isotopic relationships for springs, wells and groundwater in the southeast Mojave Desert. This information, however, is poorly referenced and the conclusions drawn in Zdon et al. (2018), particularly with respect to the purported connection between Bonanza Spring and the Fenner and Cadiz Basins which are unsupported by the evidence cited. In fact, there is disagreement between the data presented in Zdon et al. (2018) and data published elsewhere. Whether these conflicts arise from reporting errors in the manuscript, or from the presentation of selective information from a larger data set, cannot be determined. In sum, a complete interpretation of all available data supports completely different and sometimes opposite conclusions reached in Zdon et al. (2018).

The Journal

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[1] This journal has a relatively low impact factor of 0.850 (2016), and a 5-year impact factor of 0.845. Impact factor is a measure of the frequency with which the average article in a journal has been cited in a particular year, and is used to measure the importance or rank of a journal. (For comparison, the journals "Science" and "Nature" have Impact Factors of 37.205 and 40.137, respectively).

external peer review. Included in the references are a personal communication, general subject area book chapters, an oral presentation by one of the authors, 6 self-citations, reports and manuscripts from areas not in the Mojave Desert field area, and sources that do not come from refereed journals subject to peer review. Over a quarter of the references are more than 30 years old, and more current references (e.g. on recharge area estimation methods and other more recent field approaches) are not included.

Temperature

In Zdon et al. (2018), the authors reach a major conclusion, in part based on water temperature readings, that, "*water within Bonanza Spring is from a basin-fill water source, deriving its water from recharge north of the Clipper Mountains, such as the Providence and New York Mountains, and could be impacted if groundwater levels decrease at, or near, the spring.*" As supporting evidence, they further assert that, *"Bonanza Spring water temperature is indicative of waters that have been at depths of greater than 750 feet below the spring vent and risen to groundwater surface despite being in such a small catchment."* This is based on the author's reporting a temperature of 27.5 (or 81.5°F) for the water at Bonzana Spring in the manuscript, which they assume is geothermally influenced. This value, however, directly conflicts with a value of 14.2°C (57.6°F) reported by Andy Zdon and Associates (2016) for Bonanza Spring. This measured spring water temperature documented by Andy Zdon and Associates is less than the yearly average air temperature calculated by Zdon et al. (2018) at 21.0°C (69.8°F). A different value for water temperature is reported by Rose (2017) of 26.5°C (79.7°F) for the spring. It is unclear if the value reported in the Zdon et al. (2018) is a mistake, if an independent measurement was made, and/or if the spring temperature varies greatly as is indicated. Supporting information for the single value of 27.5 (or 81.5°F) is not given in the manuscript.

The date and time of year, time of day, location of the sampling point (Bonanza has a long surface flow above ground where ambient air temperatures could affect water temperatures), meteorological conditions, preceding precipitation, and many other factors associated with the temperature measurement are not reported in the manuscript, making further interpretation difficult. Ambient air temperatures in the area, reported by weatherbase.com, show that annually temperatures in the region may vary as widely as 100°F, and the average high temperatures in summer can be about 65°F different than the average low temperatures in winter. The location, altitude, and timing of water sampling can then particularly affect both aqueous temperature, and stable isotopic values whose fractionation can be strongly affected by temperature. This is particularly true of hydrogen and oxygen isotopic values referred to in the manuscript from T.P. Rose (2017) for precipitation in the "Clipper Mountains" which were measured less than a quarter mile from Bonanza Spring. The significance of the potential for isotopic variation is discussed below.

Cool water documented at the spring by Andy Zdon and Associates (2016) is inconsistent with a deep source. Giving the authors of Zdon et al. (2018) the benefit of the doubt and assuming the temperature reported in the manuscript of 81.5 °F represents a single, accurate independent measurement, but not the full range of measurements available in the literature, the spring water temperature at Bonanza Spring is at the very least must be considered variable;

again, this is inconsistent with a deep source and connection to the basin waters which are vertically far below the spring. Available data clearly demonstrate that the temperature of Bonanza Spring water varies greatly, indicating a local source. Additional data would need to be collected from a precisely documented, consistent location over time to demonstrate otherwise.

