# GEOLOGIC CONTROL AND NITRATE LEVELS OF SPRINGS AROUND LAKE HAVASU, MOHAVE AND LAPAZ COUNTIES, ARIZONA, AND SAN BERNARDINO COUNTY, CALIFORNIA

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*Abstract*. Twenty springs in the Lake Havasu management area of the BLM have been evaluated for their geologic, biologic, and archaeologic characteristics. Water from active springs eventually flows into Lake Havasu or the Colorado River south of Parker Dam. This region is geologically complex, containing many rock types that have been subjected to tectonic extensional stresses. Springs emanate from rocks as diverse as gneiss, rhyolite, diabase, volcanic breccia, and fanglomerate. The geologic control for water migration at these springs falls into one of four conduit types: fault controlled, fracture systems within crystalline rocks, bedding contact between a more permeable layer and overlying impermeable layer, and crosscutting contact (dike intrusions). All springs lie within drainage channels seeping either from the channel walls or base. Some springs are perennial and some are seasonally active after a series of heavy precipitation events, indicating variations in residence times and extent of subsurface connectivity. Two springs were still inactive after several months of higher than normal rainfall in 2004. Total hardness content of spring water varies from 39 to more than 1200 mg/l, mostly as calcium. Caliche occurs as stains on bedrock or as accumulations of microcrystalline powder within alluvium at nearly all the springs. Unexpected elevated nitrogen-nitrate levels, as high as 24.7mg/l, are present in some of these backcountry spring waters. The source of the nitrate is speculative, but it may have been deposited by eolian action from playas to the west in the Mojave Desert.

## INTRODUCTION

Twenty springs located within the 1.5 million acre Lake Havasu field office area for the Bureau of Land Management (BLM; Figure 1) were investigated to determine water seepage, water quality, and geologic setting. Spring elevations range from 417 feet above mean sea level next to the Colorado River to 3587 feet in the Mohave Mountains. This area is located within the Lower Colorado River topographic low of extreme aridity. Annual average precipitation varies from 10 to 13 cm, almost all in the form of rain resulting from summer monsoon thunderstorms and winter frontal bands. Temperatures in the summer can reach over 52° C (125° F), making this area one of the hottest regions of the world. These conditions, coupled with typical spring flows no greater than a liter or two per minute, highlight the springs' importance to wildlife, and in the past, to Native Americans followed later by prospectors and ranchers.

The geology of the region is complex; however, studies have revealed that the region was heated from below starting about 20 Ma, swelling and stretching the middle and upper crust (Lister and Davis 1989; Nielsen and Beratan 1995; Miller and John 1999; Howard et al. 1999). Portions of the overlying crust, consisting of 1.4 Ga metamorphic rocks such as gneiss, uplifted and broke away from the highs to slowly slide downhill, creating low-angle normal faults known as detachment faults. In the process, small structural basins formed where conglomeratic sediments were deposited by streams. Fractures and high-angle normal faults within these basins created conduits for magma that erupted at the surface as ash and lava flows, forming small volcanoes and rhyolite domes. Beneath the surface, hundreds of diabase and dacite dikes intruded the metamorphic rocks (Howard et al. 1999). These events ended about 8 Ma and the Colorado River carved its way through this region about 5 Ma (Howard and Bohannon 2001), helping to create the present landscape and exposing many of the rocks created earlier. Springs issuing from these rocks today indicate that at least some faults and fractures are still conduits for local and watershed-scale groundwater flow.

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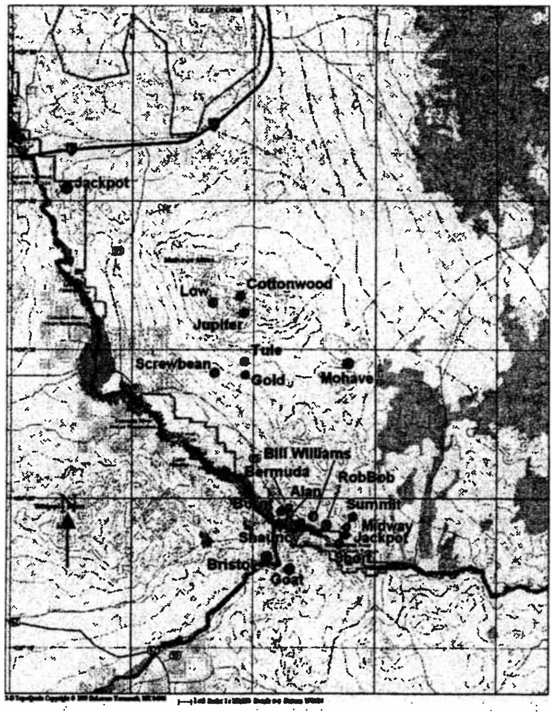


Figure 1. Locations of springs near Lake Havasu along the Arizona-California border that were evaluated for their geologic occurrence and water chemistry.

