JVST A
Journal of Vacuum Science & Technology A
PERSPECTIVE
avs.scitation.org/journal/jva

# Uranium and arsenic unregulated water issues on Navajo lands

Cite as: J. Vac. Sci. Technol. A **38**, 031003 (2020); doi: 10.1116/1.5142283
Submitted: 11 December 2019 · Accepted: 25 February 2020 ·
Published Online: 20 March 2020

View Online Export Citation CrossMark

Jani C. Ingram,[1] Lindsey Jones,[2] Jonathan Credo,[3] and Tommy Rock[4]

## AFFILIATIONS

[1]Department of Chemistry and Biochemistry, Northern Arizona University, Flagstaff, Arizona 86011
[2]Water Infrastructure Finance Authority of Arizona, Phoenix, Arizona 85007
[3]Clinical Translation Science, College of Medicine, University of Arizona, Tucson, Arizona 85721
[4]Navajo Community Consultant, Oljato, Utah 84536

**Note:** This paper is part of the Special Topic Collection on 30 years of the Nellie Yeoh Whetten Award — Celebrating the Women of the AVS.

## ABSTRACT

The geologic profile of the western United States lends itself to naturally elevated levels of arsenic and uranium in the groundwater and can be aggravated by mining. The Navajo Nation, located in the American Southwest, is the largest contiguous Native American Nation and has over a 100-year legacy of hard rock mining. Concentrations of uranium and arsenic above drinking water standards in unregulated water sources pose various human-health risks to the Navajo Nation due to the lack of public water infrastructure that exists. Although high natural background concentrations may occur in some environments, anthropogenic contamination concerns are especially troublesome for the Navajo Nation, where past uranium mining activity and natural sources affect unregulated water supplies. Community engaged research on uranium and arsenic present in unregulated water wells in the western portion of the Navajo Nation has been a focus of the Ingram laboratory since 2003. These studies have provided important information, particularly for uranium and arsenic, to the communities and the Navajo tribal leaders.



## I. BACKGROUND

The Navajo Nation is the largest contiguous Native American reservation in the continental United States. Located within the Four Corners region of the American Southwest, its borders span 71 000 square kilometers across Arizona, New Mexico, and Utah. The Navajo Nation is recognized by the United States' government as a sovereign nation, though the United States retains plenary power. The Navajo Reservation is divided into 110 tribal Chapters governed through five management Agencies: Chinle (14 Chapters), Crownpoint/Eastern (31 Chapters), Fort Defiance (27 Chapters), Shiprock (20 Chapters), and Tuba City/Western (18 Chapters).[1] The Navajo Nation is within the Colorado Plateau region where the climate is largely controlled by orographic effects and elevation. Areas below 1370 m are semiarid. The average precipitation is 20–30 cm on average per year. However, some lowland areas may receive less than 8 cm of precipitation per year. Most of the Navajo Nation is in a rain shadow where much of the precipitation comes from the south and is blocked by the southern rim of the Colorado Plateau. Up to 65% of the yearly precipitation occurs during the late summer months (July and August) and can result in flash flooding. All runoff goes to the Colorado River, either directly or via one of the tributaries (the San Juan and the Little Colorado Rivers).[2]

The geologic profile of the western United States lends itself to naturally elevated levels of arsenic and uranium in the groundwater; some wells have been shown to exceed the Environmental Protection Agency Drinking Water limit of 10 parts per billion (ppb) for arsenic and 30 ppb for uranium.[3] Mining can exacerbate this problem by introducing mine tailings waste that is high in arsenic and uranium into groundwater systems.[4] Areas with natural mineral deposits can have high levels of dissolved metals due to acid rock drainage (ARD). ARD is a natural process caused by the weathering and oxidation associated with all sulfide minerals, which mobilizes metals and must be considered when creating remediation goals.[5] A subset of ARD is acid mine drainage that occurs due to mining activities increasing the acidity of waters due to the enhanced exposure of pyrite and other sulfide minerals to oxygen and water sources, thereby increasing the level of dissolved metals in the water. Also, mining operations can increase the amount of water being discharged after contact with sulfide minerals, resulting in even greater mobilization of metals.[6]

From 1948 to 1956, uranium mining took place on the Colorado Plateau and the Navajo Reservation. Past activities resulted in an estimated 1200 mine sites in the Navajo Reservation;[7] however, most of the mines were concentrated in the Four Corners area and the southwestern region near Cameron, AZ, as shown in Fig. 1.[8] In the Four Corners region, the mines were mainly underground mines while in the Cameron area open pit mining occurred.[9] It is estimated that Arizona mines on the Colorado Plateau and the Navajo Reservation produced 32 million pounds of uranium oxide between 1947 and 1987.[10] In addition to the uranium issues, arsenic is also known to be a contaminant of interest in Arizona. The Colorado Plateau consists of layers of sedimentary rock (Supai Sandstone) that contain deposits of arsenic, which contribute to elevated levels of arsenic in the groundwater.[11] Additionally, alkaline groundwater in northern Arizona as well as in other parts of the United States contributes to high arsenic levels in the groundwater.[12] The presence of iron oxide minerals in Arizona increases adsorption or coadsorption of arsenic, which, depending on the conditions (pH, salt content, etc.), can increase soluble arsenic in the groundwater.[9]

