

Are springs and tinajas in Saguaro National Park threatened by groundwater withdrawal outside the park?



Geoscientist-in-Park Guest Scientist, Courtney King, at a perennial tinaja in Wildhorse Canyon, Rincon Mountain District, Saguaro National Park

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Abstract

Because surface water in the desert is so important for both people and wildlife, Saguaro National Park and science partners have been studying the park's intermittent streams, springs, and spring-fed stream pools called *tinajas* for more than 10 years. A recent analysis of groundwater chemistry suggested that the source of water in some springs and tinajas could be mountain-block scale water-bearing zones along which water flows downward from upper elevations until it is ponded at the base of the Rincon Mountains behind the Catalina detachment fault. The water trapped below the fault extends beyond the park boundaries into areas that are subject to active groundwater pumping. The purpose of this study was to better understand the chemistry, origins, and hydrologic relationships of the park's surface waters. We selected >20 perennial tinajas and springs for water chemistry and isotope analysis based on their geological and hydrological properties and compared their signatures to those in local aquifers.

Results suggest that the source of water for these sites varies in both time and space. We found strong evidence that base flow into some tinajas during the driest months of the year is from a combination of local alluvial and near-surface bedrock sources as well as older, regional water from deeper within the Rincon mountain block. A fault associated with the Catalina fault, the Javelina subdetachment fault, appears to be critical for maintaining water in many low-mid elevation tinajas through the driest seasons. Chemistry data suggests that there is some potential, but not conclusive evidence, that base flows could be impacted by groundwater pumping outside the park. We make specific and general recommendations for sampling that may resolve this question and future hydrogeological investigations that would benefit Saguaro National Park. We recommend that the park participate in long-term efforts to protect regional water resources in the face of Tucson's growing population, rising temperatures, and changing precipitation regimes. We produced a Visitor Center interpretive video about water in the park and are developing a second video on the importance of water chemistry and geology in conservation.

Introduction

Information gathered over the past two decades with support from WNPA (Swann et al. 2008, Wallace et al. 2010), the Friends of Saguaro National Park, and scientific partners from the University of Arizona (UA) and US Geological Survey (USGS), have revealed the value of springs and spring-fed stream pools (locally known as *tinajas*) for wildlife in Saguaro National Park (e.g., Zylstra et al. 2015). The data also suggest that for some of these surface water sources, the base flow – water that is critical for wildlife during the driest times of the year – may originate in mountain-block scale water bearing zones that could be vulnerable to the effects of groundwater overdraft (Filippone 2017).

It is difficult to not be amazed by desert waters, which are often hidden in deep pockets and seem to appear randomly on the landscape. In Saguaro National Park, which is 78% roadless Wilderness, these natural sources are essential for hikers and campers to replenish water during long hikes. In addition, many species of animals depend on surface water, including both aquatic species such as lowland leopard frogs (*Lithobates yavapaiensis*; Zylstra et al 2015) and many birds and mammals that must drink regularly. Because water is so essential for life, park staff have made a concerted effort to better understand its origins and dynamics, while engaging the community to help to better protect it for future generations.

Water that appears at a given location on the earth's surface may arrive there through a wide variety of pathways. Understanding these pathways can reveal how the water is connected both above and below ground, and often has important conservation implications. For example, in Mammoth Cave National Park, monitoring and research revealed that the cave's water is connected to wastewater systems in nearby towns, which led to development of a new regional sewage system that would better protect park resources (Alexander 1996). An important tool that can be used to determine these links is analysis of the water itself. The amount of dissolved ions such as calcium and sodium reflect the travel time and distance as well as types of rocks or soil the water has flowed through before reaching the surface, and can help identify different "types" of water in an area. Also important for understanding water origin are ratios of elemental isotopes. For example, oxygen molecules in water include the more common "light" oxygen ($\delta^{16}\text{O}$), with 16 neutrons and protons, and the less-common "heavy" oxygen ($\delta^{18}\text{O}$). Because the ratio of these two isotopes varies in precipitation, with more light oxygen occurring in snow and ice and at higher elevations, it can be used in combination with water's hydrogen isotopes to help determine in the season when the water originally fell to earth. Tritium, a radioactive isotope of hydrogen, naturally occurs in very low amounts in the environment but was released in larger quantities during atmospheric atomic bomb testing in the 1950s. Because it has a very predictable half-life, tritium can be used to determine *when* the water fell as rain since the 1950s, and can also identify waters that pre-date that period. Additional valuable information can be gleaned from isotopes of other elements found in water, such as sulfur and carbon.

