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Water in the Native World

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Cover photo: *Native American students participating in the Guardians of Living Water Summer Camp overlook the sacred BigHorn River at Pretty Eagle Point, Fort Smith MT. The Guardians of Living Water was developed in partnership among the Crow Environmental Health Steering Committee, Crow Agency School, Montana State University, and Little Big Horn College to increase children's water-related environmental health literacy skills through art and science activities grounded in the Apsáalooke culture.* Credit: Christine Martin
Back cover photo: *Minneapolis, MN*. Credit: Ron Reiring, original work, CC BY-SA 2.0
Inside back cover photo: *Minneapolis Reflection*. Credit: Matthew Paulson, original work, CC BY-NC-ND 2.0

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Water in the Native World

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To Indigenous peoples, water is sacred. Water is the lifeline of Indigenous cultures, ceremonies, livelihood, and beliefs. Indigenous peoples have a repository of knowledge related to water, its use, and its spatial and temporal distribution. Hydrology and water resources can greatly benefit from Indigenous perspectives that includes place-based knowledge that helps us better understand complex natural and human systems. Sivapalan et al. (2012) termed "social-hydrology" as the science of people and water that is aimed at understanding the dynamics and co-evolution of coupled human-water systems. For Indigenous people, the study and observation of water were never separated from the people. For some Indigenous people, separating people and water is impossible as the origin, occurrence, form, and quality of water often define an Indigenous person, clan, people, and/or community.

Internationally, Indigenous people are known as "water protectors" and they have been fighting to protect their waters from overuse and contamination. However, the voices of Indigenous people are rarely heard in hydrological sciences. The representation of Indigenous scientists in hydrology is also very small and they are often asked to participate in water research on tribal lands to ensure ethical protocols, strong tribal partnerships, and cultural sensitivity. Indigenous hydroscientists not only produce scientific investigation and knowledge, but they also have a passion and a deep commitment to doing science for the purpose of helping their communities address water challenges. In a sense, Indigenous hydroscientists become "water protectors" by using science as a tool to address water challenges facing tribal communities. Indigenous water scientists play a key role in bridging Western science with Indigenous knowledge and it is imperative to recruit and retain more Indigenous students in hydrological sciences. In this Special Issue, "Water in the Native World," nearly all of the co-authors are Indigenous and two publications (Bulltail and Walter 2020; Conroy-Ben 2020) are led by an Indigenous lead author. With the need to consider the people in water research, Indigenous perspectives can also be gained through Indigenous scientists in health and social sciences. Indigenous health and social scientists have been present in health and social science research longer and in greater numbers than in hydrosciences. It is important to bridge hydrosciences with health and social sciences to critically examine health disparities and social dynamics. This Special Issue provides several examples of bridging hydrosciences with health and social sciences including Ellis and Perry (2020), Martin et al. (2020), and Kozich et al. (2020). This Special Issue is compiled by an Indigenous hydroscientist (Dr. Karletta Chief, Diné) and aims to bring to the forefront "Water in the Native World" where water challenges facing Indigenous communities are addressed and led by Indigenous hydroscientists; where Indigenous perspectives are not only included in the research but also *drive* the research questions; where Indigenous community members are co-authors; and where Indigenous students participate in data collection, analysis, synthesis and publication in the important research facing their communities.

In 2017, a group of Indigenous hydroscientists were awarded a National Science Foundation (NSF) Integrative and Collaborative Education and Research (ICER) Grant entitled "Water in the Native World: A Symposium on Indigenous Water Knowledge and Hydrologic Science." This team of Indigenous hydroscientists and professors included

Dr. Karletta Chief (Diné), University of Arizona; Dr. Otakuye Conroy-Ben (Oglala Sioux), Arizona State University; Dr. Ryan Emanuel (Lumbee), North Carolina State University; Dr. Shandin Pete (Salish and Diné), Salish Kootenai College; and Dr. Raymond Torres (Chemhuevi), University of South Carolina. This collaborative team aimed to not only address research questions regarding water challenges facing tribes, but to also build a network of Indigenous water scientists and allies to work together. The Symposium (Chief et al. 2019), held at a tribal college, Salish Kootenai College, in Pablo, MT in August 2018, aimed to: 1) define research and education priorities in the hydrologic sciences that are relevant to Indigenous peoples in a rapidly changing world; 2) create a network of Indigenous hydrologists and traditional knowledge holders of water; and 3) identify educational needs and tools to support Indigenous perspectives in hydrology.