While the link between environmental uranium exposure and health problems is still being determined, the perception of the Navajo people is that uranium has poisoned people from their communities.[13,14] The Navajo's perspective can be understood in light of the many abandoned mines following the mining boom, general fear surrounding environmental uranium exposure and an increased risk of cancer, kidney disease, and other health problems, and their limited success in gaining compensation following the passage of the Radiation Exposure Compensation Act in 1990.[11]

One example of health risk and uranium exposure that has been documented is kidney cancer; the kidney is a target organ of uranium.[15,16] Three sources of publicly available data indicate higher rates of kidney cancer among Native Americans in the southwest, as compared to non-Hispanic whites. This is in contrast to the general trend of lower overall cancer burden seen for Native Americans. One source of data is the Annual Report to the Nation

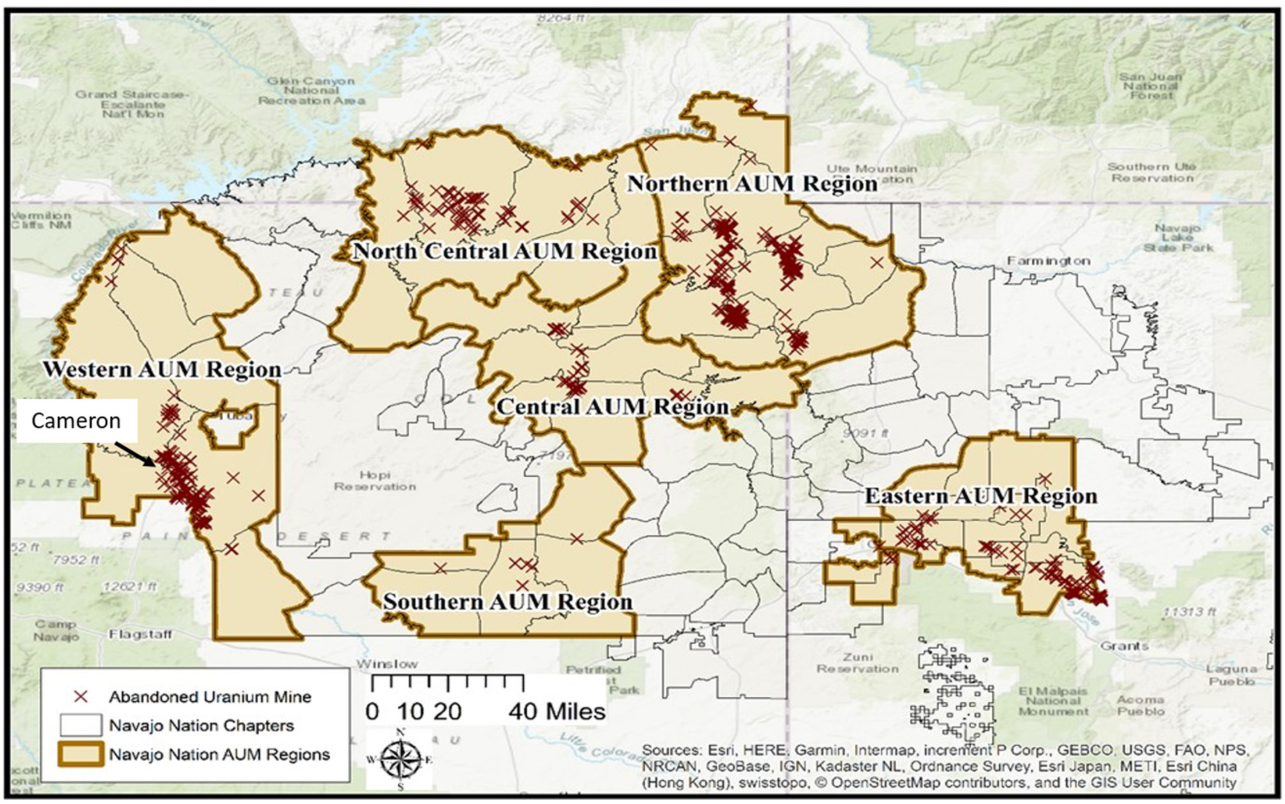


**FIG. 1.** Map of the Navajo Nation with the abandoned uranium mine sites represented by "X's" and the Navajo Agencies and Chapters outlined within the map (Ref. 8) [OSM Map On Garmin. (May 13, 2019). OpenStreetMap Wiki. Retrieved 10:12, June 12, 2019 from https://wiki.openstreetmap.org/w/index.php?title=OSM_Map_On_Garmin&oldid=1851574].