## METHODS

Individual spring sites were evaluated by mapping the geology of the area immediately around the spring, giving particular attention to the geologic control of water flow. Soil and water samples were taken where possible for laboratory chemical analysis. Water chemistry parameters measured include pH, hardness, alkalinity, TDS, dissolved oxygen, phosphates, and nitrates. Initial tests were performed using Hach calorimetric water test kits and a Corning Checkmate II 6-parameter probe. Subsequent nitrate testing was outsourced to state-certified laboratories for collaboration of the calorimetric results.

### Geologic Control

Miocene volcanic and sedimentary rocks occur at the lower elevations around Lake Havasu and the lower Colorado River (Howard et al. 1999). Cretaceous to Miocene igneous bodies have intruded Proterozoic metamorphic rocks of the higher elevation mountain cores. Springs can be found in nearly all these rock types at the bottoms or side walls of washes, where either faults, fracture systems, or bedding planes intersect the surface or where diabase dikes cut across fractured gneiss or rhyolite (Figure 2). These types of springs are collectively grouped as depression springs, as they occur in drainage channels (Fetter 2001). A transmissive fault at Jackpot Spring in the Havasu Wilderness section of Havasu National Wildlife Refuge cuts through rhyolite, issuing enough water to support cattails and local wildlife (Figure 3). Springs from fractured rock are the most common type in the area, although fracture and faulting sometimes occur together as at Gold Spring in Standard Wash south of Lake Havasu City (Figure 4). Two seeps actually occur at this location in fracture sets on the walls of a slot canyon carved along a mapped fault (Howard et al. 1999).

Springs also occur at two locations (Mohave Springs and Goat Spring) where gently dipping, permeable fanglomerate (alluvial fan conglomerates and sandstones), overlain by basalt, intersect a wash bottom. Diabase (mafic magma similar to basalt) dikes that intrude gneiss at the south end of Lake Havasu act as barriers to groundwater traveling through fractures of the gneiss, forcing the water upward to emerge in washes (Figure 5). The

