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HYDROGEOLOGY AND GEOCHEMISTRY OF HORACE SPRINGS, PUEBLO OF ACOMA, NEW MEXICO

Christopher Wolf [1]

[1]Daniel B. Stephens & Associates, Inc., 6020 Academy Rd., NE, Albuquerque, New Mexico 87109, cwolf@dbstephens.com

Abstract—Horace Springs is the start of a perennial reach of the Rio San Jose at the Pueblo of Acoma, New Mexico. As the meandering Rio San Jose flows through a gap between Horace Mesa to the north and La Ventana Mesa to the south, the alluvial aquifer system lies in the gap, causing a decrease in the alluvial aquifer's cross-sectional area resulting in groundwater discharging to the streambed. Horace Springs, currently, discharges about 3.5 to 4 cubic feet per second of water into the stream channel and is classified as a rheocrene spring.

Geology in the area is characterized by Mesozoic sedimentary rocks that have sandstone and limestone aquifer systems. The San Rafael Fault Zone is a northeast trending fault zone west of Acoma, and rocks have been down-dropped towards the east. Along the fault, the San Andres Limestone and Glorieta Sandstone (Psg), which forms a combined aquifer system, are just below alluvial cover and lava flows west of the fault; east of the fault the aquifer is displaced over 800 feet deeper below ground surface. The groundwater in the Psg, which flows from west to east, is brought to the surface due to juxtaposition of the Psg against the lower permeability Chinle Formation along the fault contact. This water discharges at a spring, Ojo del Gallo, and also recharges the alluvial-basalt aquifer. Horace Springs discharges from the alluvial-basalt aquifer downgradient (east) of the fault.

Water chemistry was used to evaluate potential aquifers contributing to Horace Springs. Water that discharges at Horace Spring is predominantly derived from the Psg, with components from aquifers in the alluvial-basalt, Entrada Sandstone and Dakota Sandstone.

INTRODUCTION

Horace Springs is a critical hydrological feature at the Pueblo of Acoma. The combined spring discharges from Horace Springs and nearby Anzac Springs fill the perennial reach of the Rio San Jose with water, the most valuable resource in the arid climate of New Mexico. Since time immemorial, Acoma has relied on the Rio San Jose for irrigation, coldwater fishery, wildlife habitat, domestic, and cultural uses, as well as recreation. The spring discharge represents the beginning of a gaining reach within the Rio San Jose, where the shallow groundwater in the alluvial-basalt aquifer discharges into the Rio San Jose. This gaining reach extends across Acoma but often becomes a losing reach before the Rio San Jose flows across Acoma's eastern boundary, about 14-miles downstream.

Water is sacred to the people of Acoma as described by one of Acoma's former Governors, Gregg Shutiva (Shutiva, 2013):

> "*Acoma's world-view when it comes to water, there is one central belief…we are connected to the environment. Our spirituality is connected to the environment…what some might see as a bubbling spring, we see it as a precious life source…*"

The hydrology of Horace Springs is complicated and has been discussed for over 50 years in the scientific literature. The spring clearly discharges from the alluvial-basalt aquifer system; while the upgradient sources of water have been postulated, they are not clearly understood (Baldwin and Anderholm, 1992). Based on historical geochemical data and knowledge of the local hydrology, the San Andres Limestone and Glorieta Sandstone aquifer system (SAGA) appears to be a major contributor to the alluvial-basalt aquifer upgradient of Horace Springs and is reflected in the water chemistry observed in the spring system.

SURFACE WATER HYDROLOGY OF THE RIO SAN JOSE

The Rio San Jose begins at the confluence of Bluewater Creek and Mitchell Draw in the Zuni Mountains. The Rio San Jose is currently a perennial stream at Acoma due to discharge from Horace and Anzac Springs, but upstream and downstream from Acoma it is an ephemeral stream. There are approximately 14 miles of stream channel on the Pueblo.

Prior to development in the area upstream of Acoma, natural flow in the Rio San Jose was sustained by surface runoff and spring flow (Risser, 1982), plus some areas of the stream receive groundwater discharges. Historically, the stream received inputs from sources that have since been altered by upstream users of groundwater and surface water. The two main components of flow that no longer contribute are surface flows from the headwaters in the Zuni Mountains and spring discharge from Ojo del Gallo (Fig. 1). These historical components of natural streamflow were estimated to total 16,400 acre-feet per year (ac-ft/yr) at the western boundary of Acoma and consisted of 7,800 ac-ft/yr of runoff from the Zuni Mountains, 5,000 ac-ft/yr from Ojo del Gallo, and 3,600 ac-ft/yr from Horace Springs (Risser, 1982). Currently, Bluewater Reservoir captures runoff from the Zuni Mountains, and Ojo del Gallo is no longer discharging any significant streamflow into the Rio San Jose.

