New Mexico Geological Society

Downloaded from: https://nmgs.nmt.edu/publications/guidebooks/76



Hydrochemistry of an Alpine Carbonate Spring System, Sandia and Manzano Mountains, Northern New Mexico: Implications for Recharge and Ecosystem Sustainability

Laura J. Crossey, Christopher Somer, Rebecca Frus, Kambray Townsend, Naomi DeLay, Karl Karlstrom, Brittany Griego, Rebecca Bixby, and Livia Crowley
2026, pp. 421-431. https://doi.org/10.56577/FFC-76.421

in:

Geology of the Albuquerque Region - Fall Field Conference 2026, Connell, Sean D.; Koning, Daniel J.;, New Mexico Geological Society 76th Annual Fall Field Conference Guidebook, 452 p. https://doi.org/10.56577/FFC-76

This is one of many related papers that were included in the 2026 NMGS Fall Field Conference Guidebook.

Annual NMGS Fall Field Conference Guidebooks

Every fall since 1950, the New Mexico Geological Society (NMGS) has held an annual Fall Field Conference that explores some region of New Mexico (or surrounding states). Always well attended, these conferences provide a guidebook to participants. Besides detailed road logs, the guidebooks contain many well written, edited, and peer-reviewed geoscience papers. These books have set the national standard for geologic guidebooks and are an essential geologic reference for anyone working in or around New Mexico.

Free Downloads

NMGS has decided to make peer-reviewed papers from our Fall Field Conference guidebooks available for free download. This is in keeping with our mission of promoting interest, research, and cooperation regarding geology in New Mexico. However, guidebook sales represent a significant proportion of our operating budget. Therefore, only *research papers* are available for download. *Road logs*, *mini-papers*, and other selected content are available only in print for recent guidebooks.

Copyright Information

Publications of the New Mexico Geological Society, printed and electronic, are protected by the copyright laws of the United States. No material from the NMGS website, or printed and electronic publications, may be reprinted or redistributed without NMGS permission. Contact us for permission to reprint portions of any of our publications.

One printed copy of any materials from the NMGS website or our print and electronic publications may be made for individual use without our permission. Teachers and students may make unlimited copies for educational use. Any other use of these materials requires explicit permission.

This page is intentionally left blank to maintain order of facing pages.

New Mexico Geological Society Guidebook, 76th Fall Field Conference, 2026, p. 421–431, https://doi.org/10.56577/FFC-76.421

HYDROCHEMISTRY OF AN ALPINE CARBONATE SPRING SYSTEM, SANDIA AND MANZANO MOUNTAINS, NORTHERN NEW MEXICO: IMPLICATIONS FOR RECHARGE AND ECOSYSTEM SUSTAINABILITY

LAURA J. CROSSEY[1], CHRISTOPHER SOMER[1], REBECCA FRUS[2], KAMBRAY TOWNSEND[3], NAOMI DELAY[1], KARL KARLSTROM[1], BRITTANY GRIEGO[1], REBECCA BIXBY[4], AND LIVIA CROWLEY[5]

[1]Department of Earth & Planetary Sciences, University of New Mexico, 1 University of New Mexico, Albuquerque, NM 87131; lcrossey@unm.edu

[2]U.S. Forest Service, Pacific Northwest Research Stations, Corvallis, OR 97331

[3]New Mexico Environment Department Ground Water Quality Bureau Pollution Prevention Section, 1190 St. Francis Drive, Santa Fe, NM 87505

[4]Water Resources Program, University of New Mexico, Albuquerque, NM 87131

[5]Cibola National Forest, 2113 Osuna Road NE, Albuquerque, NM 87113

Abstract—The Sandia Mountains and adjacent areas represent a valuable regional site for studying the aquifer sustainability of the Pennsylvanian Gray Mesa Formation, an important carbonate aquifer in the region. This paper examines spatial and temporal geochemical characteristics of precipitation, streams, and springs in the Sandia and Manzano Mountains, utilizing over 300 analyses collected over two decades, including datasets from the University of New Mexico and the Cibola National Forest. We use water chemistry data, including stable isotope analysis, to infer flow paths and recharge characteristics, and present data on the aquatic communities in travertine springs in the Sandia Mountains. Major ion analysis indicates that high-elevation springs in the Sandia Mountains (Las Huertas, Capulin, and Cienega) are dominated by calcium-bicarbonate waters and that separate spring groups have distinctive solute chemistries that have persisted from 2012 to 2025, including higher salinity at Capulin Spring. Compositional invariance across seasons and strong clustering of measured parameters at individual spring locations indicate that residence time in the aquifer confers particular characteristics in fault-partitioned reservoirs. Stable isotope analysis indicates that spring discharge is dominated by winter precipitation with an evaporation component reflecting summer recharge. Significant differences between the Manzano and Sandia Mountains recharge waters are noted: the Manzano spring mixing array has a lower proportion of winter recharge and can be considered a "predictor" for future change in Sandia springs in warming climate-change scenarios. Remarkably high carbon dioxide contents of the Las Huertas spring/stream group, the major perennial stream in the region, reached log $pCO_2 > -1$ and resulted in travertine accumulation. Geochemical modeling indicates that the travertine likely results from external carbon dioxide of tectonic origin infiltrating Pennsylvanian carbonate aquifers. A downstream longitudinal sampling of this system shows that higher CO_2 is introduced along the Ellis and Las Huertas fault systems. Water chemistry data, including travertine-associated parameters, influenced diatom communities in the watershed in terms of species richness, cell density, and species distribution in each spring. Seasonality impacted the silica saturation index, leading to differential frustule dissolution among the diatom taxa collected from the springs.

INTRODUCTION

In semiarid regions of New Mexico, groundwater plays an important role in the lives of human, floral, and faunal populations. During droughts, the resilience of groundwater systems is a major concern for water managers and stakeholders. Alpine sources of groundwater recharge are a significant factor for New Mexico's groundwater regimes, and the Sandia Mountains adjacent to the most populous regions of New Mexico are a key recharge area for alluvial and basin-fill aquifers (e.g., Johnson et al., 2002). This work is based on a joint effort between the University of New Mexico (UNM) and the Cibola National Forest, conducted between 2012 and 2025 in the Sandia and Manzano Mountains. We augment previous reports (Frus, 2016; Crossey et al., 2019; DeLay et al, 2021) with new data (2022–2025) from springs of the Sandia Mountains and focus primarily on using water chemistry to infer varying groundwater flow paths. We present selected data associated with the aquatic communities in springs in the Sandia Mountains.

Beyond regional implications, this research offers insights into changing precipitation patterns and recharge dynamics over the past two decades. Understanding the balance between winter snowmelt and monsoonal rain contributions to groundwater is increasingly crucial as climate change alters precipitation regimes in semiarid environments. Stable isotope geochemistry provides a useful approach for distinguishing between these precipitation sources, enabling detailed analysis of seasonal contributions to recharge (see Penna and van Meerveld, 2019). This technique also allows long-term comparisons with historical records, enhancing our ability to detect shifts in hydrologic inputs over time. Through examining the occurrence of active travertine formation, we can determine geochemical and hydrologic controls on the travertine

precipitation process. We hypothesize that calcite supersaturation of Sandia Mountains waters, as evidenced by modern travertine deposits, fluctuates seasonally. Specifically, we expect greater potential for calcite precipitation during fall baseflow conditions and diminished potential for travertine precipitation during the spring season, when snowmelt runoff dominates stream discharge. These findings have significant practical applications because they inform current recharge patterns and water quality trends, through which local authorities can better predict water availability and plan for future needs.