The goal of this project was to analyze water from sources in Saguaro National Park for isotopes and ion chemistry and compare them with previous studies of water in and near the park. Since previous experience indicates that the seasonal timing and collection methods are critical to maximizing the value of the results, sampling was very carefully planned and implemented. We hoped to use these data to better understand the origin and relationship of the park's waters and determine whether base flow into springs and tinajas could be compromised by groundwater withdrawal outside the park. Pearl et al. (2018) provides further details of our results.

Field Methods

We selected study sites based on location, geology, hydrology, size, and history of water presence during the dry season (Fig. 1). We sampled from low elevation springs and tinajas (<1400m) on or near the mapped or inferred subdetachment faults and older faults that crosscut the fault zone near the base of the Rincon Mountains (Davis, 2013, Force, 2002, Miksa, 1993). We sampled only from tinajas with bedrock basins (i.e. no direct connection to alluvium), outflow with no obvious stream inflow, and of reasonable size to completely bail out. We also considered their perennial nature, vulnerable aquatic species, and anticipated ability to recharge at a rate exceeding evapotranspiration. We utilized over 20 years of survey data for threatened leopard frogs (Zylstra et al. 2015) to select the most perennial pools while ensuring minimal impact to the aquatic ecosystems (e.g., by not sampling from pools containing leopard frogs).

Because we were interested only in groundwater inputs to springs and tinajas, and because nearly all of these features in the park are associated with ephemeral or intermittent stream drainages, we typically collected samples (Fig. 2) during the very dry months of late May- June, when low elevation streams are not flowing. The one exception was a single tinaja in Loma Verde drainage (LV3), which we sampled in February, March, April, June, and during a July rain event as a case study for understanding seasonal changes in water chemistry at a single location. To avoid false

isotope values and misleading chemical composition due to evaporation and source mixing, all springs and tinajas were completely emptied of water and sediment, then allowed to refill over a period of no longer than two days (but usually only a few hours) before collection. Any wildlife (typically aquatic insects) were moved to adjacent pools or held briefly in buckets and returned to the pool. Because samples collected prior to 2016 were not bailed prior to collection, those data are potentially compromised by surface inflows and evaporation and are only included in this study for comparative purposes.

After the target tinaja was emptied and refilled with groundwater, we collected water in four sterile 500ml bottles for ion chemistry, and a fifth bottle for stable isotope and tritium analysis. The samples were placed in an insulated bag for the hike out and then deposited in a repository refrigerator. All samples were tested for ion chemistry (Na, Mg, Ca, F, SO_4^{2-} , NO_3^- , HCO_3^- , CO_3^{2-} , pH, total dissolved solids, and specific conductance by the Test America facility in Phoenix, and for stable isotope composition ($\delta^{18}\text{O}$, δD , $\delta^{34}\text{S}$, $\delta^{18}\text{O}$ of sulfate) and tritium by the UA Environmental Isotope Laboratory. To compare our samples with other representative samples, we accessed a large collection of data from springs and groundwater wells in and around Saguaro National Park (Filippone 2017; Eastoe 2004; Eastoe 2012). Based on a thorough review of the literature of local groundwater (see Pearl et al. 2018), we analyzed isotopic values with simple comparisons (as performed by Olson (1982) and Gu (2005)). Chemistry data was treated similarly, principally comparing ion composition against total dissolved solids (TDS).