on the Status of Cancer, featuring cancer in American Indians and Alaska Natives,[17] which reports that between 1999 and 2004, the age adjusted kidney cancer incidence rates for the southwest region were 25.1 and 12.6 per 100 000 for Native American males and females, respectively. In contrast, the rates for non-Hispanic white males and females were 15.8 and 8.2, respectively, indicating a 50% increased likelihood of kidney cancer for both sexes of Native Americans. Arizona-specific cancer data[18] show that for the years from 1995 to 2003, kidney cancer incidence rates were 18.87 and 11.65 per 100 000 for American Indians and non-Hispanic whites, respectively. The third source of cancer data is the *Cancer among the Navajo* report from the Navajo Cancer Workgroup and Navajo Epidemiology Center.[19] The tribal-specific analysis of surveillance cancer incidence, stage at diagnosis, and mortality data reported to the Arizona Cancer Registry, New Mexico Tumor Registry, and Utah Cancer Registry is for 2005–2013. The report indicates that Navajo people are 7.2 times more likely to pass away from gallbladder cancer, 4.4 times more likely to pass away from stomach cancer, 2.1 times more likely to pass away from kidney cancer, and 1.8 times more likely to pass away from liver cancer compared to non-Hispanic whites.

The quality of water from private wells, which are not regulated by a government agency, creates concerns for public health. Twenty-three percent of private wells in the United States exceeded a human-health benchmark for one or more contaminants.[20] Unregulated wells typically have more contamination issues than regulated wells because they may not be as deep or as well constructed as municipal wells.[21] Also, unregulated wells are not regularly tested for contaminants and often lack water treatment systems.[22] Unregulated wells provide important water sources for sparsely populated areas where regulated water sources, such as municipal water systems, are unavailable. This fact is especially evident on the Navajo Nation where approximately 30% of homes lack access to municipal water supplies in their homes and rely on hauling water to meet their needs. Because many Navajo people live in low-density areas, the cost to benefit ratio of developing water infrastructure is unfeasible.[23] Additionally, for many generations, livestock have played an important role in the Navajo culture and economy. Raising livestock requires relatively large amounts of land, thereby preventing some Navajo from living in areas where public water supplies are available. Instead, they live in sparsely populated areas where the closest water supply is from unregulated, shallow, windmill-powered wells that were installed for livestock use. There are approximately 900 windmill wells throughout the Navajo Nation.[24]

The Navajo Nation has established water quality standards for surface water and drinking water sources. These standards are enforced at monitored wells to ensure that negative health effects do not occur. The Navajo Nation Water Quality Program (NNWQP) is operated under the Navajo Nation Environmental Protection Agency and is responsible to ensure that the water quality standards are enforced. The NNWQP states that the domestic water supply must not exceed 30 $\mu$g/l for uranium and 10 $\mu$g/l for arsenic, similar to the Environmental Protection Agency Drinking Water limits. In addition, arsenic must not exceed 200 $\mu$g/l for livestock water. There is no listed maximum for uranium in livestock water.[25] These standards are not applied to the unregulated water sources that are the focus of this work; however, Navajo people who do not have municipal water sources in their homes use these unregulated water sources. Thus, it is important to provide the information to these families so that they can decide where they should get their drinking and household water. Thus, the use of unregulated water wells by rural Navajo people is the motivation for this work.

The environmental analytical laboratory at the Northern Arizona University (NAU) has been focused on working with Navajo communities to analyze unregulated water sources since 2003. This work has encompassed the analysis of close to 300 unregulated water wells on the Navajo Nation for elemental species.[26] A perspective on the work in the western region of the Navajo Nation is provided with a focus on uranium and arsenic water analyses on samples collected over a 15 year period. In addition to the water chemistry, a discussion of the dissemination of the results to the Navajo communities is provided.

## II. METHODS

### A. Study area

The Navajo Nation is comprised of five agencies and within each agency tribal chapters exist like counties within a state. The NAU laboratory has focused much of their work on chapters within the Western Agency of the Navajo Nation. Water samples were collected between 2003 and 2018 from a variety of unregulated groundwater sources (total of 82 sources) accessed by windmills, troughs, springs, and water storage tanks. Samples were identified from working with the Navajo Tribal Utility Authority branch offices, previous surveys conducted by the U.S. Army Corps of Engineers,[27] along with community and chapter members.