The Symposium began with a cultural welcoming ceremony by the Confederated Salish and Kootenai Tribes. This welcome acknowledged our relations with one another and the environment and blessed our thoughts so that the Symposium would be successful. This ceremony set the tone for discussions about water in both technical terms and as a source of Indigenous identity. Participants, who came from nine states and 15 tribal affiliations, presented and led technical discussions on topics ranging from water quality disparities (Conroy-Ben and Richard 2018), water contamination, and earth surface processes to public policy and resource management. Several presenters highlighted the negative effects of mining and reclamation measures on tribal communities (Bulltail and Walter 2020) and water insecurity among tribes in the Southwest (Ellis and Perry 2020) and beyond. A few presenters included the social context in water research such as Kozich et al. (2018). Presenters also demonstrated the success of hydrological research on tribal nations where university-tribal partnerships were honored, nurtured, and strengthened through the project (Tsinnajinnie et al. 2018; Tulley-Cordova et al. 2018). Presentations by elders placed technical work in the context of multiple tribal cultures (Ellis and Perry 2020). In addition to discussing ways to make hydroscience findings more accessible and interpretable for the general public (e.g., to make our work operational), participants joined breakout groups and were challenged to bring Indigenous views and priorities concerning the interactions of land, air, and water into both scientific discourse and environmental decision-making. By asking questions such as, "how can the larger community of environmental scientists and practitioners benefit from Indigenous perspectives and experiences?," participants looked beyond internal discussions among Indigenous scholars and practitioners toward establishing a greater presence of Indigenous knowledge in earth system science. Such a presence would help, for instance, reduce disparities in water quality and quantity on tribal lands (Conroy-Ben and Richard 2018; Conroy-Ben and Crowder 2020), which supply a disproportionately large share of freshwater supplies in the United States.

Toward this end, Symposium leaders authored papers in a Special Issue of the *Journal of Contemporary Water Research and Education* (JCWRE) published in April 2018 entitled "Emerging Voices of Tribal Perspectives in Water Resources" (https://onlinelibrary.wiley.com/toc/1936704x/2018/163/1). Authors also led sessions at national meetings, including the American Geophysical Union Fall Meeting in oral and poster sessions entitled "Native Science-Research to Action." Symposium leaders challenged the scientific community to include Indigenous voices and perspectives in scholarly discourse regarding the environment.

This April 2020 Special Issue of *Journal of Contemporary Water Research & Education* entitled "Water in the Native World" was born through the 2018 NSF Symposium discussions and expanding network. This Special Issue sought out manuscript submissions that focus on water research on tribal lands and water challenges facing tribes including hydrology, water resources, water quality, climate change, water rights, traditional knowledge, cultural values, and environmental monitoring and analysis. The seven papers in this Special Issue cover surface and groundwater challenges facing tribes in the Southwestern United States, Montana, and Michigan. Topics include: 1) contaminants on tribal lands with examples from the Southwest and Montana; 2) cultural values of water with examples from Hopi Tribe, Crow Tribe, and the Keweenaw Bay Indian Community (KBIC); and 3) climate change impacts on important tribal fishery. Four papers focused on water quality on tribal lands including Conroy-Ben and Crowder (2020) on emerging contaminants; Jones, Credo, Parnell, et al. (2020) on uranium and arsenic; Jones, Credo, Ingram, et al. (2020) on arsenic; and Bulltail and Walter (2020) on mine produced waters. Three papers focused on cultural values of water including Ellis and Perry (2020) who discuss a Hopi spring that is a sacred site; Martin et al. (2020) who write about the perspectives of Crow elders on water and climate change; and Kozich et al. (2020) who interviewed KBIC tribal members on their perspectives of tribal fisheries and combine these results with water temperature measured during a fish harvest to recommend fishery management policies.

The first paper in "Water in the Native World" is entitled "A confluence of anticolonial pathways for Indigenous sacred site protection" by Ellis and Perry (2020). This paper is a prime example of the need to have Indigenous perspectives in the discourse of water management and policy, particularly when Indigenous perspectives on water use, water rights, and water conservation are so different from Western perspectives. Ellis and Perry (2020) discuss the challenges facing the Hopi Tribe in advocating for the protection of a sacred site, *Sipapuni*, in the Western paradigms of water rights litigation and cultural resource management, particularly alongside the legacies of coal mining. *Sipapuni* is the place of emergence for the Hopi people and is a geologic dome created from the deposition of minerals at a spring along the Little Colorado River upstream from the Colorado River-Little Colorado River confluence. The Little Colorado River and *Sipapuni* are being impacted by water use from industrial and non-tribal interests within the Little Colorado River watershed. At this time, the Arizona court has denied Hopi rights to the Little Colorado River and to a water right for cultural waters because claims for *Sipapuni* were not quantified. The traditional cultural values of the Hopi do not fit into the Western water rights paradigm, but the Hopi are forced to operate within that system. The motivation for this research is driven by Black Mesa Trust whose Executive Director, Vernon Masayesva, warns that *Sipapuni* is dying from decreasing water flows. Masayesva explains *Sipapuni* as the umbilical cord to the Colorado Plateau and the heartbeat of Mother Earth.