Results

Isotopes. We collected 20 samples during 2017-2018 for isotope analysis. Water associated with the Santa Catalina detachment fault (hereafter, “detachment water”) typically has low values of $\delta^{18}\text{O}$ (oxygen) and δD (deuterium, an isotope of hydrogen). Detachment water has $\delta^{18}\text{O}$ values less than -9‰, and distinctly plots below the standard Global Meteoric Water Line (GMWL; Eastoe, 2012; Gu, 2005; Olson, 1982) for both values (Fig. 3). In our study only one sample from the Grotto in Rincon Creek (-9‰ $\delta^{18}\text{O}$), had values in the detachment range. A second pool in Loma Verde Creek (pool AV5) has low δD , but a $\delta^{18}\text{O}$ value that was well above other detachment samples. All other samples had high values of both δD and $\delta^{18}\text{O}$.

Detachment water is also characterized by high values (6-10‰) of $\delta^{34}\text{S}$ (sulfur), low values of $\delta^{18}\text{O}$ of sulfate, and tritium values less than 0.8 (tritium units; TU; Fig. 4). As of this writing, 2018 samples of $\delta^{18}\text{O}$ of sulfate and $\delta^{18}\text{O}$ have not been analyzed because the UA runs these samples infrequently; we hope to have results in <3 months. For tritium, park sites with low values include Douglas Spring (<0.8TU), Grotto#1 in Rincon Creek (0.3TU), and Loma Verde 3A (0.9 TU). The low tritium value in Loma Verde 3A is accompanied by $\delta^{18}\text{O}$ of sulfate less than 7‰ (Figure 4) and high $\delta^{34}\text{S}$ values above 7‰, all of which is consistent with detachment related water. However, most other samples from this study have $\delta^{34}\text{S}$ values of approximately 5‰, and high values of $\delta^{18}\text{O}$ of sulfate, which are not consistent with detachment water.

Ion chemistry. Olson (1982) stressed the importance of high total dissolved solids (TDS) as a identifying feature of detachment related water, and Gu (2005) identified detachment related water as having high sodium and sulfate, as well as high fluoride concentrations (Fig. 5). We collected 20 samples during 2017-2018 for ion analysis, using sodium and sulfate as the distinguishing identifiers for the potentially detachment related samples, in addition to TDS.

Previously identified detachment waters have TDS values well over 500 mg/L. In this study, values from 4 sites (Loma Verde 3, Upper Wildhorse, Steel Tank Seep, and Rincon Pool B) had values over 300 mg/L. However, surface water from Loma Verde drainage typically has high TDS of 290 mg/L, which complicates interpretation of these data.

For most sites in both the current and past studies we found strong linear relationships between TDS and sodium, bicarbonate, calcium, magnesium, potassium, silica, and chlorine. In contrast, detachment waters do not follow a linear relationship: they are positively removed from this linear trend for sodium, sulfate, and silica, and negatively removed from the linear trend for bicarbonate, calcium, and magnesium. Fluoride has an exponential relationship with TDS, with detachment water falling within an exponential fit. Potassium, which is sourced from local rock weathering, has a broad spread of values with a weaker linear trend than other ions. Overall, ion chemistry results do not indicate a strong relationship of park tinajas with detachment water.

Loma Verde case study. Water samples collected throughout the year from LV3A in the Loma Verde drainage provide insight into how water chemistry and isotopic signatures may vary seasonally. This small tinaja is located in the zone of the Javelina subdetachment fault (Force 2002) and was previously identified as having common ion abundances and low tritium levels similar to detachment water (Filippone 2017). Our six samples varied greatly in sodium, sulfate, calcium, and fluoride, with concentrations increasing in the groundwater entering the tinaja as the input from local groundwater sources (alluvium and shallow fractures) is presumed to cease. In the very dry month of June, the water chemistry was compellingly close to that of detachment water, with high levels of characteristic ions such as fluorine, sodium and sulfate. However, the June data fell within the linear relationship of calcium and TDS, unlike typical detachment water, providing contrasting evidence that the LV3A samples high in calcium may not be detachment related. In contrast to ion chemistry, the isotopic composition of water in LV3A remained relatively similar throughout the year, with $\delta^{18}\text{O}$ values of $-5\text{‰} \pm 0.25\text{‰}$, $\delta^{18}\text{D}$ values of $45\text{‰} \pm 1\text{‰}$, and $\delta^{34}\text{S}$ values of $8\text{‰} \pm 0.25\text{‰}$. The $\delta^{18}\text{O}$ of sulfate had the largest range, with low values in March of 4.4‰ , and high values in April of 6.2‰ (June LV3A was not tested for $\delta^{34}\text{S}$ or $\delta^{18}\text{O}$ of sulfate).