### B. Field and laboratory methods

Fieldwork methods include recording the location of the unregulated wells using global position system, taking pictures of the field site, measuring the water pH with a pH strip, and collecting water samples. At each location, two 125 ml water samples were collected. All of the water samples were filtered (60 ml syringe, Luer-Lok tip; Whatman syringe filter 25 mm GD/X, 0.45 $\mu$m pore size). One sample from each location was acidified with approximately 5 ml of concentrated (69%–70%) nitric acid (EMD, OmniTrace) to maintain metal ions in solution. The other sample was filtered only in order to determine the natural pH and anions. Until further preparation, water samples were stored at 18 °C. Water samples were analyzed for dissolved uranium and arsenic using US EPA water analysis methods (6020B and 200.8)[28,29] via inductively coupled plasma-mass spectrometry (ICP-MS), Thermo Fisher Scientific X-Series 2 ICP-MS with an ESI APEX HF. The analysis was confirmed by analyzing the Standard Reference Material 1640a, which has certified concentrations of uranium and arsenic. To ensure the quality of the data, other quality assurance and control measures were followed including analyzing blanks and analyzing calibration check standards. Usage of internal standardization was to correct for instrument drift and matrix effects during the data collection. For the water analysis, multielement calibration standards were prepared containing 0, 0.1, 0.5, 1.0, 2.0, and 5.0 $\mu$g/l of the analytes with an internal standard of 1.0 $\mu$g/l of iridium-193. Calibration standards were used to produce calibration curves for each analyte. The instrument signal for the analyte of interest and the internal standard were given in the form of counts per second (CPS). The CPS of the analyte of interest was divided by the CPS of the internal analyte. This produced a ratio that accounts for the signal of the external standard to the internal standard produced during instrument drift. The known concentration on the x axis of the external standards was plotted on a scatter plot versus the ratio on the y axis. After the least's squares best fit line (as determined by the Excel software) was applied to the scatter plot, the resulting linear equations could be used to calculate the concentration in $\mu$g/l for each sample. The square of the correlation coefficient, $R^2$, values were assessed with each calibration. $R^2$ values of 0.999 or better were deemed sufficient to utilize the calibration. The detection limits were determined as 3× standard deviation of blank/slope of calibration curve. The detection limit for uranium was determined to be 0.001 $\mu$g/l; the detection limit for arsenic was determined to be 0.030 $\mu$g/l.

## III. RESULTS AND DISCUSSION

A recent publication from the Ingram laboratory reports quantification of arsenic and uranium concentrations in unregulated water sources in the western region of the Navajo Nation.[26] In this study, water samples from unregulated water sources were collected between 2014 and 2017; a total of 294 unregulated water samples were collected across the Arizona and Utah side of the Navajo Nation and analyzed for 21 elements. This study had two objectives, to quantify the arsenic and uranium concentrations in water systems in the Arizona and Utah side of the Navajo Nation and to determine if there are other elements of concern. Of the elements tested, 14 elements had at least one instance of a concentration greater than a national regulatory limit, and six of these (vanadium, calcium, arsenic, manganese, lithium, and uranium) had the highest incidence of exceedances and were of concern to various communities on the Navajo Nation. The study findings are similar to other studies conducted in Arizona and on the Navajo Nation and demonstrate that other elements may be a concern for public health beyond arsenic and uranium.[11,20,30]

Since 2003, much of the water research from the Ingram lab has focused on 12 chapters in the Western Agency of the Navajo Nation (Fig. 2). Seven of the chapters are located within the western abandoned uranium mine region and the remaining chapters were included in the study based on community requests to test water in those chapters. Uranium mining occurred in the Western Agency of the Navajo Nation from 1951 to 1986, and the U.S. Environmental Protection Agency has identified 126 abandoned uranium mine structures in the area correlating to that

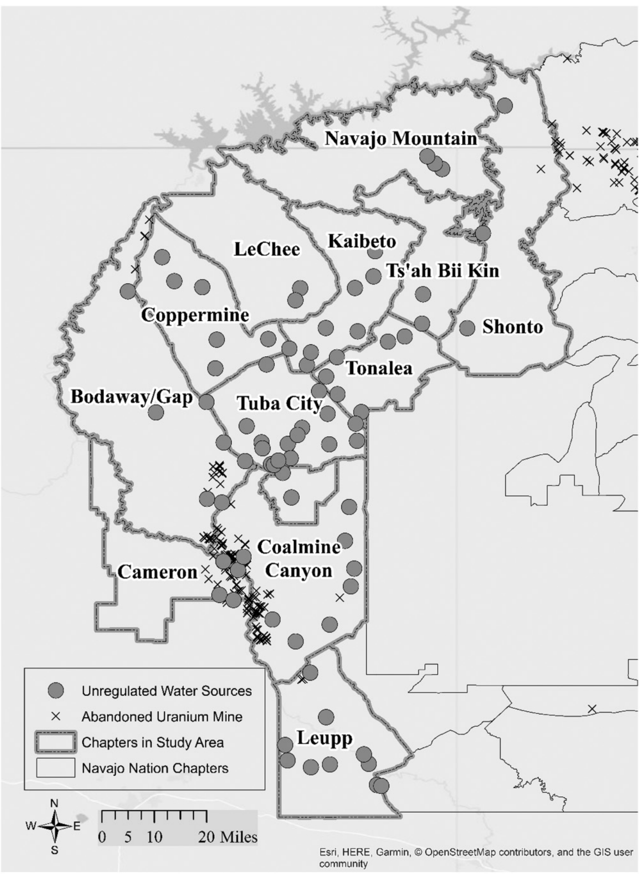


**FIG. 2.** Western Agency Navajo Nation Chapters with the location of unregulated water sources sampled and abandoned uranium mine structures [OSM Map On Garmin. (May 13, 2019). OpenStreetMap Wiki. Retrieved 14:25, July 23, 2019 from https://wiki.openstreetmap.org/w/index.php?title=OSM_Map_On_Garmin&oldid=1851574].