The U.S. Geological Survey (USGS) has a stream gaging station downstream of Horace Springs (Rio San Jose near Grants, NM, now referred to as Rio San Jose at Acoma, #8343500). The station was installed in the late 1930s and has a continuous record starting in water year 1937. For the period of record from October 1936 to October 2004, an average value of 6.15 cubic feet per second (cfs) was calculated based on monthly mean val-

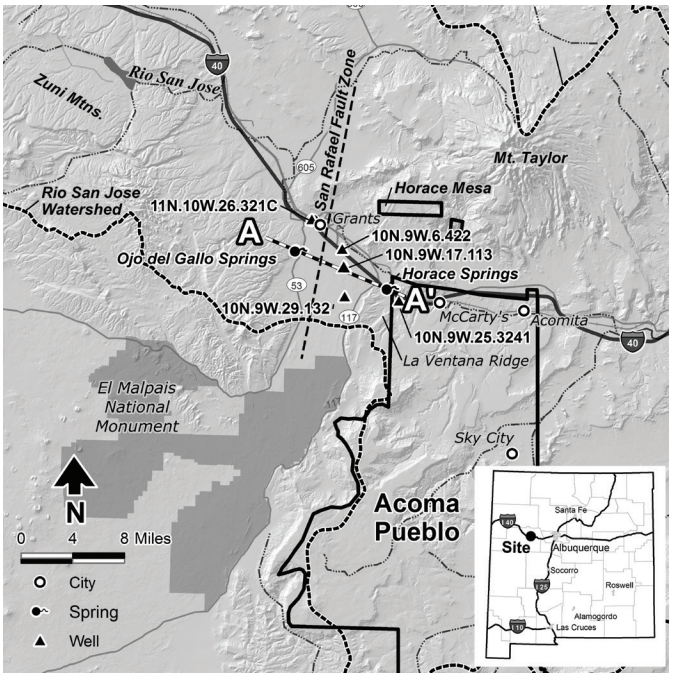

FIGURE 1. Map of Acoma Pueblo, New Mexico, showing Horace Springs and Ojo del Gallo Springs. Horace Springs occurs along the Rio San Jose where the river flows between Horace Mesa and La Ventana Ridge.

ues. In contrast, for the period from 1990 to 2004, an average value of 4.21 cfs was calculated based on the monthly mean values, and the annual mean flow in 2004 was about 3.5 cfs. The measured discharge from Horace Springs appears to be declining since about 1990 based on the mean annual average streamflow and a 5-year moving mean calculation (Fig. 2). The gauge infrastructure was recently updated and gauging began again in 2013 indicating annual average streamflow of 4.1 to 3.9 cfs.

The Rio San Jose has been diverted to irrigate crops by the Pueblo of Acoma and subsequent settlers in the area. Early surveys by the United States indicated that "very old" irrigation ditches were identified at Acoma (Gordon, 1961), and settlers began diverting flow from the Ojo del Gallo in 1870 (Risser, 1982). By 1880, a series of dams was built to capture the perennial flow in Bluewater Creek for irrigation use. As the demand for irrigation water increased, irrigation wells were constructed in the Bluewater basin to extract groundwater to supplement the available surface water flows. These wells withdrew water from the SAGA.

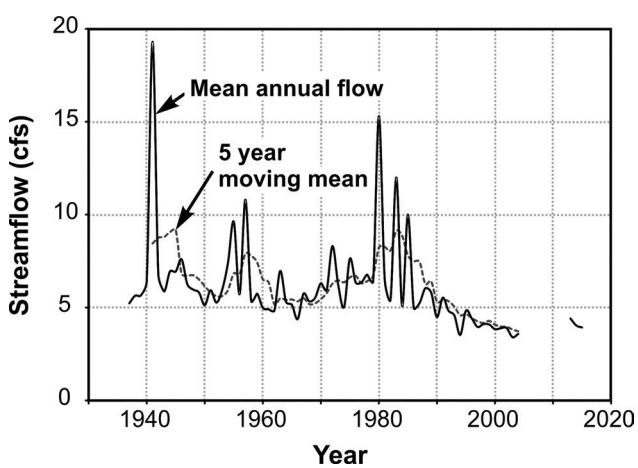

FIGURE 2. Streamflow measured at the Rio San Jose at Acoma Pueblo, New Mexico, (gage #08343500) from 1936 to 2016. No data is available when the gage was undergoing rehabilitation from October 2004 to January 2010. The solid line is the mean annual flow and the dashed line represents a 5-year moving mean. Since 1990, annual flows have been below 5 cubic feet per second (cfs).