Discussion and interpretive products

Understanding the sources, origins, and connectivity of water sources is essential for water conservation in arid ecosystems such as Saguaro National Park. However, collecting the proper samples from dynamic surface water sources such as springs and rock pools is complicated. Water that appears in a particular spring or spring-fed tinaja typically includes a mixture of both surface flow and groundwater that is often highly evaporated. By collecting samples of pure groundwater during the driest times of years in this study, we were able to gain insights into these groundwater sources. However, it is challenging to collect samples at exactly the right time, when streamflow into the pool has ceased, but outflow indicates a groundwater source. In addition, our results from Loma Verde 3A indicate that the groundwater itself changes seasonally. Figure 7 is a conceptual diagram of the seasonal changes in water sources that may occur in a tinaja: 1) water entering directly or indirectly as rain during the monsoon season (July) and winter (February); 2) streamflow during wetter months, typically in winter and summer; 3) modern water stored in local alluvium and 4) small bedrock fracture networks after streamflow ceases; and 5) water circulating deep within the mountain block. All five types may

occur during wet periods, when the water is dominated by streamflow; but during the driest month only mountain block water may be present. This conceptual model is supported by water chemistry results (Fig. 6) that shows higher concentrations of key ions in groundwater collected in the driest month of the year.

We emphasize that some tinajas may not receive water from any groundwater sources, while only a small percentage may receive deeper groundwater from the mountain block. The detailed chemical and isotopic results of our study, placed in the context of other data from wells that are known to draw water associated with the Catalina detachment fault, provide evidence that water found in some perennial tinajas is very old and has likely flowed along long, complex pathways. However, only two tinajas, the Grotto in Rincon Creek and Loma Verde 3A, show strong characteristics of detachment fault water based on a range of isotopes and ion analysis. Even in these sites, the evidence suggests that detachment water may be mixed with more modern water – suggesting that the answer posed in the title of this project is, “probably not, for most low elevation springs and tinajas in the park.” That said, we recommend further testing of the Grotto and several other pools (identified in Pearl et al. 2018) to confirm that the connection between detachment water and water in springs and tinajas is weak and that these tinajas are not threatened by drawdown of the groundwater associated with the Catalina detachment fault.

Whether or not springs and tinajas in the park are vulnerable to groundwater withdrawal outside the park boundary, there are other conservation implications of our findings that some springs and tinajas are sourced by waters that are probably very old and have origins in deep fractures within the Rincon Mountain block. Long-term environmental changes upstream of these sources would affect both the quality and quantity of these waters. These changes may be occurring already, and include factors that lead to reduced infiltration, such as higher temperatures, reduced snowpack and fire suppression that leads to high-severity fires and extreme soil erosion. Factors which could diminish water quality include poor air quality with high levels of mercury and other heavy metals that make their way through the environment into groundwater.

In addition to recommending sites for further sampling, we suggest that the park pursue a broader research program aimed at a more comprehensive understanding of hydrogeology of the Rincon Mountains. The park has gathered enough preliminary data with interns and technical help from NPS hydrologists that a graduate study focused on this topic and supported by the USGS and/or UA has great potential for providing data that would help develop long-term strategies for protecting the park’s surface waters. In addition, we urge the park continue to engage with other organizations involved in water monitoring, water use and water conservation, especially agencies such as Pima County, utilities such as Tucson Water, and non-governmental organizations such as Watershed Management Group, to help support long-term water conservation in Tucson Basin. As both a water provider (that protects a large and significant watershed) and water user (by providing clean water for hikers and wildlife), the park’s involvement in regional water conservation protects its vital interests while serving the greater interests of the community.

With teacher-ranger-videographer Daniel Bell, we produced a video on water at Saguaro National Park as an interpretive product for this project. In addition, we gave a number of talks

on the park's water sources to park staff and the public, brought student groups into the field on water-related field trips, and produced social media content on water resource conservation.