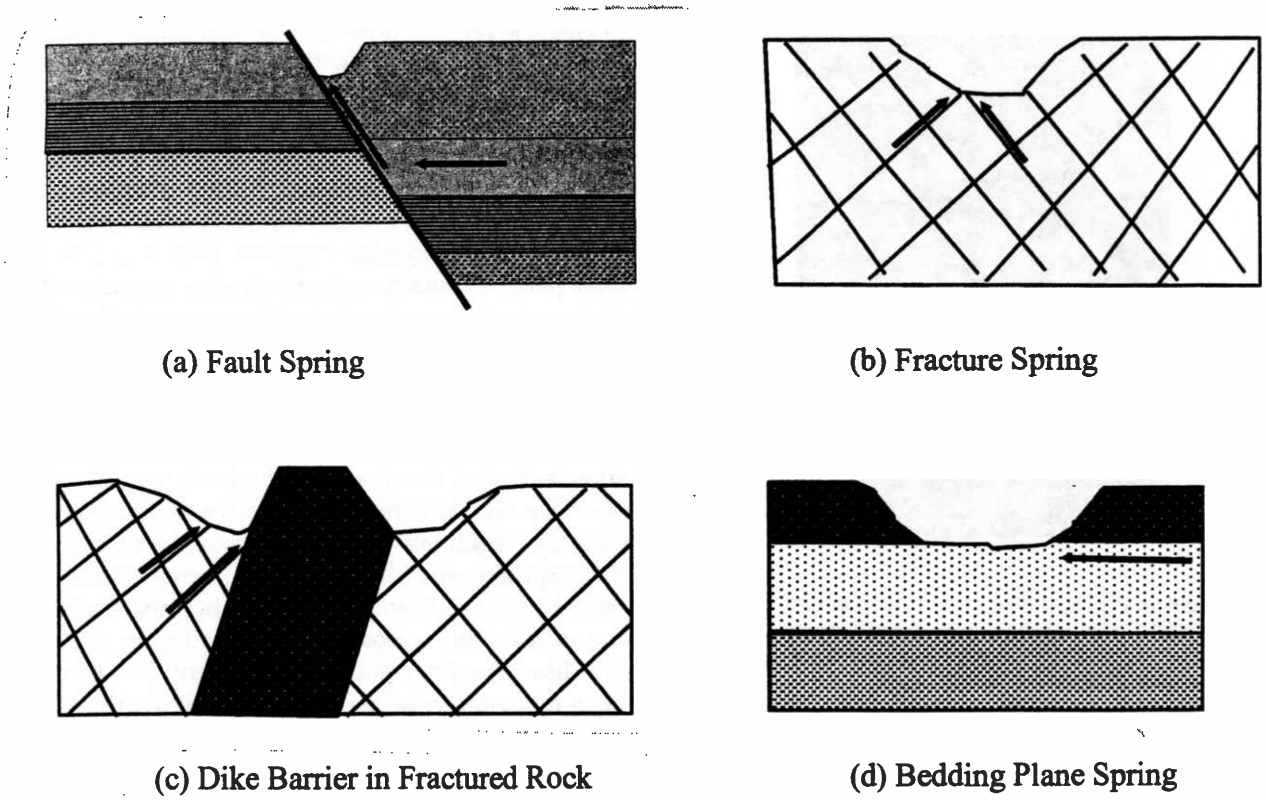


**Figure 2.** Water flowing (arrows) to the surface around Lake Havasu is primarily controlled by one of the following types of geologic conditions: (a) following faults in volcanic rocks; (b) following open fracture systems in gneiss or rhyolite; (c) following fractures in gneiss, but blocked by diabase dikes; or (d) following bedding planes until they intersect the surface.


**Figure 3.** Fault control at Jackpot Spring in Havasu NWR.

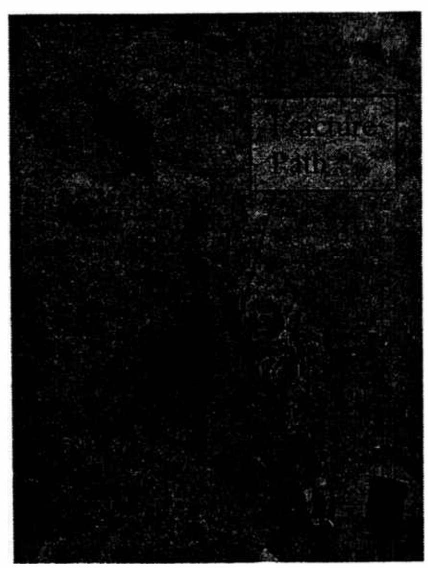


**Figure 4.** Fracture control at Gold Spring south of LHC.

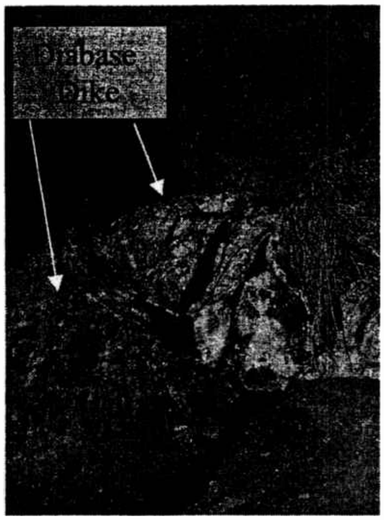


Figure 5. Diabase dike crosscutting gneiss at Jackpot Spring at the south end of Lake Havasu. The white color on the dike is a coating of caliche precipitated from the spring water.

dikes are also fractured to some extent, yet the fractures do not transmit water and many are annealed with calcite precipitation.

### Hydrology

Drought has plagued the desert Southwest for the past 5 years, yet 14 of the 17 springs visited over the last year and a half were active to some degree. Most springs were mere seeps, weeping water from fractures, faults, or bedding planes, although many were surrounded by dense vegetation, suggesting either perennial flow or greater past activity. Spring-fed pools were present at only four of the localities, indicating larger discharges. Although we had no way to measure the discharge at each site, none were flowing more than probably a liter per minute. Caliche surface coatings on bedrock noted at or near all spring locations and sediment-filled, man-made dams for holding water downstream of several spring sites also indicate greater spring activity in the past.