As industry grew in the area around Grants, groundwater development continued to increase to support power generation and uranium extraction activities. Large amounts of groundwater were withdrawn to dewater underground mines and process uranium ores.

As the City of Grants grew to support the local industry, the Grants wastewater facility began discharging effluent into an ephemeral reach of the Rio San Jose in 1957, and by 1978, the flow became perennial from the discharge point east of Grants to Horace Springs (Risser, 1982). Risser (1982) estimated that 1 to 2 cfs of effluent mixed with the spring discharge from Horace Springs, and combined flow totaled about 7 cfs. Regular discharge from the wastewater plant stopped in 1992. These discharges were deleterious to water and stream sediment quality.

The USGS prepared a numerical groundwater model in MODFLOW to evaluate the potential impacts of current and projected groundwater withdrawals on flow in the Rio San Jose and SAGA as well as Ojo del Gallo and Horace Springs (Frenzel, 1992). The model had available data to 1986 and projected conditions to 2020. They concluded that groundwater pumping will have little impact on Horace Springs but would directly decrease flow at Ojo del Gallo. The springs were modeled as streams in the numerical model.

Acoma requested that the model be updated to reflect additional data available from 1986 to 1999 (DBS&A, 2001). The updated model altered how the alluvial aquifer discharged at Horace Springs. The specified outflow of 2.5 cfs, that under predicted spring discharge, was changed to a head-dependent boundary condition allowing the model to more accurately simulate variable flow at Horace Springs (DBS&A, 2001). Using different climate scenarios, the model predicted that spring discharge averaged 4 cfs after 1995, and this result has been observed in the gauge records (Fig. 2). This value is about 1 cfs (20%) lower than the mean streamflow observed over the period of record (Fig. 2) and about 30% of the value for natural streamflow calculated by Risser (1982).

GEOLOGY OF THE ACOMA AREA

The geology at Acoma is typical of the Colorado Plateau, with sedimentary Cretaceous rocks, including the Mancos Shale and Dakota Sandstone, and Jurassic sedimentary rocks exposed at the surface (Fig. 3). The rocks dip slightly toward the San Juan Basin. About 100 to 160 feet of alluvium was deposited along stream channels including the Rio San Jose during wetter periods in geologic history (Love, 1989).

The Mt. Taylor volcanic field, including the currently inactive volcano north of Acoma, has erupted basaltic, rhyolitic,