Flow of Bonanza Spring

Zdon et al. (2018) reach the conclusion, *"Bonanza Spring flow has been consistent for more than 100 years despite multi-year wet periods and longer periods of drought (as indicated by the literature).*" This is demonstrably untrue. Although the authors give no numerical values for Bonzana Spring discharge in their publication, they do state, *"Thompson (1929) noted the presence of Bonanza Spring as a spring that yielded about 10 gallons per minute (similar to what it produces currently) that was piped to the community of Danby for use at the railroad."* In Andy Zdon and Associates (2016) the flow of Bonanza Spring is recorded as less than 1 gallon per minute (gpm) - significantly less than the 1929 value. On June 1, 2018, the flow of Bonanza Spring was also estimated at less than 1 gpm. This variability does not indicate "consistent" flow. Further, Rose (2017) reports an entirely different, higher flow value for Bonanza Spring. The reported flow at Bonanza Spring varies by at least an order of magnitude. Inconstant flow (particularly coupled with inconstant temperature readings) is not compatible with an assumption of a constant, sustainable deep groundwater source which is a conclusion of Zdon et al. (2018). Additionally, the vegetation around Bonanza Spring has apparently changed in the past, sometimes dramatically, when viewing Google Earth imagery. This could be another indicator of inconstant discharge and flow at the spring, or alternatively periodic destruction of vegetation from localized flash flooding events.

Catchment Size and Water Balance for Bonanza Spring

Zdon et al. (2018) reach a conclusion regarding Bonanza Spring that, "*site field conditions related to large size of the spring and associated small watershed size indicate that the spring flow observed is not compatible with its watershed and the low volume of precipitation anticipated in that watershed.*" The authors do not present a water balance, however, to justify or illustrate this point, nor do they justify their presumption that any recharge area in the Clipper Mountains for the spring would be restricted to a small surface water catchment immediately above the spring.

Importantly, Zdon et al. (2018) do not consider a full range of recharge scenarios, and neglect to fully evaluate the most likely scenario of groundwater recharge from an extensive area of fractured and faulted volcanic geology, immediately above Bonanza Spring in the Clipper Mountains. They present only two possibilities for groundwater recharge that would supply the spring: either that recharge could only occur from a small, restricted surface water catchment immediately above the spring, or that recharge occurs over a vast area flowing down into the alluvial basin over a thousand feet below the spring (and then through some unexplained or geologically supported mechanism water rises to the spring).

A water balance calculation or water budget is an accounting of water movement into and out of, and storage change within, an aquifer surrounding a spring. Water-budget methods can be used to estimate the sum of both diffuse and focused recharge, and account for the sum of many phenomena such as preferential flow paths along faults and fractures. Accurate estimations of the components of water balance, including groundwater recharge area, are extremely important for properly understanding the source of spring flow.

Using very conservative values, a water balance may be calculated, and shows that even a very small recharge area could provide enough water to generate Bonanza Spring flow, while a more likely, larger local recharge area (not even considered in Zdon et al.) would produce much more sustainable flow observed at the spring. The worst case, conservative estimate can be carried out to determine if, by using a high value for spring discharge and a low value for catchment area and rainfall/recharge (solely to that small catchment), minimum rainwater could provide enough input to supply the spring. Zdon et al. (2018) do not quantify Bonanza Spring discharge, nor do they quantify recharge supplying the spring.

For calculating a worst case scenario for very high spring flow and low recharge area, and using a conservative (high) 10 gpm historic 1929 value that Zdon et al. (2018) state is "*similar to what it produces currently*," the annual high flow for Bonanza Spring would be about 702,625 ft^3/yr. This yearly volume, equivalent to 10 gpm, is considered a higher, conservative value because it is a greater discharge than the sum of what is reported by Andy Zdon and Associates (2016) for both Bonanza and Lower Bonanza springs combined, and is more than ten times higher than that measured on June 1, 2018. The surface catchment according to the manuscript in Zdon et al (2018) is "approximately 50 acres" (2,178,000 ft^2), although the source of this estimate is not given, and review of topographic maps, local geology, and Google Earth Pro reveal this being an estimate of a recharge area is an underestimate; (a larger value for surface catchment area would collect more annual rainwater volume, therefore using the following 50 acre estimate for a smaller catchment area is conservative).