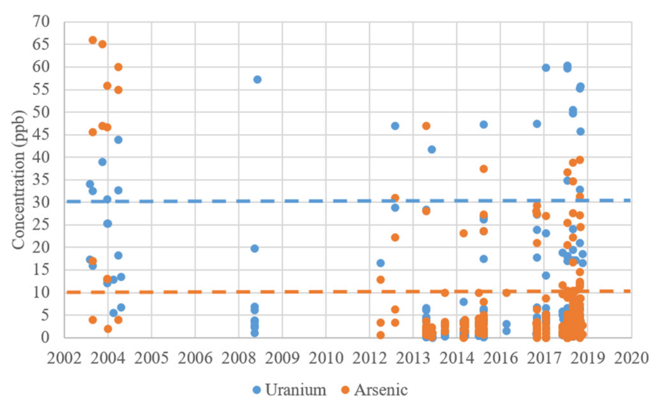


**FIG. 3.** Combined uranium (dark) and arsenic (light) data collected from 2003 to 2018 with outliers above 90 ppb excluded. The dashed lines indicate the maximum contaminant levels for uranium at 30 ppb (dark) and arsenic at 10 ppb (light).

time.[8] There were 82 wells or water sources identified and tested within these chapters.

The uranium and arsenic data collected in years 2004, 2008, and 2012–2018 are shown in Fig. 3 to examine the temporal variability. Overall, no clear temporal trends in the uranium and arsenic concentrations for the unregulated water sources sampled are observed in the uranium and arsenic concentrations over the period that water samples were collected. The lack of trends may be partly due to the types of water sources tested. A majority of the unregulated water sources tested were windmills, which only pump water when the wind is blowing, and the water is pumped into storage tanks. The storage tanks can be open on top or covered. The uncovered storage tanks are likely strongly influenced by evaporation which would strongly affect the levels of uranium and arsenic concentrations compared to the covered tanks.

One example of the complexity of temporal variations in concentration of uranium and arsenic is shown in the comparison of Badger Spring [Fig. 4(a)] and Tohatchi Spring [Fig. 4(b)], which are both shallow dug wells. These wells are located within eight miles of each other. The levels of uranium are clearly higher for Tohatchi Spring compared to Badger Spring while the arsenic levels are comparable for both water sources. In looking at the trends in the temporal changes from July 2003 to November 2018, they are somewhat similar for uranium, but the arsenic changes over time at Badger Spring are more pronounced than those at Tohatchi Spring. This water source is likely coming from alluvium sources and would be strongly influenced by recharge from precipitation, which would also explain the temporal variability found in these wells. This example demonstrates the complexity of the water chemistry in unregulated wells on Navajo. It would be predicted that Badger and Tohatchi Springs would be fairly similar due to their proximity and well type, but differences are observed.

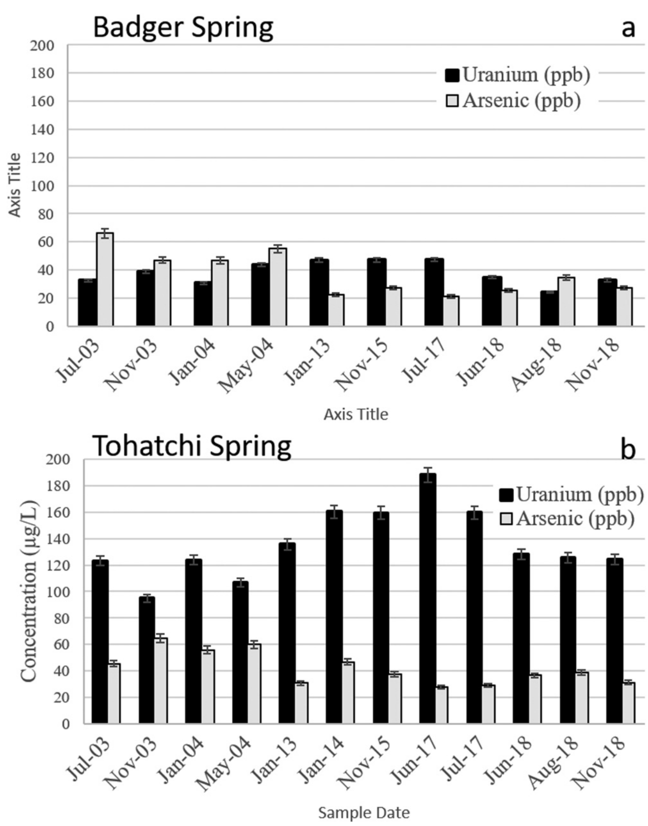


**FIG. 4.** Concentrations of uranium (black) and arsenic (gray) samples collected over time from Badger Spring (a) and Tohatchi Spring (b). The reproducibility for uranium measurements is, on average, 3% and for arsenic measurement, on average, 5%.