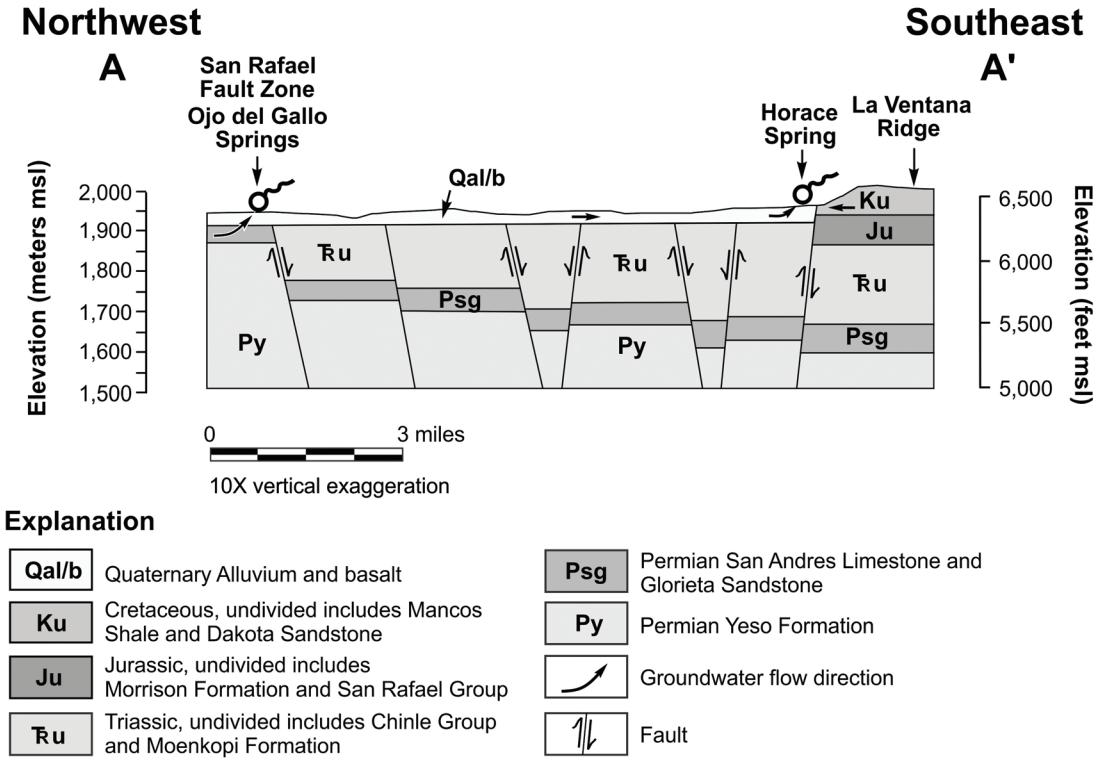

FIGURE 3. Hydrogeologic cross-section A-A' (location shown on Figure 1) near Acoma Pueblo, New Mexico, showing the Permian San Andres Limestone and Glorieta Sandstone (Psg) discharging to shallow alluvium and basalt aquifer along the San Rafael Fault Zone. The juxtaposition of Psg against lower permeability rocks of the Chinle Group (Tru) results in Psg groundwater discharge to ground surface and recharge to the alluvial aquifer. Horace Springs is located downstream and downgradient of Ojo del Gallo Springs. The chemistry of water discharging at Horace Springs is dominanted by alluvial groundwater that has been recharged by the Psg. Additional chemical components in Horace Springs reflect interaction with basalt, Cretaceous sandstones (Ku) that outcrop near the spring, and sandstones within the San Rafael Group (Ju). Geologic interpretation based on Maxwell (1977), Ciskoski (2013), and Kelly and Reynolds (1989).

and tuff flows in several episodes, as evidenced by the numerous flows that are prominent across the region. The lava beds are locally known as malpais. The San Rafael Fault Zone lies west of the Acoma boundary and is significant because it has approximately 800 feet or more of displacement with a general downward motion on the east side of the fault. West of the fault, the Permian San Andres Limestone and Glorieta Sandstone (Psg) is an important aquifer with wells about 300 feet deep producing potable water. East of the fault however, the Psg is found at depths of over 2,000 feet and contains geothermal water (USGS, 1989; Baldwin and Anderholm, 1992). The juxtaposition of sedimentary rocks (Psg juxtaposed against the Chinle Formation) across this fault (Fig. 3) causes groundwater to surface at Ojo del Gallo Spring (White, 1989).

HYDROGEOLOGY OF HORACE SPRINGS AND OJO DEL GALLO SPRINGS

Horace Springs and Ojo del Gallo are important springs for the Pueblo of Acoma for cultural reasons as well as for the flow they contribute to the Rio San Jose. Each spring flows from a different aquifer, as discussed by Gordon (1961):

"*The discharge from Ojo del Gallo was almost entirely from the San Andres Limestone whereas the discharge from Horace Springs is from the alluvium and basalt. A part of the water discharged from Horace Springs may, however, have been transmitted to the alluvium and basalt from the San Andres limestone between Grants and San Rafael.*"

Horace Springs

Horace Springs is critical to the Pueblo of Acoma because the spring discharges into the Rio San Jose, creating a perennial reach as it flows across the pueblo. The springs are located at the southern end of Horace Mesa, which consists of Jurassic- and Cretaceous-age sandstone and shale and is capped by Tertiary rhyolitic lava flows and tuff breccia (Fig. 3). The southwest end of Horace Mesa is bounded by a northeast trending fault that crosses Horace Mesa and continues to the south along La Ventana ridge. Several faults have been observed in outcrops of the Two Wells and Paguate Tongues of the Cretaceous-age Dakota Sandstone (Maxwell, 1977; Ciskosi, 2013). The gap between the mesas is about 1.5 miles wide and allows the movement of groundwater, surface water, and sediment out of the Bluewater-Grants area toward the Pueblo of Acoma. The Rio San Jose flows through this break in the mesas, and the alluvial-basalt aquifer is continuous through the area. Lava flows are also present through the gap.

The malpais provide direct recharge to the alluvial-basalt aquifer through stream losses, snowmelt, and precipitation. There was about 100 to 160 feet of alluvium deposited along

stream channels during pluvial or wetter periods in geologic history (Love, 1989). The alluvial-basalt aquifer is hydraulically connected to the Rio San Jose.

Groundwater discharges to the stream between Horace Springs and the Village of McCartys result from a reduction in the aquifer cross-sectional area between Horace Mesa and La Ventana Ridge (Risser and Lyford, 1984). At Horace Springs, the direct discharge into the stream channel is classified as a rheocrene spring (Springer and Stevens, 2008).