Setting

The study area includes the Sandia Mountains and, to a lesser extent, the Manzano Mountains of north-central New Mexico (Fig. 1). The Sandia Mountains are located along the eastern flank of the Rio Grande rift and comprise an uplifted block of Proterozoic Sandia granite and metavolcanic rocks locally overlain by thin Mississippian Arroyo Peñasco Group (sandstone) and Pennsylvanian strata of the Sandia Formation (limestone and sandstone), which is itself overlain by thick east-dipping limestone of the Grey Mesa Formation (Fig. 2;

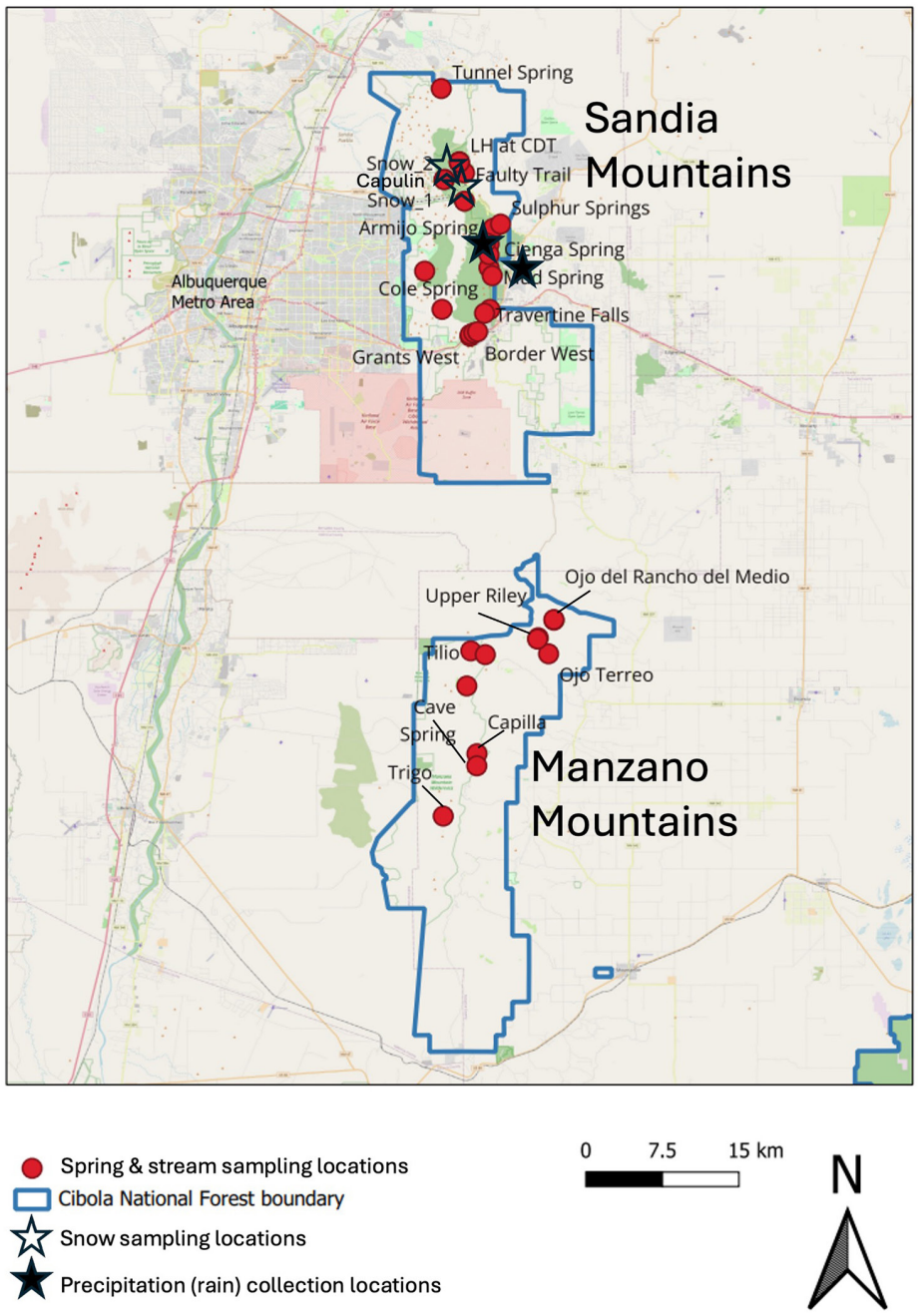


FIGURE 1. Regional location map of the study area. Blue outline indicates the Cibola National Forest boundary in the Sandia and Manzano Mountains. Red circles indicate the stream and spring locations used in the study, including legacy samples. Locations are tabulated in Appendix 1; selected names are shown. Stars indicate the snow sample locations, and black stars represent Sandia Park and the Cienega Spring exclosure, from which the precipitation records derive. Precipitation data are in Appendix 4. LH=Las Huertas; Ca=Capulin; Ci=Cienega/Sulphur).

Connell et al., 1995; Read et al., 1995; Karlstrom et al., 1997; Lucas et al., 1999; Frus, 2016; Lucas et al., 2026). Permian, Pennsylvanian, and Mississippian formations crop out at higher-elevation regions of the Sandia Mountains, within the Placitas fault zone, and along Las Huertas Canyon. Shales in the overlying Atrasado, Bursum, and Abo Formations are confining beds partially isolating the underlying limestone aquifer (Fig. 2; see Lucas et al., 2026). The Gray Mesa Formation (previously known as the Madera Limestone, Lucas et al., 2026) has been identified as the primary hydrostratigraphic unit in