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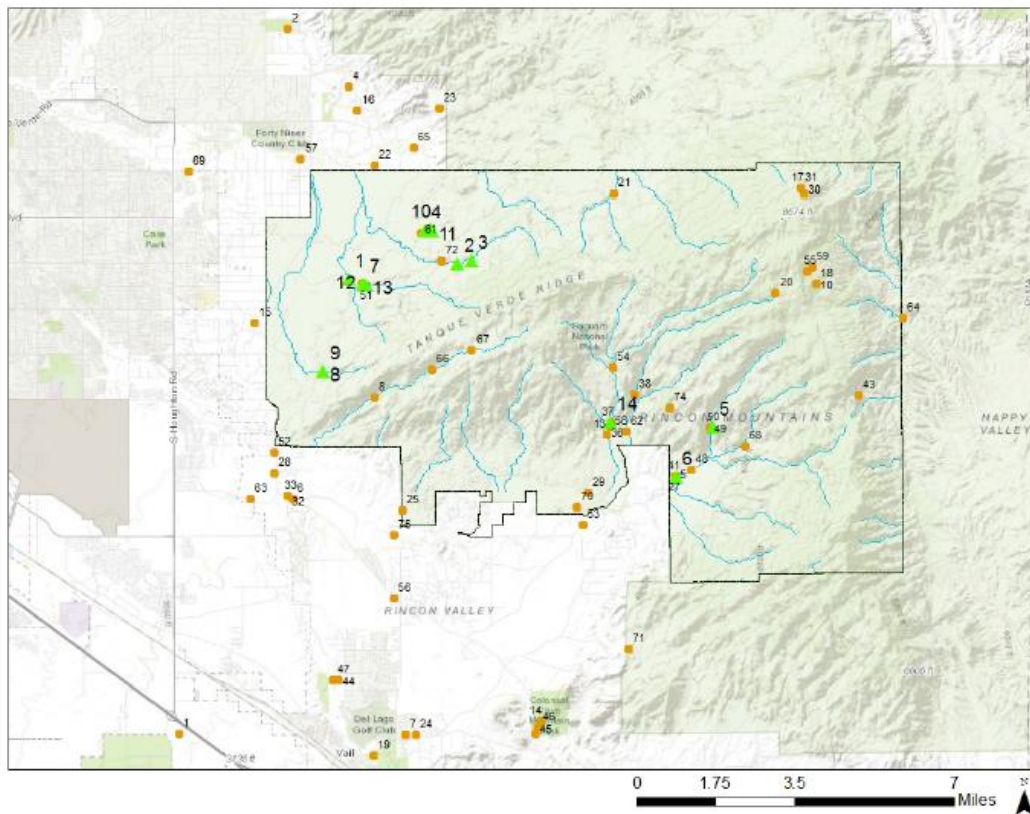


Figure 1. Sites of isotope water samples in and near Saguaro National Park, Rincon Mountain District. Blue lines mark main drainages. Orange squares are sites analyzed for isotopes in previous studies. Large green triangles are samples analyzed for isotopes in this study.



Figure 2. Geosciences-in-parks interns Courtney King and Jessie Pearl collecting water samples. Screen shot from interpretive video developed as part of project.