The second and third papers by Jones, Credo, Parnell, et al. (2020) and Jones, Credo, Ingram, et al. (2020) also focus on the Southwest and provide results on arsenic and uranium contaminants in water and its impact on tribal communities. On the Navajo Nation, approximately 30% of Navajo residents do not have access to running water and as a result, there is risk of Navajos resorting to non-potable water sources. In addition, the Navajo Nation has over 500 abandoned uranium mines and naturally occurring arsenic is found in water sources. Jones, Credo, Parnell, et al. (2020) published "Dissolved uranium and arsenic in unregulated groundwater sources - Western Navajo Nation." Since 2003, they have sampled 82 unregulated wells on the western side of the Navajo Nation and tested for uranium and arsenic. The study area included seven of the 110 Navajo chapters. They compared uranium and arsenic concentrations to the Maximum Contaminant Level (MCL) for drinking water standards. Uranium and arsenic were primarily highest in the southwestern portion of the study area and corresponded to a region where there are many abandoned uranium mines. In addition, arsenic was also high in the Tuba City Chapter. They found that nine groundwater samples exceeded the uranium MCL and 14 exceeded the arsenic MCL. This study provided insight to areas on the Navajo Nation where groundwater sources may pose a health risk to Navajos as well as identified groundwater wells that could be considered for addition to the public drinking water systems. The authors demonstrated the importance of community engaged research in hydrological sciences where the Navajo community provided approvals for the authors to collect water samples and conduct research. Jones, Credo, Parnell, et al. (2020) also reported results back to the Navajo communities and engaged in data transparency.

The third paper entitled "Arsenic concentrations in ground and surface waters across Arizona including Native lands" by Jones, Credo, Ingram, et al. (2020) compiled online water quality databases to understand visually arsenic concentrations in groundwater and surface water sources in Arizona, resulting in 33,000 water samples collected from 1990-2017. They found that 20.7% of water samples exceeded the arsenic MCL and in particular 40% exceeded arsenic MCL in Pinal and Yavapai counties. The public databases display a lack of water quality information on arsenic on tribal lands in Arizona particularly on Fort Apache, Navajo, Hopi, San Carlos Apache, and Tohono O'odham Nations. These maps are a tool for decision makers to address the water quality disparities and risks that exist across Arizona, particularly on tribal lands.

The fourth and fifth papers focus on water challenges facing a Montana tribe (the Crow Tribe). The fourth paper by Martin et al. (2020) entitled "Change rippling through our waters and culture" employs qualitative research to document traditional knowledge and observations of climate change impacts on the water, ecosystems, community health and well-being of the Crow Tribe in Montana. Crow Tribal elders were interviewed to identify key impacts based on life-long observations. The key determinants of health that Martin et al. (2020) found were cultural, social, economic, and environmental factors. The Crow elders described the deep impact of climate change on their community and despite these impacts, the resiliency of the tribe to maintain their culture and livelihood remains. Climate change is impacting tribes in unique ways due to their deep connection to water, land, and sacred places; therefore it is important to have tribal perspectives in studying climate change impacts to tribal waters.

The fifth paper by Bulltail and Walter (2020) focuses on investigating the impact of coal mining on surface water quality on and around the Crow Reservation. Their paper is entitled "Impacts of coal resource development on surface water quality in a multi-jurisdictional watershed in the western United States." At eight sites, 25 surface water samples were collected in September 2016 and cations and Sodium Adsorption Rates (SAR) were measured at a Montana commercial lab. The water quality results were compared to historical water quality data. Many tribes have an abundant source of natural resources and have been impacted by mining. Mining impacts exist today through legacy mining, and current mining and mining exploration on tribal lands continue. Therefore, research such as that conducted by Bulltail and Walter (2020) is important to understand mining impacts on tribal waters and to protect tribal waters from contamination.

The sixth article by Conroy-Ben and Crowder (2020) is entitled "Unregulated and emerging contaminants in tribal water." Authors analyzed data from the Unregulated Contaminant Monitoring Rule (UCMR) for Tribal Public Water Systems (PWS). Emerging contaminants are contaminants of concern to health and the environment, but are not regulated. Endocrine disruptors found in wastewater treatment effluent have been found to change the sex of amphibians. However, emerging contaminants have not been widely studied on tribal lands until the Safe Drinking Water Act was amended with the UCMR requiring monitoring of 30 new contaminants every five years starting in 2001. As of 2019, four campaigns had been completed (UCMR1 to 4) and tribal lands were included. On tribal lands, metals, chlorate, and dioxane were detected in UCMR3 and some exceeded the Environmental Protection Agency's health reference limit (HRL). Considering that many tribal nations depend on water for their livelihood, and cultural and spiritual values, these emerging contaminants on tribal lands highlight emerging contaminants that should be considered for monitoring and water treatment on tribal lands. Less than 3% of tribal PWS were included in UCMR1-4. These results indicate the importance of including more tribes in the UCMR campaigns to assess the presence of emerging contaminants on tribal lands.

The final paper by Kozich et al. (2020) entitled "Walleye (*ogaawag*) spearing in the Portage Waterway, Michigan: Integrating mixed methodology for insight on an important tribal fishery" focuses on integrating science with tribal perspectives to recommend ways to improve the management of tribal fisheries in Michigan. For many federally recognized tribes, rights to hunting and fishing are protected through Indian treaties; however, different factors may impact the ability of tribes to protect their hunting and fishing rights such as climate change, pollution, drought, or off-reservation water use. In this paper, Kozich et al. combine water temperature measurements made in the Portwage Waterway in Michigan during walleye (*ogaawag*) harvest with a survey administered to the KBIC to recommend changes in fishery management for priority zones.