Ojo del Gallo

Ojo del Gallo emanates from the SAGA along the San Rafael Fault Zone. Due to the juxtaposition of the SAGA against the low-permeability Chinle Formation, groundwater is directed toward the surface. The area around the spring is characterized by carbonate tufa deposits that are typical of limestone-derived spring flow (White, 1989). While the spring is no longer discharging a significant amount of water, the SAGA is probably still discharging to the alluvial-basalt aquifer, a significant portion of which is underlain by the SAGA, in the area above Ojo del Gallo and Horace Springs.

HYDROLOGY AND GEOCHEMISTRY OF THE SAN ANDRES LIMESTONE AND GLORIETA SANDSTONE AQUIFER

The SAGA is potentially an important contributor to water quality and flow at Horace Springs. The hydrology and geochemistry of this aquifer are discussed below.

Hydrogeology of the San Andres Limestone and Glorieta Sandstone near Acoma

The groundwater in the SAGA originates in the Zuni Mountains from infiltration of snowmelt and precipitation on rock outcrops, with additional recharge occurring through the channel of Bluewater Creek (Baldwin and Anderholm, 1992). Generally, the groundwater flows from west to east, away from the mountains toward Acoma. Karst features have developed in the limestone due to dissolution along fractures, which gives parts of the SAGA high transmissivity values.

In the Grants area, supply wells completed in the SAGA are capable of producing large quantities of water (hundreds of gallons per minute) from a few hundred feet below ground surface (ft bgs). Due to the offset along the San Rafael Fault Zone, however, the SAGA is more than 2,000 ft bgs at Acoma. Test wells, such as 10.9.25.3241Anzac 86-1, completed by the USGS on the west side of Acoma, had poor water quality with specific conductance values over 7,000 micromhos per centimeter (μmhos/cm) (USGS, 1989; Baldwin and Anderholm, 1992).

Geochemistry of San Andres Limestone and Glorieta Sandstone

The SAGA is an important aquifer west of Acoma that supplies good-quality and quantities of water to supply wells. The geochemistry of the water helps in interpreting the source of water at Horace Springs because the SAGA is discharging to the shallow alluvial-basalt aquifer in the area of Ojo del Gallo (Gordon, 1961).

Water quality in the SAGA is determined by the chemistry of the recharge water, mineralogy of the aquifer, and residence time of the groundwater. Water-rock interactions such as minerals in the aquifer being dissolved will affect cation and anion composition of the water. Residence time is important because as it increases, the water has a greater chance of coming in contact with and dissolving aquifer materials.

SAGA water quality in the Grants area is a calcium-sulfate ($Ca\text{-}SO_4$) type, representing the dissolution of gypsum and limestone. Cation exchange is an important reaction occurring in the aquifer, where calcium is removed from solution by reacting with sodium-bearing clays. The effect is observed as a relative enrichment in sodium to calcium as the water travels down the flow path (as residence time increases) (Baldwin and Anderholm, 1992).

GEOCHEMICAL EVOLUTION OF GROUNDWATER AND SURFACE WATER IN THE ACOMA REGION

In order to understand the groundwater geochemistry for the Acoma region, representative selected water quality sampling data from the literature for the SAGA, alluvial-basalt aquifer, Entrada Sandstone, Dakota Sandstone, Ojo del Gallo, Horace Springs, and Rio San Jose (Risser and Lyford, 1984; Baldwin and Anderholm, 1992), as well as data from recent sampling by the Haaku Water Office at the Pueblo of Acoma along the Rio San Jose were examined (Table 1). In particular, available data for cations and anions for recent and historical data, to represent natural water quality, were chosen. Geochemical analyses were performed using statistics, mixing models, and Piper and Stiff diagrams. The geochemical software PHREEQC (Parkhurst and Appelo, 1999) was used to calculate the activities and saturation indices to determine mineral interactions.

The geochemical conceptual model for the SAGA evolves as groundwater reacts with aquifer minerals such as calcite ($CaCO_3$) and gypsum ($CaSO_4{\cdot}H_2O$) and experiences cation exchange between groundwater and clay minerals, causing a decrease in calcium and increase in sodium ions (Ca to Na corner on Piper diagram, Fig. 4) (Baldwin and Anderholm, 1992). The dissolution of gypsum that occurs naturally in the formation is represented by an increase in sulfate (SO_4) concentrations (HCO_3 to SO_4 corner on the Piper diagram, Fig. 4). The evidence for gypsum dissolution is a higher SO_4 concentration and is shown on the Piper diagram by the trend moving away from the HCO_3 apex to a mix of approximately 50 percent each of SO_4 and HCO_3 anions. The SAGA evolves from a calcium-bicarbonate ($Ca\text{-}HCO_3$) water to a sodium-sulfate ($Na\text{-}SO_4$) water as the groundwater flows from the recharge area in the Zuni Mountains to the discharge point at Ojo del Gallo.