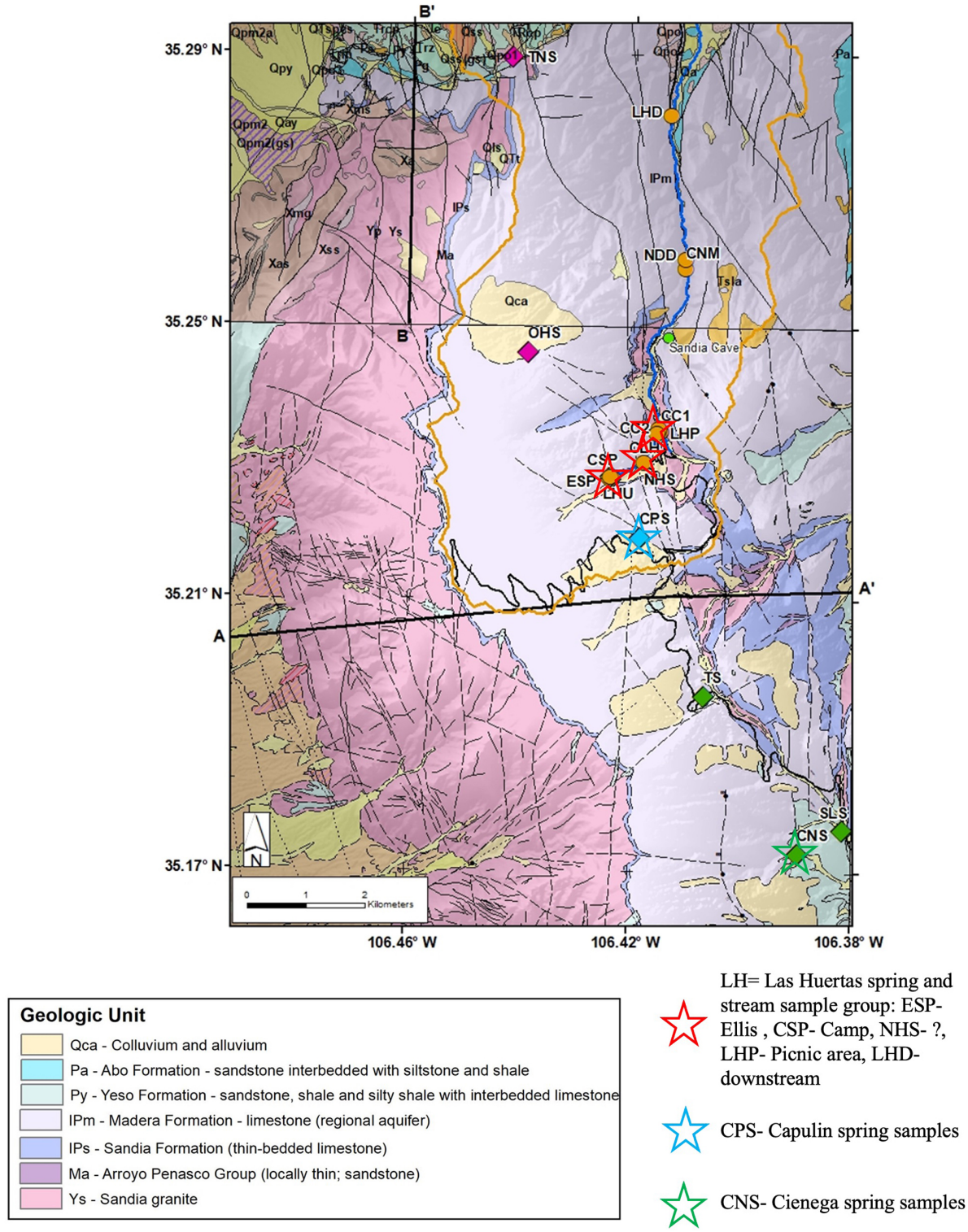


FIGURE 2. Geologic map of the Sandia Mountains (Connell et al., 1995; Read et al., 1995) showing numerous faults. Stars indicate the locations of three springs significant to this study: Las Huertas, Capulin, and Cienega. Other springs mentioned in the study include Sulphur (SLS), Tree (TS), Osha (OHS), and Tunnel (TNS). Doc Long, Oso, and Three Gun Springs are to the south and east (not shown). Study area locations are tabulated in Appendix 1. The Las Huertas Spring group is discussed utilizing these downstream locations (orange circles).

this region (Fig. 2; Johnson et al., 2002). The Sandia Mountains range in elevation from 3,255 m (10,678 ft) at Sandia Crest to about 1,550 m (5,100 ft) at the mouth of Las Huertas Creek in Placitas. Much of this paper focuses on the Las Huertas drainage and the association between widespread travertine deposition in the springs of the Sandia Mountains.

Hydrology

Johnson et al. (2002) characterized the hydrologic setting of the Las Huertas watershed, including precipitation averages and selected discharge data. Fed by spring discharge from the northwest portion of the Capulin Peak and Sandia Crest runoff, the Las Huertas drainage traverses north towards Tecolote, crosses the San Francisco fault zone, and traverses west-northwest into the lower sub-basin. This watershed drains much of the northern portion of the Sandia Mountains and begins near Sandia Crest (Figs. 1 and 2).

Methods

Surface waters and precipitation were collected in 2023–2025. Locations include samples of Las Huertas springs (Ellis Spring and Camp Spring) and Capulin Spring, as well as downstream surface waters (Fig. 1; complete list in Appendix 1). Additionally, samples from the Cienega and Doc Long Springs were sampled for comparison with previous studies. Snow samples were collected near the Capulin Snow Play Area. These data were compiled with previously reported data for the Las Huertas watershed and the surrounding Sandia and Manzano Mountains (Townsend, 2023; Griego, 2022; DeLay et al., 2021; Crossey et al., 2019; Frus, 2016; Johnson et al., 2002). Geochemical analyses were conducted in UNM labs using standard methods, which are described in detail in Townsend (2023). Major cations and trace elements were measured using a Perkin-Elmer Inductively Coupled Plasma Optical Emissions Spectroscopy (ICP OES), and anions were analyzed using ion chromatography with the Dionex DX-500 ion chromatograph in the Analytical Chemistry Laboratory at UNM. Alkalinities were measured in the lab using a 0.02 NH_2SO_4 standard solution to titrate samples down to a pH of 4.5, as measured with an Oakton 300 series pH meter. Stable isotopes of water (oxygen and hydrogen) were analyzed at the Center for Isotopic Studies at UNM, using laser cavity ring-down spectrophotometry (Romanini et al., 1997). The isotopologues are reported using the standard delta notation (see Sharp, 2017) and were plotted with the Global Meteoric Water Line (GMWL), a line representing the linear relationship of isotopic enrichment of δD and $\delta^{18}O$ for natural waters from around the globe (Craig, 1961).

Dissolved inorganic carbon (DIC) was calculated with the thermodynamic equilibrium speciation model PHREEQC (Parkhurst and Appelo, 2013) using pH, temperature, and measured alkalinity to estimate all DIC components: bicarbonate, carbonic acid, and carbonate. Geochemical modeling was performed with both PHREEQC and Geochemist's Workbench (Bethke, 2017). To augment precipitation data, we include precipitation samples collected by Krista Bonfantine of Sandia Park from a collector at the Cienega Spring exclosure between 2014 and 2016.

RESULTS AND DISCUSSION

Hydrochemistry

Data tables for the precipitation and water samples from this study are presented in Appendix 1 (i.e., sample source, date, location, and field water quality parameters), Appendix

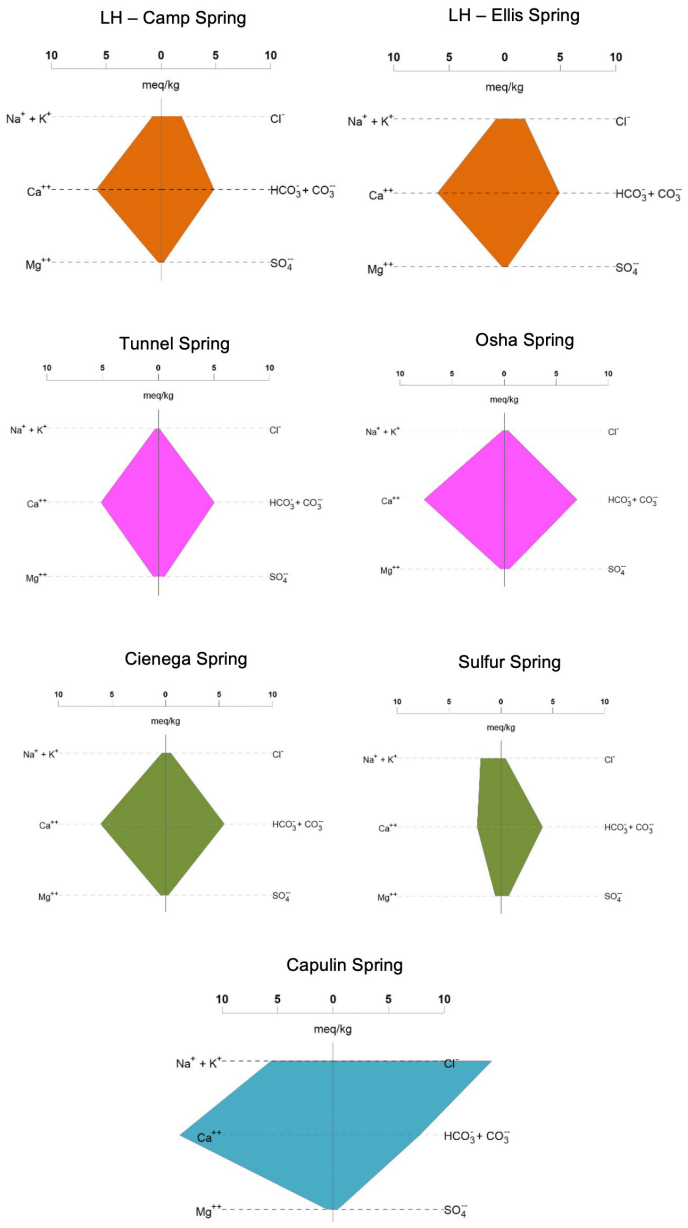


FIGURE 3. Stiff diagrams (Drever, 1988) visually illustrate differences in major ion concentrations (in meq/kg) among selected springs in the Sandia Mountains (a single representative date is used for each). Spring locations are shown in Figure 1. LH=Las Huertas. Spring names, locations, and data are listed in Appendices 1–3. The first listed springs are calicum-and-bicarbonate-dominated waters typical of limestone aquifers. Capulin Spring (bottom) has higher dissolved solids, with additional sodium and chlorine, and a higher proportion of calcium relative to bicarbonate. Color scheme matches that of the locations in Figure 2.