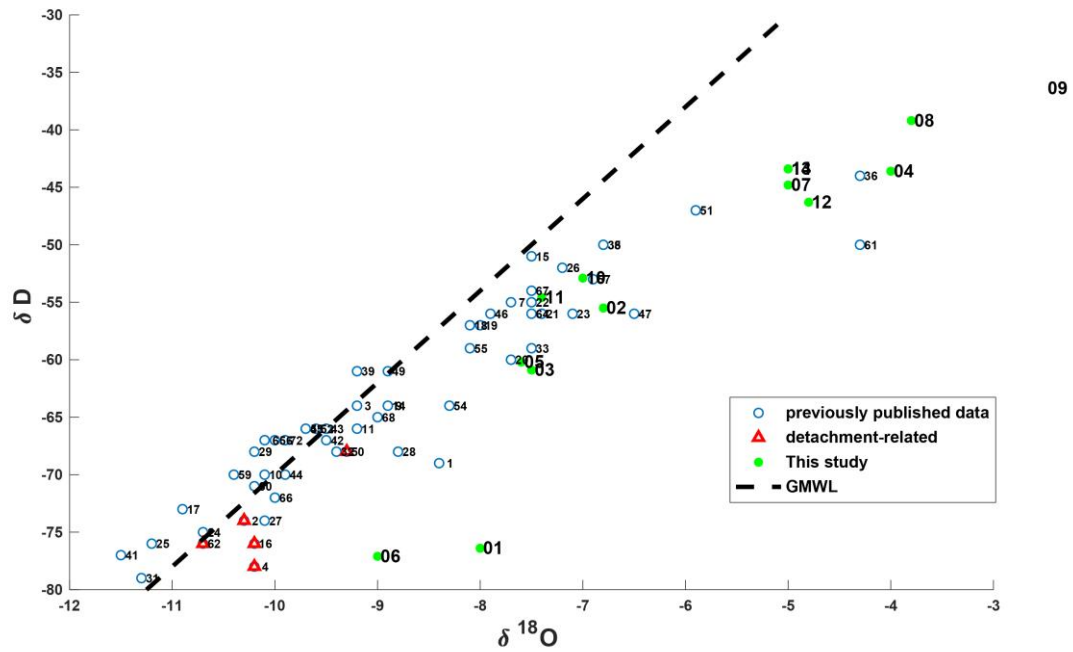


Figure 3. Scatter plot of $\delta^{18}\text{O}$ (oxygen) (vs. Standard Mean Ocean Water [SMOW]) versus δD (deuterium) (vs. SMOW) of published isotope values for Rincon Mountain District region (blue circles), water classified as detachment-related by Eastoe et al. (2004); Eastoe (2012) (red circles), and new isotope measurements (green circles; this study). Detachment fault water has low values of $\delta^{18}\text{O}$ and δD and plots below the Global Meteoric Water Line (GMWL).

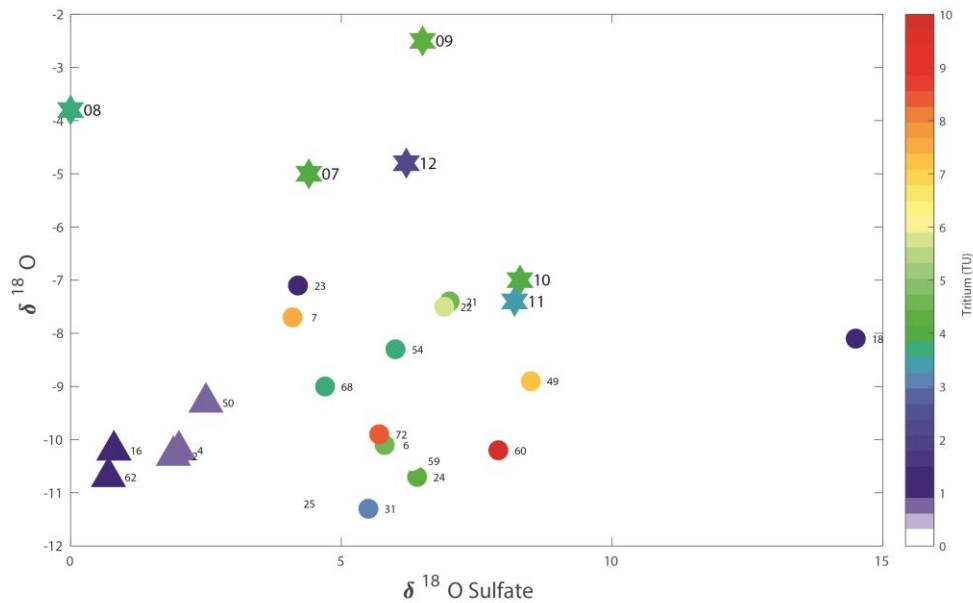


Figure 4. Plot of $\delta^{18}\text{O}$ from sulphate versus $\delta^{18}\text{O}$ (vs. SMOW) of sites within RMD (Eastoe et al. 2004; Eastoe 2012). The color of dot represents tritium units (TU). Samples from this study are marked as stars with larger numbers, and detachment water is marked at triangles. Tritium in samples from park suggests a mixture of older and newer waters, and with one exception (a tinaja in Loma Verde) have somewhat higher tritium values than detachment fault water.