Saturation indices were calculated in PHREEQC to evaluate how minerals may dissolve or precipitate from solution under chemical equilibrium conditions. The calculated saturation indices (SI) for the SAGA at City of Grants well 11N.10W.26.321C

TABLE 1: Water chemistry results for springs and wells near Acoma Pueblo, New Mexico.

Location	Local Identifier	Sample Date	Chloride	Sulfate	Calcium	Magnesium	Bicarbonate	Sodium	Potassium	pH	Silica
			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	su	mg/L
Ojo del Gallo Spring	10N.10W.03.433	7/12/1946	44	270	110	41	320	69.6	6.4	7.1	18
Horace Springs	10N.9W.23.423	5/13/1957	88	290	79	40	240	124	6	8.3	30
Entrada Well	10N.9W.29.132	12/8/1950	12	120	22	9.4	320	132[a]	8[a]	na	8.4
Dakota Well	10N.9W.25.3241	5/7/1958	160	960	210	95	310	102[a]	8[a]	7.3	12
SAG Well	11N.10W.26.321C	6/26/1962	34	300	140	31	280	62	4	7.3	15
Alluvial/Basalt Well	10N.9W.17.113	6/15/1955	41	260	120	38	330	59[a]	8[a]	7.4	28

[a]Sodium and potassium calculated from "sodium + potassium" results, assuming potassium = 8 mg/L

NOTES: mg/L = milligrams per liter
su = standard units
na = not available

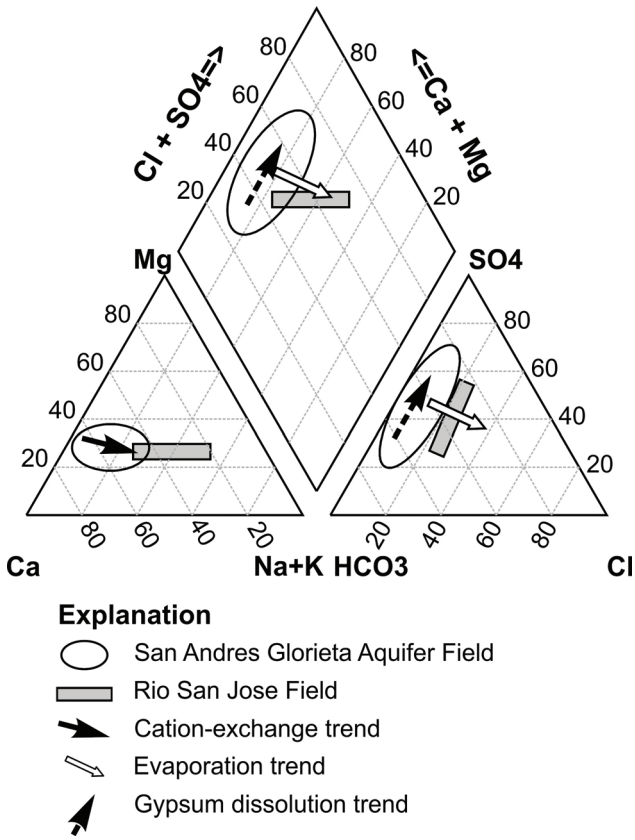

FIGURE 4. Conceptual Piper diagram showing fields based on wells completed in the San Andres Limestone and Glorieta Sandstone and surface water of the Rio San Jose. Chemical reactions between groundwater and rocks that host the aquifer determine water quality observed at wells and springs. Potential chemical reactions occuring along groundwater flow paths are indicated by the arrows: cation-exchange trend in lower left triangle shows a decrease in calcium and magnsium with an increase in sodium; evaporation trend shown in quadrilateral and lower right triangle shows an overall increase in chloride relative to other anions; dissolving gypsum will increase the relative amount of sulfate in the groundwater as shown in the quadrilateral and lower right triangle

is over-saturated (SI > 0) with respect to carbonate minerals (calcite, aragonite, and dolomite) but under-saturated (SI < 1) with respect to gypsum, indicating that gypsum will likely dissolve into solution. Based on the observed water quality, such dissolution is probably occurring and concurs with observations by Baldwin and Anderholm (1992). The reaction is evident based on the shape of the Stiff diagram (Fig. 5), which indicates a similarity to a limestone but with a higher concentration of sulfate (reflecting gypsum dissolution).