Community engagement and tribal driven research are critical and important in hydrological sciences. Research questions should be formulated by tribal communities and research is overseen by the tribe through designated tribal entities (Chief et al 2016). Helicopter research (Minasny et al. 2020), or research in which scientists dictate research with little to no engagement by tribal communities, is not welcomed by tribes. Research questions formulated by the tribes prevent reactive research where tribes are engaged as an afterthought or after scientists have obtained research grants. Engaging tribes from the beginning also ensures that the research being conducted is for the benefit of the tribe and not just conducted for research sake. Jones, Credo, Parnell, et al. (2020), Martin et al. (2020), and Kozich et al. (2020) are good examples of tribal engaged research where there is multi-lateral communication, reporting back, and oversight from the beginning of the research to dissemination of the results. The majority of Martin et al. (2020) are tribal members including tribal college and university partners, tribal community members, and tribal students. When research is conducted with tribes, it is important to acknowledge the contribution of tribal partners in co-authorship. The development and fostering of tribal partnerships are delicate and require the trust of tribes in the researchers. A strong university-tribal partnership not only involves transparency, on-going communication, and data sovereignty, but it also includes involving the tribe in the research either as co-authors or in the education and training of Indigenous students. Jones, Credo, Parnell, et al. (2020), Martin et al. (2020), and Kozich et al. (2020) demonstrated these aspects.

Indigenous hydroscientists play a key role in water research conducted on tribal lands. Jani C. Ingram, a Diné chemist and professor at Northern Arizona University in Flagstaff, AZ was a lead author in the first two papers (Jones, Credo, Parnell, et al. 2020; Jones, Credo, Ingram, et al. 2020). Dr. Ingram has conducted environmental health research on tribal lands for decades and has trained many Indigenous students in her lab, many of whom have gone on to conduct environmental research on tribal lands. For example, one of her co-authors is Jonathan Credo, a Diné doctoral MD/PhD student in the Clinical Translational Sciences at the University of Arizona Medical School. Not only does Dr. Ingram's work have a profound impact on addressing water quality disparities on the Navajo Nation and other Southwestern tribes, but she has also forged a path for Indigenous youth and college students to be trained in her lab and do research related to their own tribal communities.

Another senior Indigenous scientist co-authoring a publication in this Special Issue is Dr. Julie A. Baldwin, a Regents' Professor in the Department of Health Sciences, the Director of the Center for Health Equity Research, and Lead Principal Investigator on the Southwest Health Equities Research Consortium at Northern Arizona University, in Flagstaff, AZ. As a citizen of the Cherokee Nation of Oklahoma, she has made a life-long commitment to serving diverse communities and to advocating for health promotion programs for children, adolescents, and families. Dr. Baldwin earned her doctorate in Behavioral Sciences and Health Education in 1991 from the Johns Hopkins University School of Hygiene and Public Health. For over 29 years, she has worked primarily with tribal communities throughout the U.S. to design culturally relevant health promotion programs for youth and families. Dr. Baldwin's research over the years has focused on both infectious and chronic disease prevention. Cross-cutting themes which have characterized her work include: utilizing community-based participatory research approaches, working with underserved and/or marginalized populations, and addressing health disparities by developing and implementing culturally-centered public health interventions.

In addition to senior Indigenous hydroscientists such as Dr. Jani Ingram, are up and coming Indigenous junior faculty. Two Indigenous assistant professors who contributed research on tribal water challenges in this Special Issue are Dr. Grace Bulltail (Crow) and Dr. Otakuye Conroy-Ben (Oglala Lakota). Dr. Bulltail recently joined the University of Wisconsin-Madison in 2019 as an assistant professor of Native American Environment, Health, and Community where she is interested in understanding the intersection of watershed management and tribal sovereignty and has investigated oil and gas extraction on water quality and watershed management. Dr. Bulltail is a member of the Crow Tribe and a descendant of the Mandan, Hidatsa, and Arikara Tribes of Fort Berthold, North Dakota. In her new role at the University of Wisconsin-Madison, Bulltail hopes to continue researching water policy while focusing on transboundary watersheds and the land tenure challenges present in Wisconsin.

Dr. Conroy-Ben has been in academia for nearly 10 years, including as a post-doctorate at the University of Arizona in 2007 and as an assistant professor at the University of Utah. She is now at Arizona State University in the School of Sustainable Engineering and the Built Environment. Dr. Conroy-Ben is the only Native American professor in a tenure track position in environmental engineering. Her research focuses on the biological effects of polluted water, environmental endocrine disruption, metal and antibiotic resistance in bacteria, and wastewater epidemiology. Her work is important to tribes as her article Conroy-Ben and Crowder (2020) demonstrates that tribes manage their water and wastewater. In addition, tribes that rely on fish like KBIC may become more concerned with how wastewater effluent impacts their fish.