Springs at high elevations (above 900 m) were dry at the surface, although 5 m deep, hand-dug wells at one spring contained water. Groundwater flow paths for active low-elevation springs (150–200 m) are probably long and deep, originating in the surrounding mountains. There are no obvious intermediate or low-elevation sources in the region during dry periods. Greatly increased precipitation during the late summer of 2004 through the winter of 2005 led to the activation of two springs and significantly increased the flow of many other springs. Protracted precipitation runoff, flowing down washes and over seeps of several springs, obscured the contribution of spring discharge to the volume of water in the washes. Quick response times to heavy rainfall suggests that short, local flow paths for many springs are also important to their activity, particularly flows controlled by fracture systems and permeable bedding planes.

Two localities, both low-elevation springs, remained inactive even after 38 cm of precipitation during the rainy season. Field mapping of these sites indicated that fractured bedrock would have been the conduits for groundwater. Both sites are densely vegetated and show evidence of caliche development, so either they have been active in the recent past or groundwater is simply not reaching the surface, but is close enough to support vegetation like arundo, a short-rooted plant, and screwbean mesquite, whose roots can reach depths of 20 feet or more.

### Water Chemistry

Water samples collected from active springs where water sampling was feasible were analyzed for pH, hardness, alkalinity, total dissolved solids (TDS), dissolved oxygen (DO), phosphates, and nitrates. Few DO tests were done in the field due to the general lack of water pooling and in some cases the vegetation was too thick to get to the actual seep. Running water from most seeps was usually a few millimeters deep at best.

The water in all but two springs is very hard (>150 mg/l; Freeze and Cherry 1979), with $Ca^{+2}$ the dominant cation (Table 1). Caliche (calcium carbonate) deposits at all active springs, together with pH values ranging from 7.18 to 8.64, demonstrate that bicarbonate is a dominant anion in the water (Driscoll 1986). TDS and total hardness levels vary widely, yet when compared directly, a dichotomy appears between calcium cation dominant water, where TDS and total hardness are similar, and water rich in anions, where TDS is much higher than total hardness (Figure 6). Jupiter Spring, from high in the Mohave Mountains, and three low-elevation springs at the south end of Lake Havasu contain TDS levels high enough (1400–3300 mg/l) to class the water as brackish (Freeze and Cherry 1979). These differences may reflect the varied subsurface geology in the area and/or the residence time of the groundwater.

Table 1. Water chemistry of spring water and surface precipitation runoff around the Lake Havasu area. All values except pH are in mg/l. Italicized nitrate concentrations determined at state-certified laboratories.

| Spring | pH | Nitrate | Total Hardness | Ca Hardness | Mg Hardness | Alkalinity | TDS |
|---|---|---|---|---|---|---|---|
| Alan | 7.9 | *24.7* | 680 | – | – | 240 | – |
| Bermuda | 8.32 | 3 | 212 | 178 | 124 | 200 | 674 |
| Bill Williams | 7.4 | 0 | 328 | 248 | 80 | 200 | 1900 |
| Bristol | 7.58 | 3 | 89 | 66 | 23 | 200 | 528 |
| Goat | 8.41 | 4 | 39 | 34 | 5 | 360 | 494 |
| Gold (Upper) | 8.38 | *7.6* | – | – | – | 210 | 408 |
| Gold (Lower) | – | – | – | – | – | – | 364 |
| Jackpot (BW) | 7.52 | 2 | 310 | 275 | 35 | 120 | 1330 |
| Jupiter | 8.28 | 1 | 1200 | 480 | 720 | 80 | 1284 |
| Low | 8.26 | *10.7* | 740 | – | – | 160 | – |
| Mohave | 7.58 | 1 | 332 | 184 | 148 | 380 | 332 |
| RobBob | 7.18 | 5 | – | 585 | – | 80 | 3300 |
| Short | 7.53 | 0 | 1400 | 650 | – | 80 | – |
| Tule | 7.96 | *5.3* | 520 | – | – | 180 | – |
| Surface Runoff | – | – | – | – | – | – | – |
| Lower Bison | 8.25 | *4.6* | 760 | – | – | 280 | 734 |
| Upper Bison | 7.55 | 9 | 400 | – | – | 240 | 405 |
| Emergent Bison | 7.33 | 4 | 280 | – | – | 240 | 331 |
| Spring Falls | 8.64 | 9 | 400 | – | – | 220 | – |
| South Bison | 8.27 | 4 | 480 | – | – | 260 | 844 |
| Reverse Osmosis | 7 | 0 | 20 | – | – | 20 | 36 |