The alluvial-basalt aquifer has variable water quality and is recharged by snowmelt, precipitation, groundwater discharge from the deeper bedrock units including the SAGA, and surface water along losing reaches of the stream. The water quality ranges from good in the malpais to poor in fine-grained sediments, due to the low permeability and long residence times. Poor water quality is evident in well 10N.09W.17.113, completed near Horace Springs, which has a sodium-sulfate type water with elevated concentrations of chloride, sulfate, and sodium. Based on the shape of the Stiff diagram (Fig. 5), the water is probably derived from a shale unit such as the Mancos Shale, which outcrops nearby. Good water quality was found in well 10N.9W.29.132, also near Horace Springs; this well has a calcium-bicarbonate ($Ca\text{-}HCO_3$) type water, and based on the shape of the Stiff diagram (Fig. 5), the water is probably derived from a limestone or dolomite such as the San Andres Limestone.

Dissolved silica (as SiO_2) in these alluvial-basalt aquifer samples provides evidence that volcanic glass is reacting with the groundwater. When the silica concentration is greater than 0.5 millimole per liter (mmol/L) (which is equivalent to 30 milligrams per liter [mg/L]), volcanic glass or hydrothermal water interactions are indicated (Hounslow, 1995). The values are 0.50 mmol/L for well 10N.09W.17.113 and 0.56 mmol/L for well 10N.9W.29.132. For comparison, the City of Grants well (SAGA completion) 11N.10W.26.321C has a silica value of 0.25 mmol/L (15 mg/L) and does not appear to have recharge water that has reacted with volcanic glass.

Horace Springs emanates from the alluvial-basalt aquifer and the spring chemistry is derived from a mixture of water from the SAGA that recharges the shallow aquifer and alluvial-basalt aquifer. The SAGA water quality is apparent in Horace Springs due to the $Na\text{-}SO_4$ character of the water, which is the

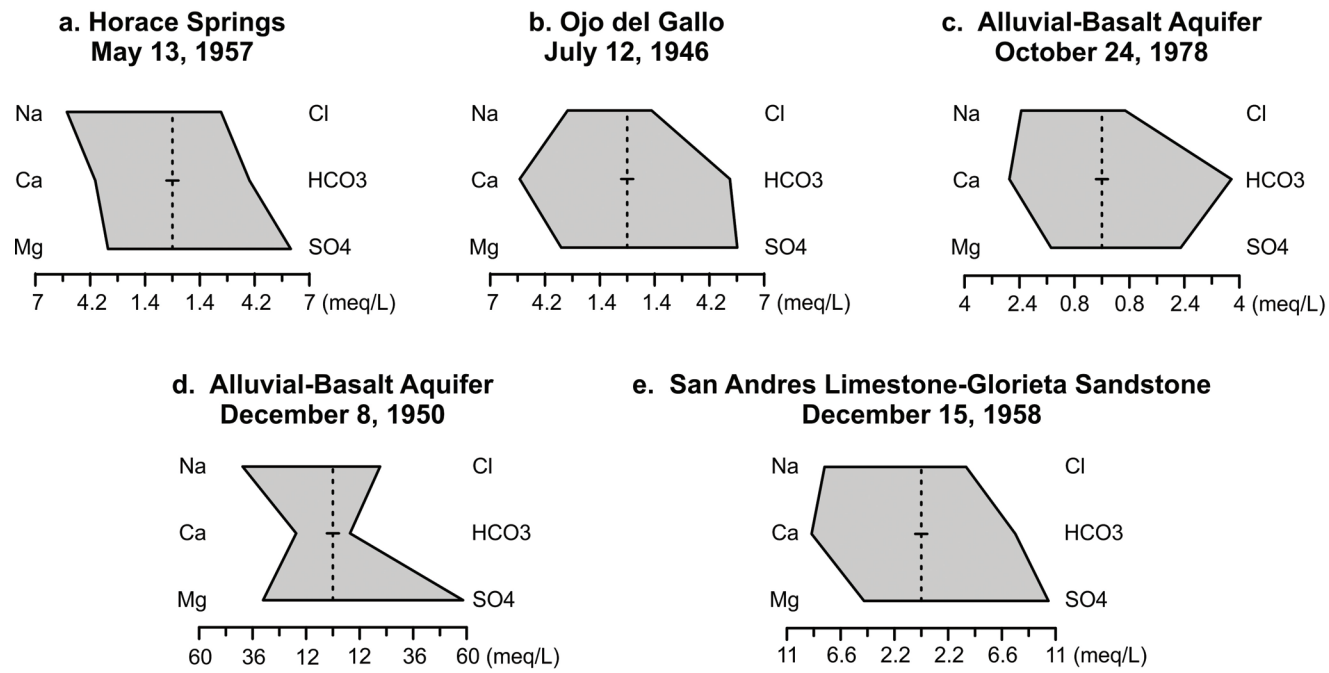

FIGURE 5: Stiff diagrams for springs and wells near Acoma Pueblo, New Mexico, using data from Baldwin and Anderholm (1992). Scales are variable and reported in milliequivalents per liter (meq/L). Major cations are plotted on the left and major anions on the right. Stiff diagram shapes are characteristic of groundwater interaction with rocks along the flow path in the aquifer system.

result of groundwater interactions (cation exchange and gypsum dissolution) in the SAGA. Water-rock interactions with the alluvial-basalt signature are evident from the dissolved silica concentrations, which range from 30 to 33 mg/L at the spring.