## IV. CONCLUSIONS

Causes of health issues such as cardiovascular disease, diabetes, and cancer for Navajo people are important to consider. As a rural population, the Navajo Nation has struggled with increasing their socioeconomic status, which may correlate to health problems.[29] The median household income for the Navajo Nation is $27 389, which, compared to the average for Arizona households of $51 310, is much lower.[31] It should be noted that, in general, the population density for the Navajo Nation is much lower than the average for the United States with only 6.33 persons per square mile (compared to 345 persons per square mile as average for United States).[32] While health issues are caused by multiple factors including socioeconomic influences, reducing the pathways of exposure to contaminants is an important step in alleviating health impacts.

One pathway of exposure to contaminants can exist in drinking water from unregulated sources. The lack of access to regulated water in their homes causes about 30% of Navajo people living on the Reservation to haul water to meet their needs. This practice of hauling water has greatly increased the cost of water for the Navajo people. The typical cost for water users in urban areas is $600 per acre-foot of water. Navajo people who depend on hauling water pay about 71 times this amount ($43 000 per acre-foot of water). For reference, one acre-foot of water is about 330 000 gallons and the per capita use of nontribal communities near the Navajo Nation is 190 gallons per day. The per capita use for the Navajo Nation is 10–100 gallons per day and largely depends on the availability of water resources.[21] Considering the cost of hauling water, it is important to recognize that unregulated water sources may provide the closest and most convenient water supply. Therefore, determining the safety of using unregulated water sources for drinking water remains an important objective for research on the Navajo Nation.

An important aspect of this work is understanding the steps and procedures that are required to conduct research on the Navajo Nation. Meeting with community members to understand their concerns, seeking approval for the research, and disseminating the results first to the local communities before scientific publication are critical to engendering trust that this research was respectful of Navajo customs. The Ingram lab disseminates findings by providing a written report, which is provided to the communities that include maps of the well locations and concentrations of uranium and arsenic. These reports are provided through in-person presentation at community meetings. Additionally, posters or handouts are provided to the communities to distribute the information for community members who cannot be present for meetings. Another approach for dissemination was a series of workshops focused on uranium issues in four communities on the Navajo Reservation. These workshops, called K'é (for the Navajo Clan system), were provided in 2018. One of the workshops was held in Cameron, AZ, in the southwestern part of the Navajo Nation where much of the work described took place. This workshop allowed researchers to have an open dialog with the community members about their water as well as providing a means for community members to request chemical analyses of environmental samples of interest.

Unregulated water sources can cause human-health issues and communicating the risks that Navajos face in drinking from these sources remains a top priority. Informing the Navajo people of the risks they face is important. Providing the chemical results can be difficult due to language and cultural barriers, which may inhibit effective communication. Researchers have worked to incorporate the Navajo peoples' perspectives to provide culturally significant communication methods.[33] In the Ingram lab, the most effective approach has been to incorporate Navajo students in the research. This has both improved the trust of the communities and provided an important training experience for future Navajo scientists.

## ACKNOWLEDGMENTS

The authors thank the Navajo Nation communities and tribal leaders for their thoughtful discussions and guidance for this work. The authors also would like to thank Michael Ketterer and Martin Mihay for their technical assistance. Funding for this work was provided by the National Institute of Environmental Health Sciences/Center for Indigenous Environmental Health Research (No. P50ES026089) and the National Cancer Institute/Native American Cancer Prevention (No. U54CA143925).