No phosphates are present in the spring water, yet nitrogen-nitrate concentrations can be striking (Table 1). Several springs south of the Mohave Mountains contained elevated nitrate levels (3–7 mg/l) before last fall/winter's rainy season. These springs show no geographic or topographic patterns that suggest the origin of the nitrates. All springs lie in undeveloped areas, although several springs occur near past mining efforts and were probably used during prospecting. The desert soil is generally poor in nutrients and there is neither active agriculture nor ranching in the region to act as a source for nitrates. During and after the rainy season, nitrate levels measured from springs and in runoff in a wide area (~100–200 km$^2$) from the Mohave Mountains east of LHC to the Bill Williams Mountains at the south end of Lake Havasu became more significant, with concentrations as high as 24.7 mg/l (Figure 7). Such a large area suggests a non-point source for nitrates.

The soils and alluvium cover over bedrock of the mountains were saturated from the sustained precipitation events during the rainy season. The bedrock itself, consisting of gneiss or volcanic deposits, contains little to no nitrate to leach to groundwater. Recent work in the desert Southwest suggests that nitrates from natural sources like playa lake beds are carried into the atmosphere and deposited elsewhere during dry periods (Walvoord et al. 2003). Normal brief precipitation events promote percolation below soil root zones and accumulation in the subsoil alluvium. During protracted wet seasons, the alluvium becomes saturated and nitrates are leached out with the subflow. This is a plausible scenario for the terrain around Lake Havasu, as the dominant wind patterns are from the west where playa lakes occur in the Mojave Desert.

## SUMMARY

Springs occur in a geologically complex, low-elevation desert environment around Lake Havasu. Groundwater paths may be relatively shallow, where infiltrated precipitation quickly migrates to the emerging seep, or moderately deep, reflecting a watershed-scale transport system. Water surfacing occurs where transmitting faults and/or fractures are present, where permeable strata overlain

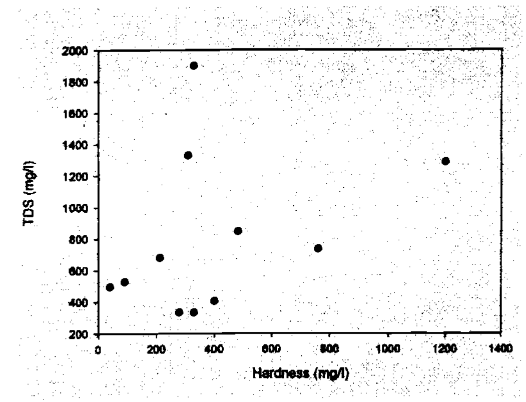


Figure 6. Total dissolved solids vs hardness waters indicate two types of water: calcium cation rich and water containing a greater amount of anions and/or other cations.

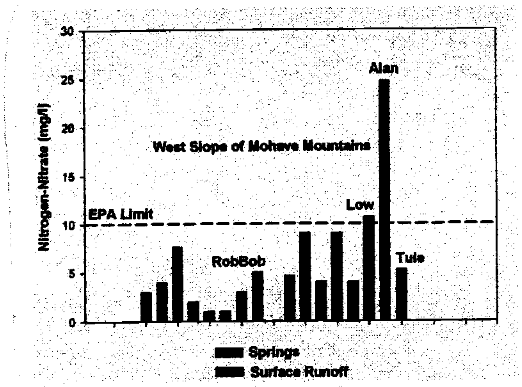


Figure 7. Nitrogen-nitrate of spring concentrations from spring water and from emerging precipitation subflow around the Lake Havasu area.

by impermeable rock intersects the surface, or where impermeable dikes in fractured rock intersect washes and act as barriers to groundwater flow. Water from the springs is generally hard to very hard, with moderate TDS levels (up to 3300 mg/l). Caliche deposits are common around the spring seeps. Nitrogen-nitrates are present in many spring waters, posing the question of origin in an undeveloped region. Nitrates were found not only from spring waters, but also in runoff subflow over a large area during and after recent precipitation events. Finding such widespread contamination suggests natural occurrences of nitrate that might be related to long-term eolian deposition onto soils and alluvium cover.

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