2 (i.e., major ions and modeled parameters), and Appendix 3 (i.e., stable isotopes and minor/trace elements). Appendix 4 provides precipitation data (i.e., rain and snow). Major ion comparisons of the springs reveal several compositional types. Stiff diagrams (Drever, 1988) utilize shapes to distinguish various water types based on the molarities (in milliequivalents per kilogram) of the major ions. Figure 3 highlights several patterns for representative samples: the Las Huertas group (LH) springs have calcium- and bicarbonate-dominated waters (with small amounts of sodium and chloride), as expected from a limestone aquifer; Capulin Spring is much saltier, with predominantly sodium and chloride but still substantial calcium and bicarbonate; Cienega Spring is similar to the Las Huertas group springs, though more dilute and without much sodium and chloride. Sulphur Spring is colored like Cienega Spring, to which it is very close geographically, but has less calcium and more sodium. Solutes are acquired via water–rock interactions, and the observed variations suggest that meteoric recharge interacts primarily with the limestone of the regional aquifer. Piper diagrams (Drever, 1988) based on major ion chemistry show distinct trends in anion composition (Fig. 4, lower right triangle), with each spring maintaining a unique composition over the study interval. Capulin Spring has the highest sodium and chloride content—but also additional calcium relative to bicarbonate (Fig. 3); the proportion of sodium is not high enough to indicate that halite (sedimentary salt) is the source, nor would that explain the additional calcium. Given the proximity of Capulin Spring to developed areas near Sandia Crest, an anthropogenic source, such as calcium chloride used in treatment processes, cannot be ruled out (Droste and Gehr, 2018).

Stable isotope analysis of local precipitation (rain and snow, Appendix 4) and springs and streams (Appendix 3) shows that precipitation varies widely (Fig. 5); data from this study expand the range observed relative to previous work. As indicated in the stable isotope plot, snow exhibits the most ^{18}O-depleted signature (down and to the left on the diagram), whereas warmer rain tends to be plotted higher and to the right in the diagram. This is because liquid–vapor isotope fractionation is much stronger at colder temperatures, and thus at higher elevations (see Sharp, 2017). Despite the broad range of precipitation values, the springs clustered in a much narrower range over the study period, and the position of the cluster shows that the Sandia springs are dominated by the snowmelt signature (with some rain contribution), whereas the Manzano springs are distinctly less influenced by a snow component.

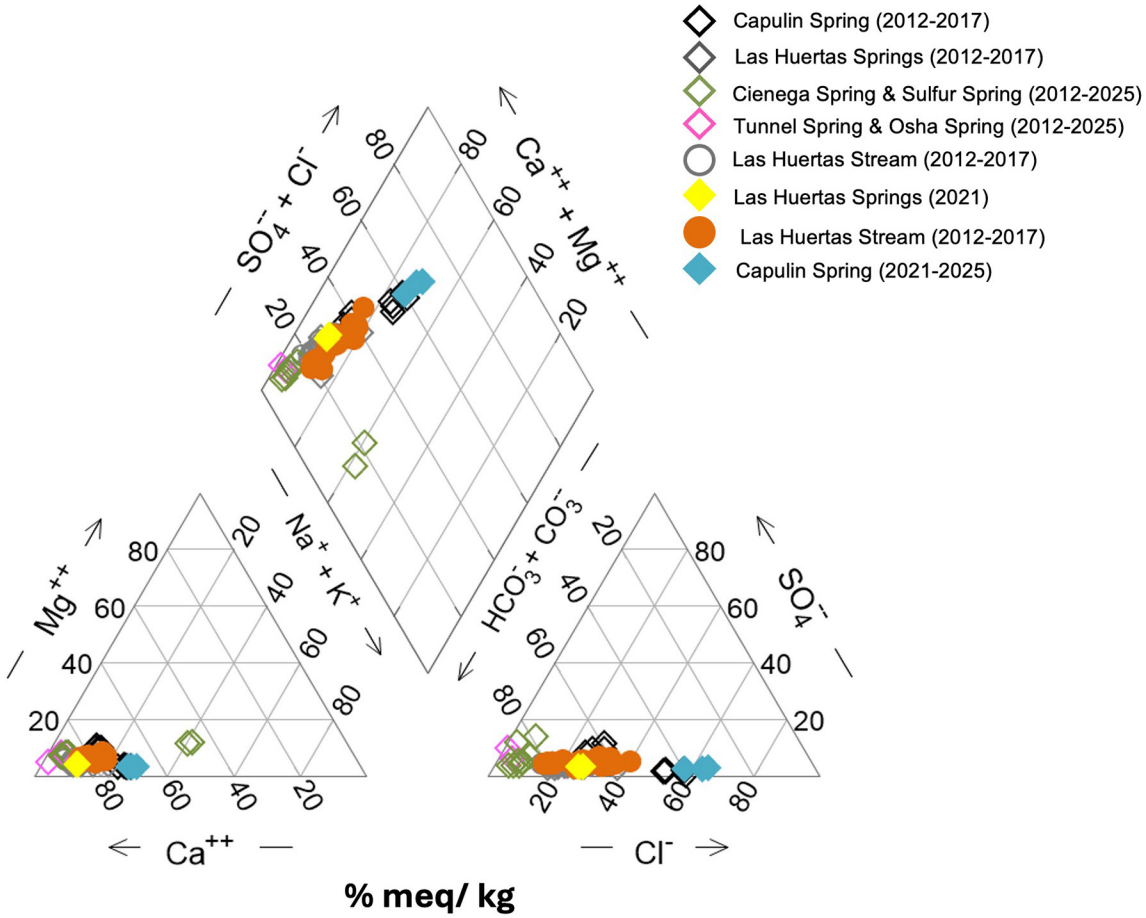


FIGURE 4. Piper diagram (Drever, 1988) of this study and all compiled water chemistry data collected within the Sandia and Manzano Mountains ranger districts from 2012 to 2017. Sample points are color-coded according to distinct spring chemistry groups in the anion ternary plot (bottom-right triangle); the colors match those used in Figures 2 and 3. All except Capulin are calcium-bicarbonate dominated. Note that each spring has a unique, characteristic composition that varies only slightly during the 2012–2025 study period. Geochemical variations are interpreted as specific water–rock interactions, as discussed in the text.