The annual rainfall depth versus altitude estimated by Davisson and Rose (2000) for the nearby Fenner Valley would give a value of about 110 mm for the 641 m elevation of Bonanza Spring Using 110 mm (0.36 ft) for the estimate of annual volume of water over the minimum catchment of 2,178,000 ft^2, the volume of potential annual input would be 748,080 ft^3, more than enough to supply spring flow to Bonanza. If a less conservative four year average precipitation of 130mm (5.12 inches/yr) for the Clipper Mountains near Bonanza Spring, actually measured and reported by Rose (2017), is used in the same calculation, the potential average rainfall annual input to the smaller, less likely recharge area would be about 884,095 ft^3/yr, or over 125% of what would be needed to supply high spring flow at Bonanza, and over 200% of what would be necessary to supply the lesser spring flow for **both** upper and lower Bonanza reported by Andy Zdon and Associates (2016). This measured average rainfall input would be over 12.5 times the water input necessary to supply the smaller flows observed by several researchers at Bonanza Spring, and if a more probable, larger recharge area was used for this calculation, the surplus water potentially supplied to the spring would be even greater. It should be noted that this excess in water supplied to the catchment by rainfall relative to spring flow does not account for some abstraction by evapotranspiration, which varies greatly seasonal and with elevation throughout the Mojave Desert.

Importantly, it should be noted that Zdon et al. (2018) do not robustly consider the possibility of a local recharge area including the Clipper Mountains at topographically higher elevations directly up gradient from the spring, (other than the very small, restricted area they define as the approximate 50 acre, surface water catchment area). They state, *"In the case of Bonanza Spring, the assumption of local recharge is problematic in that this model requires very slow movement of groundwater from the point of recharge to the spring given the small watershed. For example, the distance from the crest of the watershed to the source is approximately 1,000 feet."* However, it is very likely that the groundwater recharge area supplying the Bonanza Spring is much larger than the small, immediate surface watershed catchment noted in the manuscript. The fractured volcanic geology, local surface topography, and stable isotopic values suggest that this probable, potentially larger recharge zone would be topographically, directly up-gradient in the Clipper Mountains above the spring's surface catchment.

The authors of the manuscript do not rigorously address this likelihood of nearby recharge in the Clipper Mountains immediately up gradient of the Bonanza Spring surface catchment area. Their speculation that recharge occurs in the distant New York or Providence Mountains leaves only two very unlikely possibilities – that either recharge in these far flung ranges comes directly south or southeast through Lanfair and/or Clipper valley alluvium and then flows through the bulk of the Clipper Mountain massif to Bonanza Spring (a possibility which they themselves partially discount), or alternatively flows into the alluvium at the base of these distant ranges into the Fenner Valley, winding a tortuous pathway as much as 50 miles plus, and then is somehow pumped over a thousand feet vertically upward to Bonanza Spring.

Major Ions

Zdon et al. (2018) presents a Piper diagram of regional waters including selected springs, USGS wells, and Cadiz wells, showing the measured major ion aqueous chemistry of those sources. Trace element analysis of the waters was not reported. The authors state, *"Spring water at Bonanza Spring is a Na-HCO3 type (this is consistent with water at Lower Bonanza Spring as well). This is similar to most waters in the region except those waters at Hummingbird Spring (Ca-HCO3 type)."* Inspection of these data reveal that Bonanza Spring is dissimilar in its major ion chemistry from any well water sources, which primarily draw water from basin fill environments. This is particularly true with regard to major cations. The waters of Bonanza Spring are uniquely different than the surrounding regional well water with less than half the dissolved calcium of any well in the area and in some cases more than 4.5 times less. This difference is not supportive of the opinion put forth in Zdon et al. (2018) that Bonanza Spring issuance has a similar source to basin-fill well water and Cadiz wells.

The discussion in Zdon et al. (2018) on this topic includes the statement *"The Bonanza Spring water is also similar in type to waters from the basin fill in the Fenner and Cadiz Valleys..."*.