There is a great need to increase the number of Indigenous students in the hydrosciences. Therefore it is imperative to provide opportunities for Indigenous students to be involved in water-related research facing tribes and their communities (Jones, Credo, Ingram, et al. 2020; Jones, Credo, Parnell, et al. 2020). Martin et al. (2020) and Kozich et al. (2020) demonstrate the involvement of Indigenous students in tribal water research. Indigenous students are passionate about giving back to their communities and doing research in their communities hence providing valuable opportunities for them to participate in important water research.

With 573 federally recognized tribes in the United States with diverse cultural and spiritual water practices (Federal Register 2019), Indigenous perspectives contribute diverse knowledge and unique problem-solving approaches. With recent events like Dakota Access Pipeline (DAPL) at Standing Rock Indian Reservation, Gold King Mine Spill impacting the Navajo Nation and Ute Mountain Ute Tribes, and the Intertribal Coalition to designate Bears Ears National Monument to protect sacred and cultural lands, and a range of other water and environmental challenges facing Indigenous peoples, it is even more critical to engage Indigenous perspectives in water topics and challenges using ethical protocols, mutual understanding, and respect.

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Dr. Karletta Chief (Diné) is an Associate Professor and Specialist in Soil, Water, and Environmental Sciences at the University of Arizona (UA). Her research focuses on understanding, tools, and predictions of watershed hydrology, unsaturated flow in arid environments, and how natural and human disturbances impact water resources. Two of her primary tribal projects are The Pyramid Lake Paiute Tribe Climate Adaptation and Traditional Knowledge and the Gold King Mine Diné Exposure Project. Dr. Chief received a B.S. and M.S. in Civil and Environmental Engineering from Stanford University in 1998 and 2000 and a Ph.D. in Hydrology and Water Resources from UA in 2007. As a first-generation college graduate who was raised on the Navajo Nation without electricity or running water and with a strong Indigenous cultural and language upbringing, pursuing a STEM career was always motivated by the desire to address water challenges facing Indigenous communities. Today, as an associate professor and extension specialist in hydrology, Dr. Chief bridges relevant science to Native American communities in a culturally sensitive manner by providing hydrology expertise, transferring knowledge, assessing information needs, and developing applied science projects. She may be contacted at kchief@email.arizona.edu or University of Arizona Department of Soil, Water and Environmental Science, PO Box 210038, Room 429, Tucson, AZ 85721.

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A Confluence of Anticolonial Pathways for Indigenous Sacred Site Protection

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Abstract: The confluence of the Little Colorado and Colorado Rivers is an Indigenous socio-ecological landscape, revolving in large part around water resources. Substantial surface and groundwater use within the Little Colorado River (LCR) basin threatens the water sources of the confluence, springs in the LCR basin, and specifically the Hopi *Sipapuni*—a sacred site of cultural emergence. To address concerns about diminished flows of sacred springs, we engaged in praxis through collaborative, reciprocal, community-based research processes. Through the lens of anticolonial theory, we ask: Can federal policies be employed in an anticolonial pursuit of water and sacred site protection? How do Indigenous grassroots organizers envision protection and work to re-Indigenize water management? Semi-structured interviews with Indigenous community organizers and federal land managers were coupled with policy analysis of the National Historic Preservation Act/Traditional Cultural Properties, the ongoing LCR Adjudication, and the Treaty of Guadalupe Hidalgo. Findings point to multifaceted, complex, and contradictory themes that elucidate the continued influence of colonization on water governance and the degree to which protection solutions can be anticolonial. Criteria were generated for anticolonial protective pathways that highlight the centrality of reciprocal relationships, Indigenous Knowledges, and meaningful inclusion. While details about protection pathways for the confluence and *Sipapuni* are many, the salient finding is that the struggle for water protection in the LCR is the struggle for protection of inherent Indigenous rights.

Keywords: *Indigenous water rights, federal reserved water rights, Little Colorado River Adjudication, traditional cultural properties, National Historic Preservation Act*

The confluence of the Colorado and Little Colorado Rivers (LCR) (hereinafter "the Confluence") exemplifies Indigenous struggles for water protection across multiple scales. This area is sacred to seven tribes: Hopi, Zuni, Navajo (Diné), Havasupai, Southern Paiute, Apache, and Hualapai. It is a profoundly significant socio-ecological landscape that revolves around water resources. The waters of the LCR basin are considered here as "biocultural" to reflect their inherent interconnectedness as biological and cultural resources (The Center for Sustainable Environments et al. 2002; Maffi and Woodley 2010). Nonetheless, extensive surface and groundwater use within the LCR basin threatens the Confluence water sources, springs in the LCR basin, and specifically the Hopi *Sipapuni* (also known as *Sípàapu)*. In Hopi cosmology, this over 7-meter travertine mound-form spring on the LCR, upstream from the Confluence, is central and sacred as their place of emergence. Beyond its physical dimension, the religious, cultural, and symbolic understandings of *Sipapuni* for Hopi are profoundly complex and diverse (Ferguson 1998). In turn, Hopi relationships with water are intimately related to *Sipapuni* concerns. Hopi elders warn that *Sipapuni* waters are decreasing and it is, therefore, dying. Vernon Masayesva, Executive Director of Black Mesa Trust (BMT) conveys:

> Here's the problem, *Sipapuni* is the umbilical cord to the Colorado Plateau, we call the fourth world. That's our link. And so *Sípàapu* is slowly dying because of

> the diminishing water flow, not only just to surface, but underground rivers, aquifers. There's less and less water feeding *Sípàapu* to keep the heart beating, the heart of the mother earth (Personal communication, February 2019).