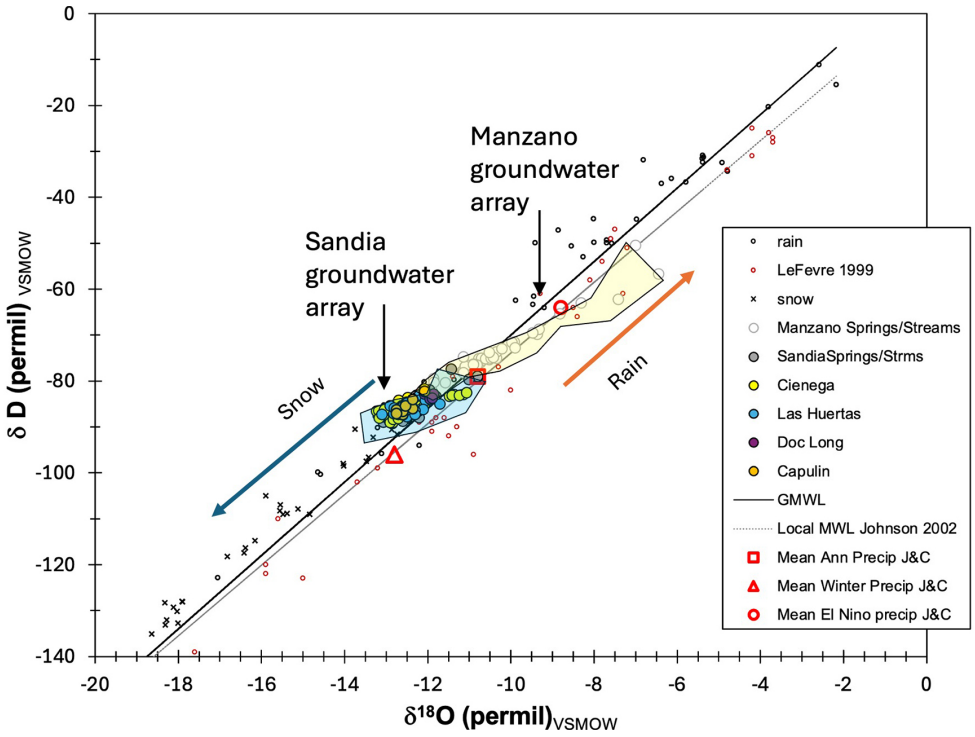


FIGURE 5. Stable isotope composition of precipitation (rain and snow) in the Sandia Mountains from 2012 to 2025 (black symbols from Frus, 2016; Crossey et al., 2019; DeLay et al., 2021; and this study). Small red symbols represent precipitation measured by LeFevre (1999; bold red symbols reflect average winter [triangle], summer [circle], and El Niño [square] precipitation from the Sandia Mountains in 1996–1997; from Johnson et al., 2002). Polygons indicate that springs and streams in the Sandia Mountains (blue polygon) are more depleted in ^{18}O than springs and streams in the Manzano Mountains (yellow polygon), reflecting higher elevation/colder temperatures/higher percentage of winter recharge in the Sandia Mountains. In future climate change scenarios, Sandia Mountains groundwater is expected to shift up and to the right, more like Manzano Mountains groundwater as snowpack decreases.

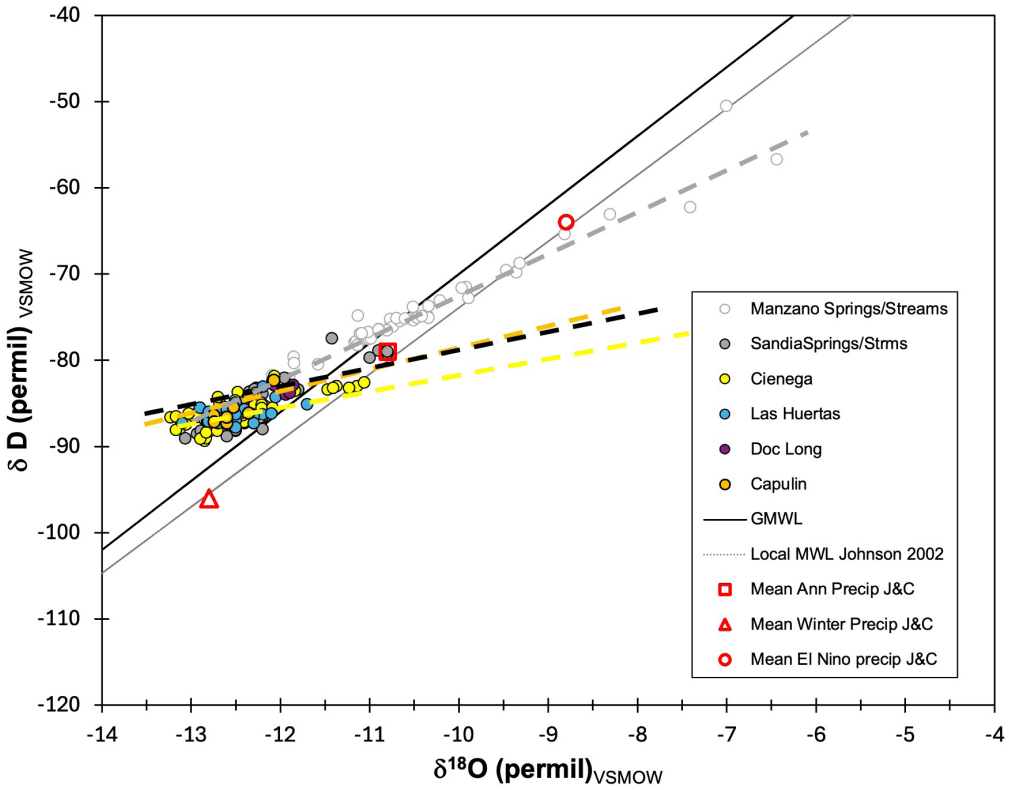


FIGURE 6. Stable isotope composition of groundwater in the Sandia and Manzano Mountains sampled at several springs. The Cienega Spring, Las Huertas group springs, Doc Long Spring, and Capulin Spring overlap and form groundwater mixing arrays with a dominance of winter recharge and a slope that is less steep than the GMWL, possibly reflecting an evaporation component during recharge, such as is also seen in the Manzano Mountains array (gray line).

We interpret this to mean that the snowpack contributes less to groundwater recharge in the Manzano Mountains than in the Sandia Mountains. We also note that the individual springs tend to strongly overlap each other isotopically, indicating that the stable isotope compositions reflect regional recharge characteristics, whereas the solutes in the individual springs reflect more specific flowpaths. The linear arrays formed by individual springs (Fig. 6, bold dashed lines) have positive slopes lower than the Global Meteoric Water Line, indicative of an evaporation component, perhaps during recharge or through monsoonal recycling (Sharp, 2017). The strong evaporative component shown in the Manzano Mountains data results in part from overland flow and downstream evaporation in open meadows.

Travertine Formation and Ecology

Las Huertas Spring and the Las Huertas drainage are unusual for a high-elevation spring springshed in that there are impressive travertine deposits below the source springs (ESP–Ellis and CSP–Camp springs). Figure 7 shows the extensive rimstone dams and terraces in the upper Las Huertas reach; similar features are observed at the Las Huertas picnic area. Other occurrences of travertine are present throughout the Sandia Mountains, and significant fossil deposits are mapped in the region. Travertine ($CaCO_3$) forms when carbonic waters that are oversaturated with respect to CO_2 degassing because of turbulence. For example, as water flows over these rimstone dams and vegetation, via the following chemical reactions (Crossey et al., 2009, 2016; Williams et al., 2013). Solutes acquired from recharging groundwater interact with limestone (calcite) in the aquifer based

$$CaCO_3 \text{ (limestone)} + H_2O + CO_2 \text{ (external)}.$$

Solutes are transported in groundwater as

$$2HCO_{3-} + Ca^{2+} \text{ (in solution)}$$

Upon emergence to the atmosphere, excess CO_2 is degassed, resulting in travertine (calcite) precipitation via

$$CaCO_3 \text{ (travertine)} + CO_2 \text{ (degassed)} + H_2O.$$

The amount of travertine precipitated is equal to the amount of external CO_2 in the system at the dissolution stage. From the water chemistry (pH, temperature [T], major ions), we can compute pCO_2 with which the water equilibrated, as well as the degree of supersaturation with respect to calcite. Using PHREEQc (Parkhurst and Appelo, 2013), we can model the saturation conditions for the Sandia Mountains springs. We can model CO_2 using the C_{ext} computation methods outlined by Crossey et al. (2009) and shown schematically in Figure 8. The amount of carbon derived from the dissolution of carbonate in the aquifer, C_{carb}, is estimated by taking the sum of calcium and magnesium ions (Ca+Mg derived from carbonate minerals) and subtracting sulfate to correct for calcium due to possible dissolution of gypsum. C_{carb} is subtracted from the computed DIC, and the remaining DIC is defined as C_{ext}, which can be parsed into CO_2 from deep sources ($C_{endogenic}$) plus soil CO_2 ($C_{organic}$) if carbon isotope data are available; we have not performed this analysis here.