The actual concentrations of major and minor constituents are not provided for the reader's review. Independent analysis of Bonanza Spring samples, collected February 2013 and March 2018 do show that the most abundant cation and anion are sodium and bicarbonate, respectively, similar to most basin fill well samples in the area. However, a sodium-bicarbonate chemistry is a generally common chemistry given the compositions of both local and regional source rocks, and therefore does not necessarily link the spring water to a regional source. Closer examination of the Bonanza Spring chemistry shows that this spring (and the associated Little Bonanza Spring) has a significantly higher sodium percentage than any of the other samples, as shown in the Piper diagram on Figure 4, and from other available well data surveyed among Fenner Valley and Cadiz Valley. The sulfate percentage for Bonanza Spring (approximately 30% of anions from Figure 4) is also higher than all nearby springs and wells.

Independent data from Bonanza Spring show the water to be undersaturated with respect to calcite, while all other regional aquifer groundwater samples from Fenner and Cadiz Valley show saturation with this common mineral. This characteristic further supports the Bonanza Spring water reflecting a more localized source, such as the calcite-poor rocks of the Clipper Mountains.

The notably high percentages of sodium and sulfate in Bonanza Spring, along with its undersaturation with calcite, suggest a more localized source rather than a regional source, since this combination of major ion chemistry does not appear in wells of the flow regime proposed by the authors.

Trace Metals

The authors mention that trace metal analysis was carried out but no results are reported. Sample preparation was made by addition of nitric acid, but sample filtration and use of ultra pure nitric acid, which is necessary for trace analysis, is not mentioned. Trace element analysis has proven useful in source analysis of springs in Death Valley (Kreamer et al. 1996). Why the results of trace analysis were left out of the Zdon et al. (2018) publication is not explained.

Stable Isotopes

Zdon et al. (2018) presents stable isotopic data showing aqueous hydrogen and oxygen at Bonanza Spring is uniquely different than any other spring they evaluate regionally (Figure 8). The isotopic signature is lighter (more negative) at Bonanza Spring (δD -82.1, $\delta^{18}O$ -10.25) which typically indicates water is sourced from a colder and/or higher elevation source. Surprisingly, the authors attribute this to a recharge source considerably distant (20 to 45 miles) to the north and northwest, the Providence and New York Mountains, and not to the surrounding Clipper Mountains where Bonanza is located. The authors do note, however, that previously a different assumption was made (including by one of the co-authors of Zdon et al. 2018): "*Of note is that Davisson and Rose (2000) assumed the local catchment for Bonanza Spring as being the whole of the Clipper Mountains although this is very unlikely as it would require substantial volumes of water to flow laterally across the distant range-front of the Clipper Mountains and across several geologic northwest-trending geologic structures, instead of following the path of least resistance down-slope toward the basin fill.*" The Clipper Mountains surround the spring rising up several thousand feet higher to the north (with the spring downslope), are in close proximity and receive substantial rainfall, but the authors speculate that the spring water is sourced instead tens of miles away in more distant ranges.

The time and date of this single isotopic spring measurement in Zdon et al. (2018) was not recorded in the manuscript, nor is there any mention of the number of duplicate samples, traveling spiked standard samples or field (trip) blanks. The exact location of the sampling point is not mentioned (fractionation could occur along the long surface flow between Bonanza Spring and lower Bonanza Spring), preceding precipitation is not mentioned, and many other factors associated with the stable isotopic measurement are not reported in the manuscript, making further interpretation difficult. Of note is some supportive evidence - Bonanza Spring was also sampled by T.P. Rose (2017) on 2/2/2000, finding stable isotopic values of δD -83.1, δ^{18}O -10.65, similar to those reported by Zdon et al. in their present publication.

Without discussion or justification Zdon et al. (2018) state, *"isotopic signatures of precipitation collected in the Clipper Mountains are much higher than those at Bonanza Spring (Rose, 2017)."* The authors use this statement as part of a justification to exclude the adjacent, upgradient Clipper Mountains as potential recharge areas contributing to Bonanza Spring discharge. Inspection of the data from Rose (2017) does not support the authors' assertion.