Translating the significance of these concerns across cultures and across the divides of colonization is challenging. Masayesva asks, "What would you do if your mother was dying? How would you respond if the Sistine Chapel was burning? If the Garden of Eden was being destroyed? If Jerusalem was demolished?" (personal communication, March 2019). For Hopi, *paatuwaqatsi* or "water is life." Yet current cultural protection and water management policies for the LCR inadequately regulate the hydrologic systems integral to the Confluence and LCR springs. Both historical and contemporary forces of colonization drive these inadequacies. To identify protection pathways for the Confluence, *Sipapuni,* and the LCR watershed, our research is guided by Hopi-led BMT and Indigenous interests within the ongoing LCR Adjudication, and is grounded in anticolonial theory.

The physical Confluence is situated within the bounds of Grand Canyon National Park (GCNP) and Navajo Nation (NN) (see Figure 1). The multi-jurisdictional nature of this territory complicates management, yet it may also provide an opportunity for collaborative and inclusive protection pathways. For now, GCNP and NN do not offer comprehensive protection for cultural sites and attendant waters in the Confluence. Protective measures are further complicated by culturally-constructed definitions of the Confluence's boundaries. Not unlike challenges faced by communities located near other protected areas in the world (Holmes 2014), protecting the Confluence presents a formidable hurdle when boundary definitions vary widely between Indigenous groups and federal land managers. Moreover, Western policies are generally predicated on concrete and bounded definitions of natural resources that are in marked contrast to the holistic or landscape-scale views of natural resources reflected by many Indigenous peoples (Tuck et al. 2014; Berkes 2018).

Restricted by a broader cultural and governance structure not designed to facilitate Indigenous people having control over their own water or sacred sites, protection pathways still must be forged with the available, imperfect tools. We examined certain tools "at hand" including the National Historic Preservation Act (NHPA)/Traditional Cultural Properties, Federal reserved water rights, and the Treaty of Guadalupe Hidalgo. Ultimately, protection is pursued through multifaceted pathways that follow both state recognition-based strategies (governance mechanisms) and out-of-state community-based strategies (Indigenous grassroots organizing) (Wilson 2014) that influence one another through dynamic responses to the impacts of colonization. While details about water protection pathways are many, these two points are fundamental: water is sacred and the struggle for control of water resources between Western society and Indigenous peoples is the struggle for protection of inherent Indigenous rights.

Background and Theoretical Context

Water-Energy Nexus of the Little Colorado River Basin

Ground and surface water interactions in the lower LCR are an influential, albeit little understood, control on water distributions throughout the basin (Pool et al. 2011). Most groundwater flow likely discharges along the lower LCR reaches as illustrated in Figure 2. Discharges, largely from Blue Springs, come primarily from the Coconino aquifer after downward leakage into the Redwall-Muav aquifer, and make the lower 13-mile reach perennial to the Confluence (Hart et al. 2002). Springs downstream from Blue Springs, such as *Sipapuni,* are more saline and likely derive from a deeper aquifer (L. Stevens, personal communication, May 2019). Significant Western science data gaps exist in understanding the remaining intricacies of LCR groundwater. Consequently, neither the exact source of *Sipapuni's* waters, nor how aquifer changes affect such springs, is known.

Arizona Department of Water Resources' (ADWR) Eastern Plateau Planning Area (EPPA) provides further context. The EPPA is predominately comprised of the LCR watershed and contains only one groundwater basin, the LCR plateau basin. Here, groundwater contributes 61 percent of the

Figure 1. Mines and generating stations in the LCR watershed among a multijurisdictional patchwork of territories including the Hopi and Navajo Reservations and Grand Canyon National Park. (Map by: James Major)

water supply with the industrial sector being the largest user. From 2001-2005, industry accounted for 49 percent of all water demand, two-thirds of which was met by groundwater and used primarily for energy production at the stations indicated in Figure 1 (ADWR 2009). Though tribal lands comprise 63.9 percent of the EPAA, tribal water demand is approximately ten percent of overall demand. This disparity in consumption rates is exemplified by Peabody Western Coal Company (PWCC), which in 1968 began pumping over 3.8 million gallons *per day* from the Navajo aquifer to slurry coal to Mohave Generating Station. Before Mohave closed on December 31, 2005, PWCC pumped approximately 4,400 acre-feet of water per year (AFA).[1] Withdrawal reduced to 1,235 AFA after Mohave closed, continuing to facilitate coal mining for Navajo Generating Station (NGS) until late 2019. For comparison, total annual water demand on the Hopi Reservation is approximately 1,000 AFA (ADWR 2009) or 23 percent of PWCC's historical use.