In 2021–2022, Townsend (2023) examined downstream trends in these processes using the C_{ext} computation method outlined above. Figure 9 shows the locations used in the longitudinal sampling. Figure 10 shows downstream plots of DIC, the computed log pCO_2, the computed C_{ext}, and the amount of calcite precipitated per liter of water along the flowpath. The overall trends from upstream to downstream are decreasing DIC, decreasing pCO_2, decreasing C_{ext}, and decreasing calcite precipitation. However, there are distinct "jumps" in CO_2 trends, indicating resupply of highly charged carbonic water along the flowpath, specifically where faults are crossed. The log pCO_2 for the atmosphere is −3.5, and that for soil gas is about an order of magnitude higher (−2.5; Drever, 1988). Thus, log pCO_2 values for this spring system (up to −0.5) are orders of magnitude higher than the log pCO_2, indicating that another source of CO_2 is present. In Edgewood, nearby in the eastern area downslope of the Sandia Mountains, Edgewood Cavern is reported to contain high CO_2 (Jenkins, 1982), and farther to the southeast of the Sandia Mountains, near Estancia, CO_2 has been commercially produced (Broadhead et al., 2009). Additionally, workers have identified tectonic sources as a significant contributor to carbonic groundwater systems at regional scales (Crossey et al., 2009, 2016; Williams et al., 2013; Priewisch et al., 2014). The association of faulting, active carbonic inputs, and fossil travertine accumulations is consistent with regional accumulations driven by tectonic sources.

An evaluation of diatom communities associated with travertine-producing springs in the Sandia Mountains identified



FIGURE 7. Las Huertas Creek has impressive travertine deposits below its source springs (i.e., ESP–Ellis and CSP–Camp Springs). Travertine ($CaCO_3$) forms from carbonic waters that are oversaturated with calcite due to CO_2 degassing caused by turbulence, for example, as water flows over these rimstone dams and vegetation, via reactions described in text.

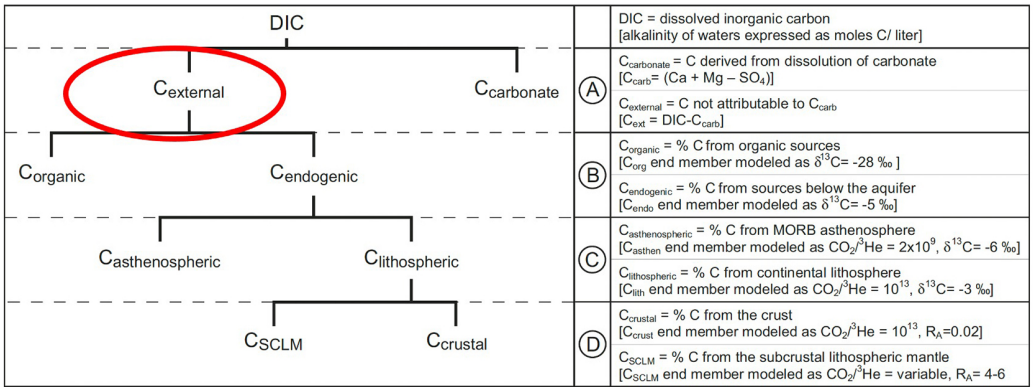


FIGURE 8. Flowchart and nomenclature for resolving CO_2 sources (modified from Crossey et al., 2009). The methodology involves mixing models using: A) water chemistry; B) water chemistry and carbon isotopes; and C) carbon isotopes and $CO_2/^3He$. MORB=mid-ocean ridge basalt; SCLM=subcontinental lithospheric mantle. For this study, available data permitted the use of step A only (red outline).

several commonalities among travertine-associated systems (Mendoza, 2017; DeLay et al., 2021). In particular, these studies found lower species richness in travertine-depositing springs versus non-travertine-depositing springs. The travertine springs, however, showed higher diatom density. Over 127 diatom taxa were identified, but four emerged as uniquely associated with travertine-depositing springs: *Diatoma mesodon*, *Gyrosigma acuminatum*, *Halamphora montana*, and *Surirella brebissonii.* Additionally, Mendoza (2017) found that both pH and dissolved silica were affected by diatom communities, with pH varying by up to 1 log unit. Although travertine forms in the absence of biological activity when high degrees of supersaturation are present, the incorporation of biological/organic debris, as well as biologically driven changes in stream chemistry, also influences its abundance and morphology.

CONCLUSIONS

Major ion analyses of spring water in the Sandia and Manzano Mountains, presented herein and in previous studies, indicate that springs are dominated by calcium-bicarbonate waters and that separate spring groups have distinctive solute chemistries that have persisted from 2012 to 2025, including higher salinity at Capulin Spring. Compositional invariance across seasons and strong clustering of measured parameters at individual spring locations indicate that residence time in the aquifer confers particular characteristics in fault-partitioned reservoirs. Stable isotope analysis indicates that spring discharge is dominated by winter precipitation, with an evaporation component reflecting summer recharge. The lack of strong seasonal compositional changes or dilution is indicative of a multi-year residence time—consistent with the evolved chemistry showing equilibration of a CO_2-charged system with the limestone aquifer. Significant differences between recharge waters in the Manzano and Sandia Mountains are noted. The Manzano Mountains spring mixing array has a lower proportion of winter recharge and can be considered a "predictor" for future change in Sandia Mountains springs in warming climate-change scenarios with diminished snowpack. The remarkably high carbon-dioxide content of the Las Huertas spring/stream group, the region's major perennial stream, reached log $pCO_2 > -1$, resulting in seasonal travertine precipitation. Geochemical modeling indicates that the travertine likely results from the infiltration of external tectonically derived carbon dioxide into the Gray Mesa Formation. A downstream longitudinal sampling of this system shows that higher CO_2 is introduced along the Ellis and Las Huertas fault systems. Water chemistry, including travertine-associated parameters, influenced diatom communities in the watershed, resulting in lower species richness and higher cell densities in travertine-depositing springs.

ACKNOWLEDGEMENTS

This study was performed with the support of the Cibola National Forest through Contract #16-CS-11030300-016. Support for students was provided by National Science Foundation (NSF) grants no. 1914490 and HRD1826758, as well as an award by the New Mexico Water Resources Research Institute at New Mexico State University to N. DeLay. Additional support from the New Mexico Geological Society Grants-in-aid to Townsend, Griego, and Somer was appreciated. UNM Alumni Fellowships provided support to students. Field support from Kyle Paffat, Cory Walk, Luke Colis, and Kate Mendoza was greatly appreciated throughout the study. Ryan Webb and Michael Albonico assisted with snow sampling and methodology. We thank Krista Bonfantine for precipitation samples. Helpful reviews by Cristina Ferguson and Johanna Blake improved the manuscript.