## REFERENCES

[1]See: http://www.navajo-nsn.gov/history.htm.
[2]M. E. Cooley, J. P. Harshbarger, and W. F. Hardt, U.S. Geol. Surv. Prof. Pap. **521-A**, 1 (1969).
[3]United States Environmental Protection Agency. National Primary Drinking Water Regulations, Ground Water and Drinking Water, February 14, 2020, see https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations.
[4]U.S. Department of Energy, Linking legacies: Connecting the Cold War nuclear weapons production processes to their environmental consequences, Washington, DC, 1997, see: https://www.energy.gov/sites/prod/files/2014/03/f8/Linking_Legacies.pdf.
[5]Y. T. Kwong, G. Whitley, and P. Roach, Appl. Geochem. **24**, 221 (2009).
[6]K. Nordstrom, Appl. Geochem. **57**, 17 (2015).
[7]W. B. O'Rear, "Summary and chronology of the domestic uranium program: U.S. Atomic Energy Commission," Technical Memorandum TM-182, 1966, p. 50.
[8]US Environmental Protection Agency, "Abandoned uranium mines project: Arizona, New Mexico, Utah, 1994–2000," San Francisco, 2007, see: https://www.epa.gov/sites/production/files/2017-01/documents/navajo_nation_aum_screening_assess_report_atlas_geospatial_data-2007-08.pdf.
[9]W. L. Chenoweth and R. C. Malan, "The uranium deposits of Northeastern Arizona," in *Guidebook of Monument Valley and Vicinity, Arizona and Utah: New Mexico Geological Society 24th Field Conference Guidebook*, edited by H. L. James (United States Geological Society, Tucson, AZ, 1973), pp. 139–149.
[10]K. J. Wenrich, W. L. Chenoweth, W. E. Finch, and R. B. Scarbourough, "Uranium in Arizona in geologic evolution of Arizona," in *Arizona Geological Society Digest 17*, edited by J. P. Jenney and S. J. Reynold (Arizona Geological Society, Tucson, AZ, 1989), pp. 259–794.
[11]K. Uhlman, C. Rock, J. Artiola, *Arizona Drinking Water Well Contaminants* (University of Arizona Cooperative Extension Publication, Tucson, AZ, 2009), pp. 1–4.
[12]A. H. Welch, D. B. Westjohn, D. R. Helsel, and R. B. Wanty, Ground Water **38**, 589 (2000).
[13]D. Brugge and R. Goble, Am. J. Public Health **92**, 1410 (2002).
[14]P. H. Eichstaedt, *If You Poison Us: Uranium and Native Americans* (Red Crane Books, Santa Fe, NM, 1994), pp. 33–45.
[15]P. Kurttio, A. Harmoinen, H. Saha, L. Salonen, Z. Karpas, H. Komulainen, and A. Auvinen, Am. J. Kidney Dis. **47**, 972 (2006).
[16]X. Arzuaga, S. H. Rieth, A. Bathija, and G. S. Cooper, J. Toxicol. Environ. Health B Crit. Rev. **13**, 527 (2010).
[17]D. K. Espey *et al.*, Annual report to the nation on the status of cancer, 1975–2004, featuring cancer in American Indians and Alaska Natives, published online October 15, 2007, see: http://www.seer.cancer.gov/report_to_nation/.
[18]Arizona Cancer Registry, 2014, see: http://azdhs.gov/phs/phstats/cancer-registry/.
[19]Cancer among the Navajo report, Navajo Cancer Workgroup and Navajo Epidemiology Center, Window Rock, AZ, 2015, see: https://www.nec.navajo-nsn.gov/Portals/0/Reports/Cancer%20Among%20Navajo%202018%20Spread.pdf.
[20]L. DeSimone, P. Hamilton, and R. Gilliom, The quality of our Nation's waters—Quality of water from domestic wells in principal aquifers of the United States, 1991–2004—Overview of major findings: U.S. Geological Survey Circular 1332, 2009, see: https://pubs.usgs.gov/circ/circ1332/includes/circ1332.pdfL.
[21]T. D. Johnson and K. Belitz, Sci. Total Environ. **607–608**, 658 (2017).
[22]K. M. C. Malecki, A. A. Schultz, D. J. Severtson, H. A. Anderson, and J. A. VanDerslice, Sci. Total Environ. **601–602**, 1533 (2017).
[23]US Department of the Interior, "Southwestern Navajo rural water supply program appraisal study of Navajo Nation," Arizona Little Colorado River Basin, 2015, see: http://www.frontiernet.net/~nndwr_wmb/PDF/SWNavajo Final Report_2015.pdf.
[24]Navajo Division of Water Resources, "Water resource development for the Navajo Nation," Shiprock, Navajo Nation, 2011, see: http://www.frontiernet.net/~nndwr_wmb/PDF/Reports/DWRReports/DWR2011%20Water%20Resource%20Development%20Strategy%20for%20the%20Navajo%20Nation.pdf.
[25]Navajo Nation Environmental Protection Agency, "Navajo nation water quality standards 2007," Window Rock, AZ, 2008, see: https://www.epa.gov/sites/production/files/2014-12/documents/navajo-tribe.pdf.
[26]J. Credo, J. Torkelson, T. Rock, and J. C. Ingram, Int. J. Environ. Res. Public Health **16**, 2727 (2019).
[27]Army Corps of Engineers, Abandoned Uranium Mines Project Arizona, New Mexico, Utah—Navajo Lands 1994–2000 Atlas, prepared by TerraSpectra Geomatics, Las Vegas, NV, 2000.
[28]US Environmental Protection Agency, EPA Method 6020B—Inductively coupled plasma-mass spectrometry, 2014.
[29]US Environmental Protection Agency, "Method 200.8 Determination of trace elements in waters and wastes by inductively coupled plasma-mass spectrometry," 1994.
[30]J. Hoover, M. Gonzales, C. Shuey, and Y. Barney, and J. Lewis. Exposure Health **9**, 113 (2017).
[31]Arizona Rural Policy Institute, "Demographic analysis of the Navajo Nation using 2010 Census and 2010 American community survey estimates," Flagstaff, AZ, 2010, see: https://gotr.azgovernor.gov/sites/default/files/navajo_nation_0.pdf.
[32]Navajo Division of Health, "Navajo population profile 2010 US census," Window Rock, AZ, 2013, see: https://www.nec.navajo-nsn.gov/Portals/0/Reports/NN2010PopulationProfile.pdf.
[33]J. DeLemos, T. Rock, D. Brugge, N. Slagowski, T. Manning, and J. Lewis, Prog. Community Health Partnersh. **1**, 321 (2007).

**Jani C. Ingram**, Ph.D. (Navajo) was born and raised in the small town of Kingman, Arizona. When she was a kid, she thought about becoming a bank teller, a middle linebacker for the Pittsburgh Steelers, or a sports statistician. She was good at math and played many sports and so thinks that this shaped her world-view. She had one chemistry class in high school that was far from great. In fact, if someone were to tell her that she would become a chemist, she would have told them that they were crazy.