Due to withdrawals, Navajo and Hopi wells near PWCC mines have declined more than 100 feet and the majority of monitored artesian spring discharges have decreased over 50 percent (NRDC 2001; Stevens and Nabhan 2002). The Navajo aquifer and related spring and wash discharge shows continued evidence of declining integrity (Grabiel 2006; Higgins 2010). Other major industrial users pull from the Coconino aquifer near the LCR headwaters farther south. Cholla, Coronado, and Springerville generating stations pull a combined 36,100 AFA (ADWR 2009) creating cones of depression where aquifer levels have declined

[1] One acre foot of water is approximately 326,000 gallons – this extraction totals over 1.4 billion gallons.

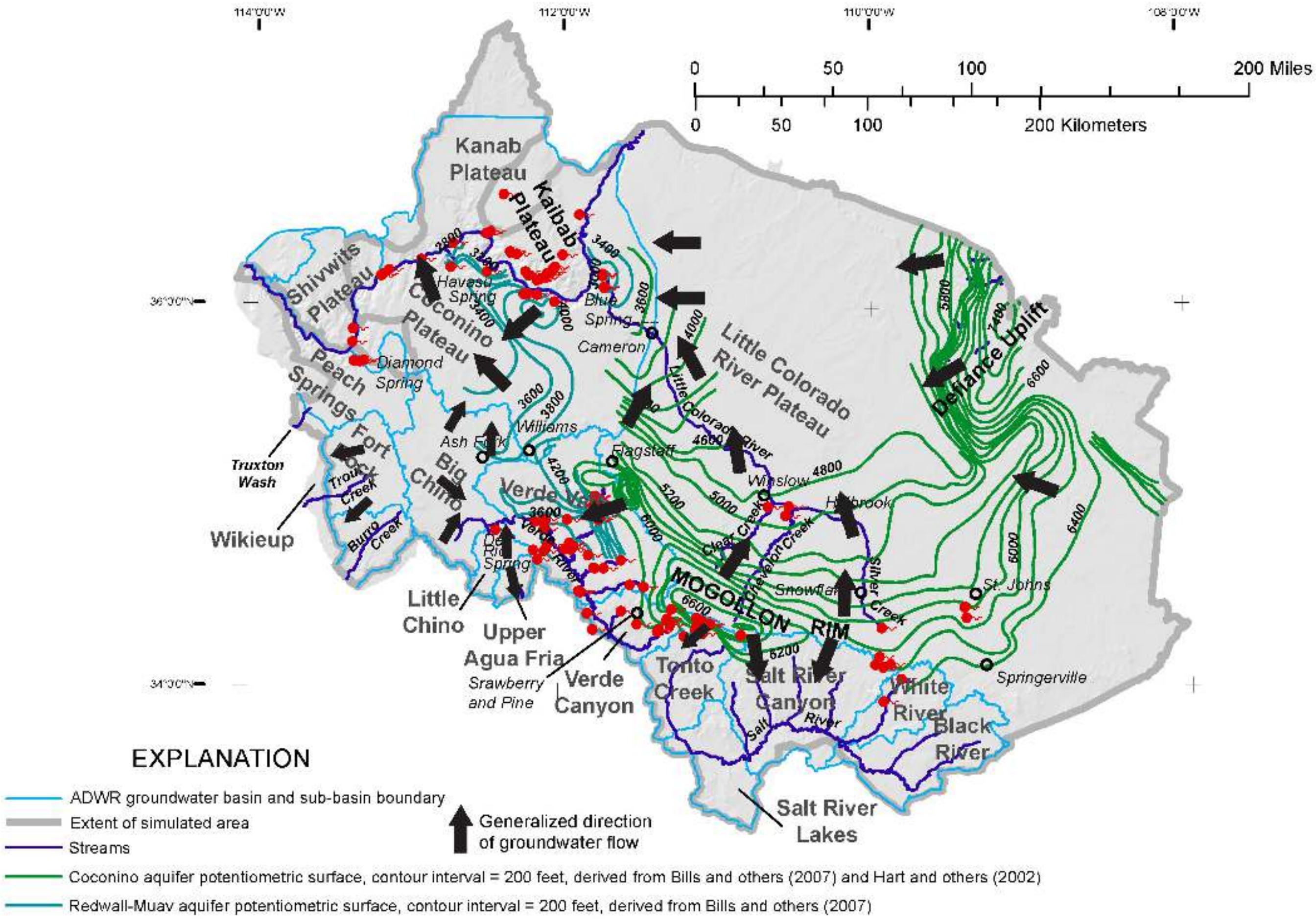

Figure 2. Generalized groundwater-flow system of major aquifers in the Northern Arizona Regional Groundwater-Flow Model study area with red dots indicating springs (Pool et al. 2011, 26).

as much as 100 feet (Hart et al. 2002). Industrial energy production annually withdraws from the Coconino aquifer over seven times the amount of water that the nearby City of Flagstaff withdraws to meet demands for 71,000 people (CPTAC 2016). Current and future water demand in the southern portion of the LCR watershed (i.e., ADWR's "East Plateau" planning area) is of vital concern, given that combined projections for energy production water use total between 100,000 and 155,000 AFA by 2060. All uses will continue to rely on groundwater through this period (ADWR 2014, 3), thus further stressing the resource.