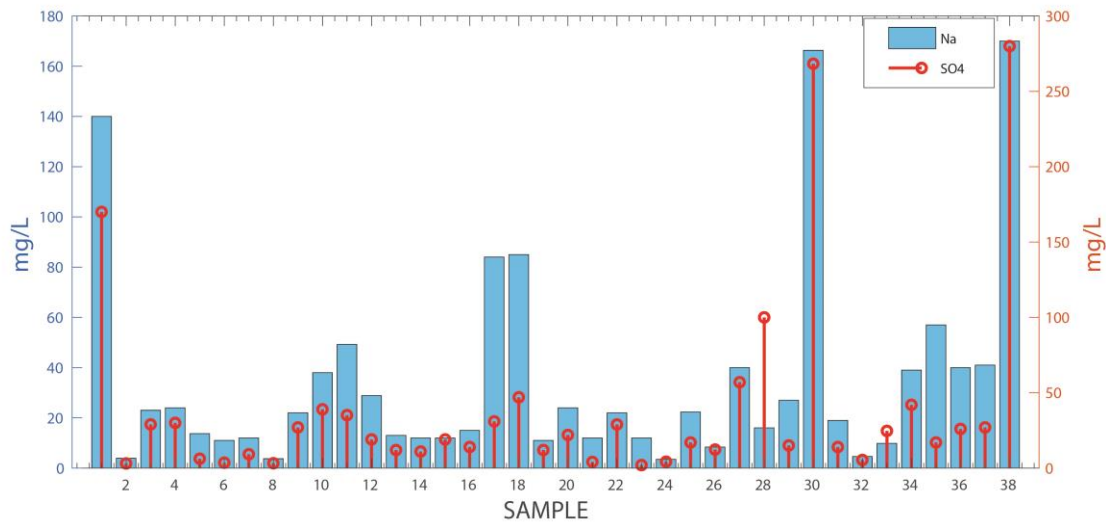


Figure 5. Sample values are of sodium (Na, left axis) and sulfate (SO4, right axis). High sulfate values are strongly associated with detachment fault. High sulfate values are found only in samples (1, 30, 38) taken of deep wells from outside park; no tinajas and springs had values above approximately 25 mg/L. High sodium values are from two tinajas in Loma Verde (17, 18).