In order to evaluate potential contributors to water chemistry at Horace Springs, a statistical analysis was performed in Aquachem (SWS, 2014) using Euclidian geometry to compare Horace Springs with potential mixing end members. Data for six variables (Ca, Na, Mg, SO_4, Cl, and HCO_3) were compared between a single Horace Springs sample and results from samples reflecting other potential sources of water to the alluvial-basalt aquifer upgradient of the spring. In such an analysis, a correlation coefficient is calculated based on the variance of these elements, and a value greater than 0.9 indicates a good match. The samples with the best match to Horace Springs include the City of Grants well ($r_2 = 0.983$), spring 10N.9W.6.442 ($r_2 = 0.975$), and Ojo del Gallo Spring ($r_2 = 0.97$).

Calculations for the alluvial-basalt aquifer indicate a strong correlation ($r_2 = 0.949$) between the chemistry in well 10N.9W.29.132 and the Entrada Sandstone. This correlation probably indicates that the Entrada is recharging the alluvial-basalt aquifer due to upward groundwater gradients east of the San Rafael Fault Zone and beneath Horace Mesa.

The composition of Horace Springs is dominated by groundwater from the SAGA that recharged and mixed with the alluvial-basalt aquifer in the Ojo del Gallo area. Near Horace Springs, this water mixes with groundwater from the Entrada and Dakota Sandstones before discharging at Horace and Anzac Springs.

Based on the similar water quality identified between Horace Springs and nearby SAGA wells, mixing scenarios were calculated in PHREEQC (Parkhurst and Appelo, 1999) to determine the potential contributions of several end members, including the SAGA, alluvial-basalt, Entrada Sandstone, and Dakota Sandstone aquifers. For the mixing, water chemistry included pH and seven major ions: sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), chloride (Cl), bicarbonate (HCO_3), and sulfate (SO_4). A sample from Horace Springs collected on May 13, 1957, was used for comparison to the calculated mixing scenarios. One of the best mixing scenarios was using Ojo del Gallo, Dakota Sandstone, and Entrada Sandstone. Based on the water quality mixing results, the source of water at Horace Springs is a combination of Ojo del Gallo, which is derived from the SAGA, Jurassic and Cretaceous sandstones (Table 2). Despite the fact that Ojo del Gallo no longer discharges significant water, the SAGA appears to be recharging the alluvial-basalt aquifer west of the San Rafael Fault Zone.

CONCLUSION

As hypothesized by Gordon (1961), Baldwin and Anderholm (1992), and Frenzel (1992), the water emanating at Horace Springs reflects the chemistry of several aquifers in the area. Bedrock aquifers are discharging to the alluvial-basalt aquifer from which Horace Springs emanates. The spring chemistry reflects a large component of SAGA mixed with Dakota Sandstone and Entrada Sandstone in the alluvial-basalt aquifer.

Understanding the hydrogeology and geochemistry of Horace Springs is important because the combination of upstream/upgradient water uses and climate change impacts the

TABLE 2. Composition of Horace Springs.

Aquifer	Contribution (%)
SAGA (via alluvial system)	60-80
Alluvial-basalt	10-30
Entrada Sandstone	0-10
Dakota Sandstone	0-10

SAGA = San Andres Limestone and Glorieta Sandstone aquifer system

viability of Ojo del Gallo and Horace Springs. Scientists and water planners need data to help understand and predict future water supplies.

Groundwater pumping has been documented as the cause of decreased flow from Ojo del Gallo. Streamflow measurements show a historical decline to below 4 cfs downstream from Horace Springs, which corresponds with the decrease in flow predicted through numerical groundwater modeling. The decreasing streamflow trend began in the 1980s and will likely continue to be problematic for the Pueblo of Acoma and those who rely on the Rio San Jose as a water resource. Anecdotal evidence suggests that the water table has dropped over time around Horace Springs, and if the water table drops significantly the gaining reach of the stream would be expected to manifest at lower elevations downstream of the current location. In the future, this phenomenon may impact infrastructure along the stream, including the stream gauge and irrigation diversion structures.

Increasing demands on the local water supply for industry, agriculture, and domestic supply, coupled with predictions of less streamflow due to changing climate conditions, will broaden the current gap between supply and demand (USBR, 2013). As these changes occur, water uses and related infrastructure must adapt at Horace Springs and across the Southwestern United States.

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