The authors state that precipitation measurement in the Clipper Mountains are isotopically heavier and infer that this invalidates these surrounding mountains as a recharge source, supplying the Bonanza Spring. As noted in Zdon et al. (2018), these same stable isotopes of hydrogen and oxygen were measured in precipitation near Bonanza Spring from 2001 to 2005 by T.P. Rose (2017) (labeled "Clipper Mountains"). According to the latitude and longitude given, the sampling point was approximately 1000 ft north of the spring and about 300 ft higher in elevation. The "winter" (October to April) precipitation measured by Rose accounted for about 79% of the yearly rainfall summed over those years and ranged in isotopic values from δD -59.3 to δD -91.0, and from δ^{18}O -7.2 to δ^{18}O -12.6. When these values are weighted with the seasonal rainfall for each individual year, the weighted "winter", October to April, 6 month averages are δD -77.55, and δ^{18}O -10.75. These delta values are very close to the values recorded in nearby Bonanza Spring discharge by Zdon et al. 2018 (δD -82.1, δ^{18}O -10.25), indicating that the spring could very well be in large part fed by local recharge in the Clipper Mountains.

Because winter temperatures are significantly cooler in the Mojave Desert compared to summer temperatures, evaporation from soil and transpiration rates from plants are appreciably less in the winter months, and a larger proportion of the precipitation is available in the winter for aquifer recharge compared with summer. According to Neff et al. (2017), *"Contributions of winter precipitation to annual recharge vary from 69% ± 41% in the southernmost Río San Miguel Basin in Sonora, Mexico, to 100% ± 36% in the westernmost Mojave Desert of California."* According to these authors winter precipitation makes up the majority of annual recharge throughout the region, and North American Monsoon (NAM) precipitation has a disproportionately weak impact on recharge. Zdon et al. (2018) apparently agree, citing studies by Freidman et al. (1992) and stating: *"Accordingly, the implication is that spring water sources in the Mojave reflect less of a mean annual precipitation source, but rather wintertime precipitation having the greater influence overall."*

The less effectual "summer" (April to October) precipitation measured by Rose over those years accounted for about 19% of the yearly summed rainfall over that time, not counting abstraction during the hotter months through evapotranspiration. As could be expected, "summer" precipitation values were heavier during the months of April to October, and ranged from δD 5.3 to δD -51.0, and from δ^{18}O 9.3 to δ^{18}O -7.2. The heaviest isotopic values were observed in the extremely dry 6-month "summer" period of 2002. In that year the location only received 0.23 inches of rain over the 6 months of April to October. Conversely, the lightest isotopic values occurred in the 6 month "summer" period that received the most rain (2.99 inches) in 2004. When these values are weighted with the seasonal rainfall for each year, the weighted average "summer" averages were δD -37.9, and δ^{18}O -4.7. These "summer" values probably have de minimis effect on groundwater, as recharge is likely dominated by winter precipitation which has stable isotopic delta deuterium and delta oxygen-18 values very similar to water issuing from Bonanza Spring, indicating that the Clipper Mountains are a likely recharge source.

Zdon et al. (2018 state, *"isotopic signatures consistent with past studies…indicating waters derived from sources north of the Clipper Mountains such as the New York Mountains or Providence Mountains"* Similarity of two deuterium samples from Bonanza Spring to those of selected well samples from regional fill aquifers several miles to the north does not constitute proof of the spring having a regional source. This must be supported by hydraulic evidence and a more complete isotopic data set that accounts for seasonality and spatial distribution of rainfall.

Tritium (^{3}H)

Tritium Analysis was conducted on selected samples in Zdon et al. (2018) and the manuscript states, *"Tritium (^{3}H) analysis was conducted using the tritium enhanced enrichment (TEE) method to obtain lower reporting limits."* The authors also state that, "*^{3}H was not detected at reporting limits of 0.56 TU in the water samples from Bonanza (and Lower Bonanza) and Hummingbird Springs*." The only laboratory for isotopic analysis mentioned in the manuscript is Isotech Laboratories for stable isotopic analysis. On the Isotech website, it is reported that they conduct liquid scintillation counting with or without electrolytic enrichment, having a detection limit of 1 Tritium Unit (TU), not 0.56 TU. Tritium electrolytic enrichment available at Isotech Laboratories, called "enhanced enrichment (TEE)" in the manuscript, allows lower reporting limits. Because the laboratory for tritium analysis was not specified in Zdon et al. (2018) and because of the discrepancy in detection limits, it is slightly unclear which laboratory was used for tritium analysis, nor is the number of duplicates, spiked samples, field or laboratory controls, or chain of custody procedures specified in the publication. Sampling dates, times, exact locations, antecedent rainfall are also not specified in the manuscript.