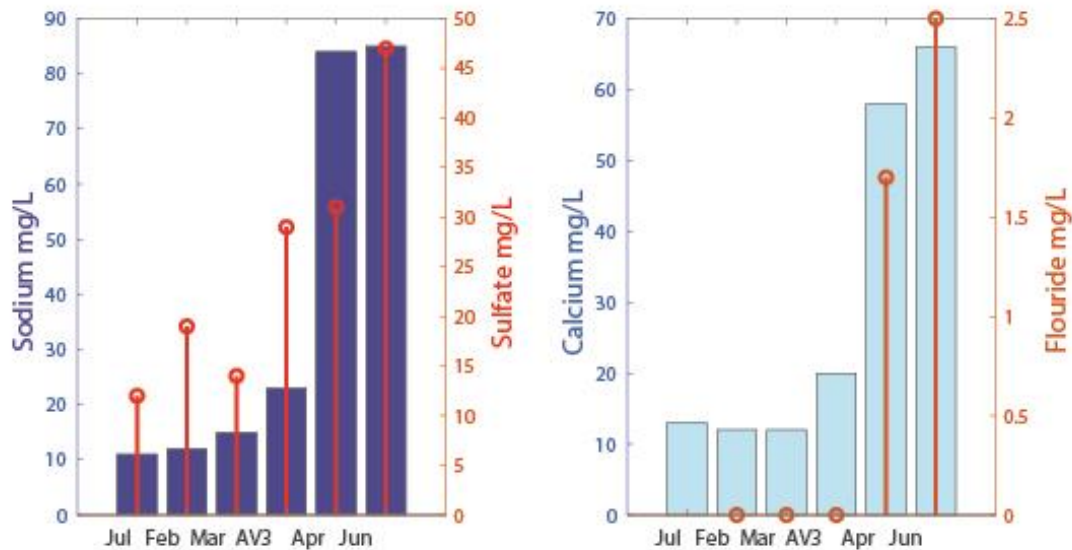


Figure 6. Time series of ion chemistry (sodium, sulfate, calcium, and fluoride) from small tinaja in Loma Verde Creek (LV3A). We removed all water from pool, then collected samples as it was refilled either from surface flow (July and February) or groundwater (March, April and June). High ion levels are associated with water that has moved through bedrock for long periods. Water chemistry generally supports the conceptual diagram in Figure 7 and suggests that after seasonal streamflow ceases, the major source water in the tinaja may be from local alluvial or bedrock aquifers. As these sources dries out, the major source is a deeper bedrock aquifer, possibly associated with the Catalina detachment fault.

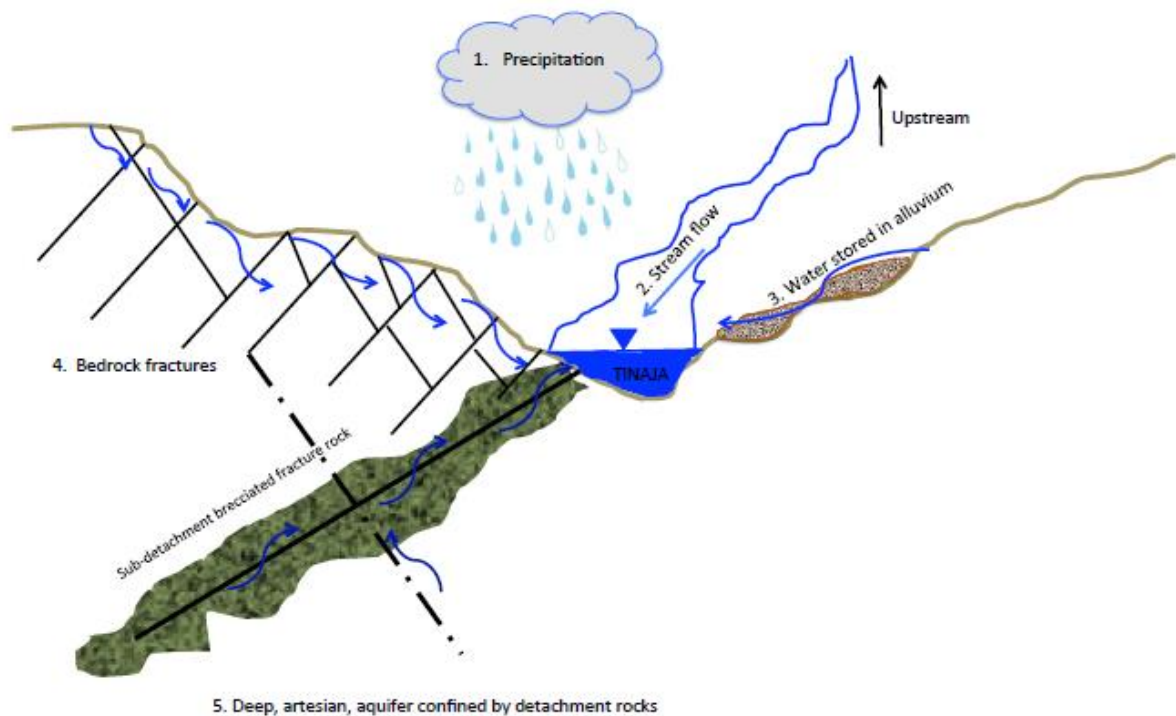


Figure 7. Conceptual model of sources of water for spring-fed *tinajas*. During wet periods, all five sources may contribute water to the pool: 1) direct rainfall; 2) seasonal streamflow; 3) alluvial groundwater; 4) bedrock groundwater from local sources; or 5) bedrock groundwater from mountain block. After streamflow ceases, the main source of water tinaja is likely groundwater that is temporarily captured locally in alluvium. When alluvial groundwater sources dry up, flow into the tinaja may be dominated by water captured in local bedrock fractures that may also dry seasonally; but for some tinajas that contain fresh water during the driest seasons, the base flow may be from an artesian aquifer deep within the mountain bedrock.