REFERENCES

Bethke, C.M., and Yeakel, S., 2017, The Geochemist's Workbench Essentials Guide, release 11: Champaign, Illinois, Aqueous Solutions, LLC. https://www.gwb.com/index.php

Broadhead, R.F., Mansell, M., and Jones, G., 2009, Carbon dioxide in New Mexico: Geologic distribution of natural occurrences: New Mexico Bureau of Geology and Mineral Resources, Open File Report 514, 131 p. https://doi.org/10.58799/OFR-514

Connell, S.D., Cather, S.M., Ilg, B., Karlstrom, K.E., Menne, B., Picha, M., Andronicus, C., Read, A.S., Bauer, P.W., and Johnson, P.S., 1995, Geology of the Bernalillo and Placitas quadrangles. Sandoval County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Open-file Geologic Map OF-GM 2, scale 1:24,000. https://doi.org/10.58799/OF-GM-2

Craig, H., 1961, Standard for reporting concentrations of deuterium and oxygen-18 in natural waters: Science, v. 133, p. 1833–1834. https://doi.org/10.1126/science.133.3467.1833

Crossey, L.J., Karlstrom, K.E., Springer, A.E., Newell, D., Hilton, D.R., and Fischer, T., 2009, Degassing of mantle-derived CO_2 and He from springs in the southern Colorado Plateau region—Neotectonic connections and implications for groundwater systems: Geological Society of America Bulletin, v. 121, p. 1034–1053. https://doi.org/10.1130/B26394.1

Crossey, L.J., Karlstrom, K.E., Schmandt, B., Crow, R.R., Colman, D.R., Cron, B., Takacs-Vesbach, C.D., Dahm, C.N., Northup, D.E., Hilton, D.R., and Ricketts, J.W., 2016, Continental smokers couple mantle degassing and distinctive microbiology within continents: Earth and Planetary Science Letters, v. 435, p. 22–30. https://doi.org/10.1016/j.epsl.2015.11.039

Crossey, L.J, Bixby, R., Walk, C., and Griego, B, 2019, Cibola National Forest Spring Inventory Annual report to Cibola National Forest, 50 p.

DeLay, N., Crossey, L., Bixby, R., Collis, L., and Griego, B., 2021, Cibola National Forest Spring Inventory Addendum: Hydrogeochemical and Biological Analysis of Spring Waters, Sandia and Manzano Mountains, New Mexico: Annual report to Cibola National Forest, 57 p.

Drever, J.I., 1988, The Geochemistry of Natural Waters: Englewood Cliffs, New Jersey, Prentice Hall, 437 p.

Droste, R.L. and Gehr, R.L., 2018, Theory and Practice of Water and Wastewater Treatment, second edition: Hoboken, New Jersey, John Wiley & Sons, 992 p.

Frus, R. J. 2016, Multidisciplinary work to determine hydrology of arid land springs and how spring waters influence water quality and ecosystem health for desert environments [unpublished PhD Dissertation]: Albuquerque, University of New Mexico, 193 p.

Griego, B., 2022, Hydrogeochemical analysis of springs in the Sandia Mountains, New Mexico [unpublished Undergraduate Thesis]: Albuquerque, University of New Mexico, 23 p.

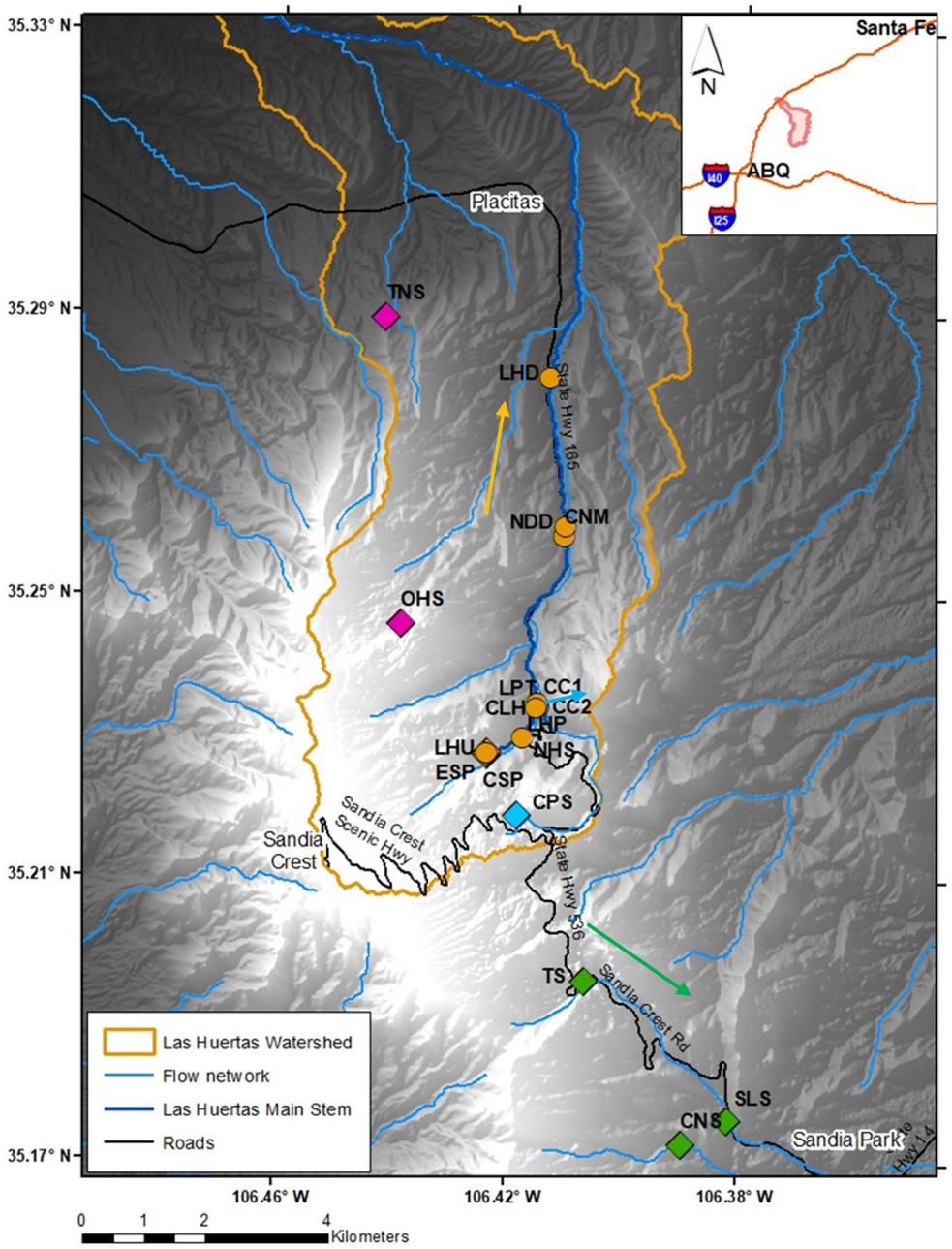


FIGURE 9. Longitudinal sampling of travertine-depositing Las Huertas Creek in the Las Huertas springshed (orange), from Townsend (2023). Symbol explanation in Figure 2. Capulin Spring flows into Las Huertas Creek with a confluence near the Las Huertas picnic area (LHP). Osha Spring (OHS) and Tunnel Spring (TNS) are also in this springshed. Cienega Spring (CNC), Sulphur Spring (SLS), and Tree Spring (TS) flow towards Tijeras Canyon.

Jenkins, D.N., 1982, Geohydrology of the Madera Group, western Estancia Basin: New Mexico Geological Society, Guidebook 33, p. 361–366. https://doi.org/10.56577/FFC-33.361

Johnson, P.S., LeFevre, W.J., and Campbell, A., 2002, updated 2008, Hydrogeology and water resources of the Placitas area, Sandoval County, New Mexico: New Mexico Bureau of Geology and Mineral Resources, Open-file Report 469, p. 191. https://doi.org/10.58799/OFR-469

Karlstrom, K.E., Dallmeyer, R.D., and Grambling, J.A., 1997, $^{40}Ar/^{39}Ar$ evidence for 1.4 Ga regional metamorphism in New Mexico: Implications for thermal evolution of lithosphere in the southwestern USA: Journal of Geology, v. 105, v. 2, p. 205–224. https://doi.org/10.1086/515912

LeFevre, W. J., 1999, Geochemical characterization of geologically complex mountain front aquifers: Placitas, New Mexico [unpublished M.S. Thesis]: Socorro, New Mexico, Institute of Mining and Technology. 209 p.