Her parents were teachers; her mom is a member of the Dinè (Navajo) Nation, and her dad was Caucasian. This makes her a person of mixed race, which could explain why she had always been drawn to diversity. After high school, she went to a junior college because she earned a basketball scholarship. She was also convinced to play volleyball as well. As a result, her junior college days were very long with practice beginning at 6 am and ending late in the evening with studying. Perhaps this was good training for life as a graduate student and university professor. Since she was at a junior college, she had the same professor for multiple classes; her chemistry professor, Dr. Barkhurst, was her instructor for all four of her chemistry lectures and laboratory courses. She can definitely say that Dr. Barkhurst is the reason she is a chemist. He was an amazing teacher, and even more amazing was that he was married to a Navajo woman, so he understood Navajo students.

In addition to classes and sports, she met her future husband, James, in junior college. He was also a basketball player. He was from Las Cruces, NM, and they decided to continue their education at New Mexico State University (NMSU). Her first year at NMSU was in the chemical engineering program; it definitely was a challenge and only somewhat interesting. She interned in a summer chemistry program at Los Alamos National Laboratory. She really liked thinking about the chemistry aspects of various issues. When she returned to NMSU the following fall, she changed her major to chemistry and accepted a fellowship with the NIH MARC (Minority Access to Research Careers) undergraduate research program. She loved it! She spent time in the lab all hours of the day and on weekends. Her project was in the area of environmental analytical chemistry; her mentor was Dr. Gary Eiceman.

She went to graduate school at the University of Arizona. It was a great experience with days of wanting to quit and days of major triumphs. Fortunately, her research advisor, Dr. Jeanne Pemberton, was an excellent mentor. She provided guidance and advice but at the same time did not tell her what to do, as was her past experience with research. She thinks of her as her Chemistry Mom as she definitely was nurturing in terms of developing her research abilities. Dr. Pemberton helped her feel like she belonged in science and not just an outsider. She was honored to have been awarded the first Nellie Yeoh Whetten Award by the American Vacuum Society at the end of her graduate work in 1990.

As she finished her graduate work, she interviewed with a number of industrial companies and decided to accept a position with the Idaho National Engineering Laboratory. She was a staff scientist at the Idaho lab for 12 years. At the Idaho lab, she became part of a team of scientists developing and applying surface analytical chemical techniques, mainly static secondary ion mass spectrometry, to contaminants on environmental surfaces. It was AWESOME! The research team was a group of mainly older men who were incredible mentors to her. As part of her job, she was given the opportunity to mentor junior staff as well as summer students who were interning at the lab. She found that this part of the job was very satisfying, and it made her begin to think about teaching.

Another adventure that her husband and she began in Idaho was parenthood. Their family reflects biodiversity in that their oldest son, Jordan, looks like his father while their second son, Joshua, looks more Navajo like his mother. Their daughter, Jalisa, is blond and blue-eyed which she believes comes from her dad's side of the family who are Germans from Wisconsin. She believes the diversity of her children's appearance is an interesting reflection of her interest in diversity.

Although she thought that she did not want to go into academia after graduation school, her thoughts changed at the Idaho lab mainly as a result of the limited mentoring she did with junior staff and summer students. She applied for a number of tenure track chemistry positions, and she was pleased to accept an offer to Northern Arizona University. She found teaching to be a lot of fun, mainly due to the enthusiasm of the students. In addition to teaching, she also developed a research program that is centered on studying contamination from abandoned mines on the Navajo Reservation. The research has provided a way for her to assist the Navajo Nation in dealing with contamination issues as well as work directly with students from a wide range of backgrounds and ethnicities to study the issues. She has worked with a number of Native American students over the years. In 2018, she was honored with the American Chemical Society Award for Encouraging Disadvantaged Student in to Careers in the Chemical Sciences. Additionally, she has worked with many non-Native American students who have made being a professor enjoyable. She feels that her lab is a place where students from all walks of life come together to work as a team for a common goal. She feels privileged to be a part of her students' training experience, and she is proud to be their Chemistry Mom. Advice she would give to her 16-year old self what seems crazy to a high school girl might actually be one of the best decisions you will ever make.

**Lindsey Jones** holds an MS in Environmental Sciences and Policy from Northern Arizona University. She is a recent graduate and her thesis work focused on uranium and arsenic contamination issues in unregulated water sources on the western portion of the Navajo Nation.

**Jonathan Credo** (Navajo) is an MD/Ph.D. student at the University of Arizona, College of Medicine and conducts active research at Northern Arizona University. His research and clinical interests are in ecotoxicology and environmental health, examining how exposures from the environment impact the health of humans, wildlife, and the environment. His current dissertation research investigates the effect of metal exposure in minority populations.

**Tommy Rock**, Ph.D. (Navajo), holds a doctoral degree from the Earth Science and Environmental Sustainability program from Northern Arizona University. Since graduating, Dr. Rock has been pursuing research that focuses on environmental health in Indigenous communities.