The lack of detection of ^{3}H in Bonanza and Lower Bonanza Spring indicates that the average residence time for groundwater emerging at the springs is more than 65 years. These data are not incompatible with flow from fractured Tertiary volcanic rocks immediately upgradient of the surface water catchment for these springs, in the Clipper Mountains. Flow through fractured rock can include not only fracture flow, but matrix flow which has much longer average residence time. A combination of slow flow through the vadose zone, and consequent imbibition of water into the rock matrix during groundwater flow can extend average groundwater travel and residence time, and is consistent with the geological materials upgradient of the catchment area of the springs in question. Geologic data indicate that the recharge area for the spring is much larger than the topographic surface drainage area. Tritium ages exceeding 65 years are common in saturated fractured media, which contains a mixture of transmissive fractures and very narrow micro-fracture networks that can have very slow transport velocities.

Conclusions

The publication by Andy Zdon, M. Lee Davisson and Adam H. Love (2018), "Understanding the source of water for selected springs within Mojave Trails National Monument, California," published in Environmental Forensics, 19:2, 99-111, is an interesting study of selected spring flow in the Mojave Desert, but suffers from critical weaknesses which undercut and invalidate some of the conclusions of the paper. The Zdon et al, (2018) publication speculates that, , "*Future groundwater development in the region, should it occur, should be cognizant of the likelihood of a hydraulic connection between recharge in the Fenner Valley, and Fenner Valley itself with Bonanza Spring. Based on the existing source characterization of Bonanza Spring, a reduction in groundwater level could result in an uncertain, but potentially substantial decrease in free-flowing water from the spring source*." This statement is directly contradicted by available spring temperature and flow data, the concentration of major ions in spring water, stable isotopic data, and the geological environment surrounding the spring. Zdon, Davisson, and Love do not deal with or present any physical hydrogeology (numerical modeling, geologic cross sections etc.) to demonstrate there is any hydraulic connection between the alluvial aquifer and the spring, and the data indicate otherwise.

In particular, the publication only makes general statements on the geological setting, location of faults, and the hydrogeologic environment, without complete referencing or justification. The exact sample locations, times, dates, number of samples, measurement error bars, ambient air temperatures, antecedent rainfall, and other important factors which could influence results are not documented in the publication. The number of duplicates, spiked samples, field or laboratory controls, or the chain of custody procedures are not specified. Incomplete data on water temperature and spring discharge is presented, whereas on the other hand, more complete data sets available elsewhere are inconsistent with the authors' conclusions. The stable isotopic precipitation values from the "Clipper Mountains" in a previous study are mischaracterized in this publication as "high" which is key in the authors' misinterpretation of groundwater recharge potential in the Clipper Mountains. Some data, such as trace metals which were collected and analyzed, are not reported. Divalent calcium cation concentrations, and sodium and sulfate concentrations, which exhibit significantly different values between Bonanza Spring and other springs and well water, are not addressed or explained by the authors.

Bonanza Spring is clearly a precious resource in the region and must be protected. However, the omission of data, and misinterpretation of hydrogeology based on selective information, lead the authors of the manuscript to dubiously ascribe groundwater recharge which sustains this spring to far-flung areas. The questionable speculation in the Zdon et al. (2018) manuscript, that recharge occurs in the distant New York or Providence Mountains, then moves tens of miles through basin alluvium and perhaps the whole of the Clipper Mountain massif, and then perhaps resurges upward over a thousand feet through undefined mechanisms, is inconsistent and incompatible with the field evidence. They do not rigorously address the likelihood of nearby recharge in the Clipper Mountains immediately upgradient of the Bonanza Spring surface catchment area. These closer, sustainable recharge sources for Bonanza Spring in the Clipper Mountains are the most probable explanation of subsurface flow and is consistent with published, investigatory results. The nearby upgradient recharge sources in the Clipper Mountains that supply the spring would, in all likelihood, be unaffected by pumping activity in wellfields screened in basin fill sediments thousands of feet lower and many miles away. Recharge sources in close proximity to the spring catchment and upgradient are the most credible hydrogeologic interpretation within a reasonable degree of scientific certainty.

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