Lucas, S.G., Rowland, J.M., Kues, B.S., Estep, J.W., and Wilde, G.L., 1999, Uppermost Pennsylvanian and Permian stratigraphy and biostratigraphy at Placitas, New Mexico: New Mexico Geological Society, Guidebook 50, p. 281–292. https://doi.org/10.56577/FFC-50.281

Lucas, S.G., Krainer, K., DiMichele, W.A., Allen, B. D., Barrick, J.E., Vachard, D., Eble, C., Bashforth, A.R., Donovan, M.P., Ernst, A., Pfefferkorn, H.W., and May, P.T., 2026, The Pennsylvanian System in the Sandia Mountains, New Mexico, USA: Smithsonian Contributions to Paleobiology, in press.

Mendoza, K.E., 2017, Diatom communities of travertine-precipitating springs on a gradient of anthropogenic disturbance in the Sandia Mountains, New Mexico: Water Resources Professional Project Report: Albuquerque, University of New Mexico.

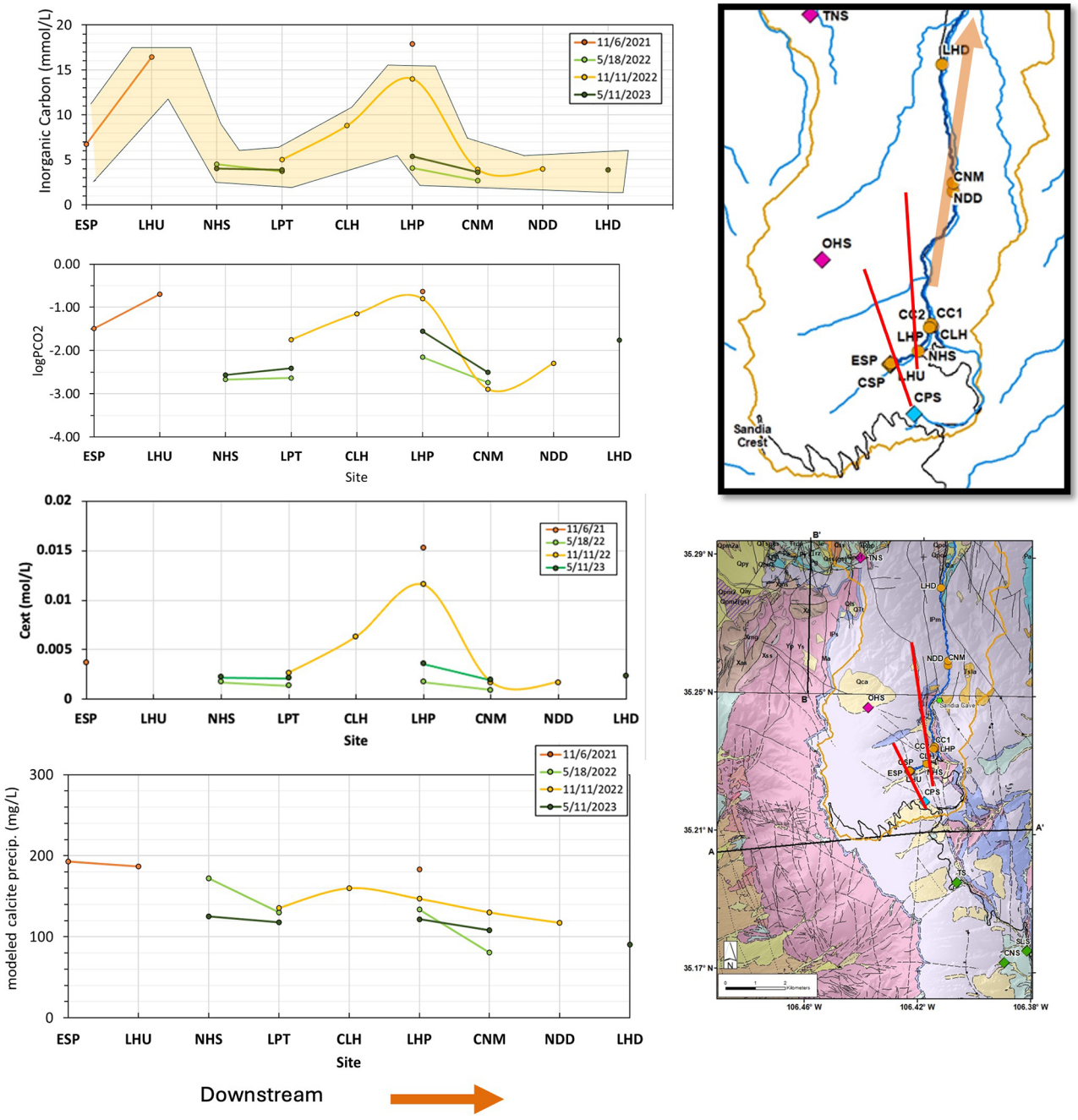


FIGURE 10. Downstream plots showing calculated dissolved inorganic carbon (DIC) with respect to location downstream from Ellis Spring (EPS) and Camp Spring (CSP) to Las Huertas downstream (LHD) in the lower reaches of the Las Huertas stream. The method for calculating the parameters is discussed in the text. Note that DIC, log pCO_2, and C_{ext} increase across mapped faults at LHU and LHP (red lines on map at right).

Parkhurst, D.L., and Appelo, C.A.J., 2013, Description of input and examples for PHREEQC version 3—A computer program for speciation, batch-reaction, one-dimensional transport, and inverse geochemical calculations: U.S. Geological Survey Techniques and Methods, Book 6, Chapter A43, 497 p. https://pubs.usgs.gov/tm/06/a43/

Penna, D., and van Meerveld, H.J., 2019, Spatial variability in the isotopic composition of water in small catchments and its effect on hydrograph separation: WIREs Water, v. 6, p. 1367. https://doi.org/10.1002/wat2.1367

Priewisch, A., Crossey, L.J., Karlstrom, K.E., Polyak, V.J., Asmerom, Y., Nereson, A., and Ricketts, J.W., 2014, U-series geochronology of large-volume Quaternary travertine deposits of the southeastern Colorado Plateau: Evaluating episodicity and tectonic and paleohydrologic controls: Geosphere, v. 10, p. 401–423. https://doi.org/10.1130/GES00946.1

Read, A.S., Karlstrom, K.E., Connell, S., Kirby, E., Ferguson, C.A., Ilg, B., Osburn, G.R., Van Hart, D., and Pazzaglia, F.J., 1995, Geology of Sandia Crest quadrangle, Bernalillo and Sandoval Counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources Open-file Geologic Map OF-GM 6, scale 1:24,000. https://doi.org/10.58799/OF-GM-6

Romanini, D., Kachanov, A.A., and Stoeckel, F., 1997, Diode laser cavity ring down spectroscopy: Chemical Physics Letters, v. 270, p. 538–545. https://doi.org/10.1016/S0009-2614(97)00406-5

Sharp, Z. 2017, Principles of Stable Isotope Geochemistry, Second edition, various pagination. https://doi.org/10.25844/h9q1-0p82

Townsend, K., 2023, Hydrochemistry of an alpine karst system, northern New Mexico: Las Huertas [unpublished M.S. Thesis]: Albuquerque, University of New Mexico. https://digitalrepository.unm.edu/eps_etds/368

Williams, A.J., Crossey, L.J., Karlstrom, K.E., Newell, D., Person, M., and Woolsey, E., 2013, Hydrogeochemistry of the middle Rio Grande aquifer system—Fluid mixing and salinization of the Rio Grande due to fault inputs: Chemical Geology, v. 351, p. 281–298. https://doi.org/10.1016/j.chemgeo.2013.05.029

Appendices can be found at
https://nmgs.nmt.edu/repository/index.cfml?rid=2026009



Long-tailed weasel (*Mustela frenata*) in the Sandia Mountains. Weasels can be found throughout the state, mainly in wooded or rocky areas. They aggressively defend their territories, which can be up to 40 acres (0.16 km^2) in area. Photograph courtesy of Celestyn Brożek.