The primary groundwater management policy in Arizona is the 1980 Groundwater Management Act. The Act established "Active Management Areas" (AMAs) to regulate withdrawals from certain aquifers of concern but does not apply to the LCR basin (except for the Joseph City Irrigation Non-Expansion Area). In fact, many municipalities located in AMAs (e.g., Phoenix) reduce their groundwater reliance by accessing Colorado River water via the Central Arizona Project (CAP) canal, which was conveyed by power generated by NGS until November 18, 2019. The coal to fire NGS was mined via withdrawal of the Navajo aquifer within the LCR basin. In short, the access Arizona, California, and Nevada have had to cheap water and power has been unjustly subsidized by Indigenous peoples' water, land, and health. This exploitation proves highly consequential for Indigenous cultural renewal in the LCR basin.

Colonial Legacies, Legal Confluences, and Anticolonial Theory

Colonialism—more accurately understood in the U.S. as settler colonialism—is a complex and ongoing system of oppression with well documented structures and impacts (e.g., Wolfe 2006; LeFevre 2015; Kēhaulani Kauanui 2016; Whyte 2017). Contemporary manifestations of colonization are also referred to as neocolonialism (Rossiter 2004). For simplification, we use "colonization" or "colonialism" to refer to historical and ongoing colonial actions of the U.S. as a settler state to occupy, control, and exploit Indigenous lands and people. For Indigenous peoples, Alfred (2017) explains, "The essential harm of colonization is that the living relationship between our people and our land has been severed" (11).

Colonization of present-day northern Arizona dates from the invasion of Spanish conquistadors into the Americas during the mid-1500s. As with many Indigenous lands around the globe, colonial acts of territorialization created and re-created reservation boundaries constricting, changing, or outright destroying access to homelands and sacred sites (Linford 2000; Whiteley 2008). In the endless attempt to control and exploit Indigenous lands, colonialism also drives water, mineral, and other natural resource extraction (McCool 2006; Whyte 2017; Powell 2018; Yazzie 2018; Gilio-Whitaker 2019). Such industrialization degrades water, air, plant, animal, and human health on Indigenous lands (Benson 2012; Colombi 2012; Vogel 2012; Taylor 2014; Montoya 2017; Berry et al. 2018; Bair et al. 2019; Estes 2019). Colonization, in the name of conservation, also created National Parks (e.g., GCNP) and other land management boundaries, dispossessing Indigenous people from their lands for the strange concept of nature untrammeled by humans (Smyth 2002; Guyot 2011; Kelly 2011; Sletto 2011; Stevens 2014). Colonialism renamed Indigenous sites with the names of invaders (Lindford 2000; LaDuke 2005) while colonial "mentalities" were made manifest in dominant Western epistemologies and socioeconomic policies (Dongoske et al. 2008; Tuck et al. 2014; Black and McBean 2016; Dongoske and Curti 2018).

In association, self-determination, autonomy, and sovereignty are employed here to refer to the *inherent* rights to self-governance, independence, and freedom (Alfred 2001)—including the inherent right to make decisions about traditional waters and lands (Wilson 2014). Broadly, sovereignty is a complicated term (Wilson 2014) and should be understood as pluralistic. In the classic sense, sovereignty refers to self-rule by people in a specific territory (Agnew 2009). However, the legal understanding and application of tribal sovereignty is convoluted in practice in the U.S. (Wilkinson 1988). Tribal sovereignty is legally complicated by the Trust Doctrine which established U.S. guardianship, trustee, and fiduciary responsibilities towards tribes (*Seminole Nation v. United States* 1942; Miller et al. 2012). In other words, there is constant tension between legal notions of sovereignty and tribes' inherent rights of self-determination and autonomy. Effectively, tribal sovereignty can be understood as a continual process achieved through both state-recognition *and* Indigenous community-based mechanisms (Simpson 2011; Wilson 2014; Barker 2017).

Anticolonial theory lays the groundwork for addressing the social and ecological devastation caused by colonization. The value and epistemological orientations of critical theory within a localized context guide anticolonial analyses (Denzin and Lincoln 2008; Tuhiwai Smith 2012). Anticolonial theory categorizes a broad scope of work to rectify the harms of colonization while not diluting the more specific objectives of "decolonization"—understood here specifically as physical land repatriation (Simpson 2004; Unsettling Minnesota Collective 2009; Tuck and Yang 2012; Patel 2014; Dhillon 2018). A universally agreed upon definition does not exist for anticolonial theory and decolonization is often used synonymously; however small a semantic difference (which is an ongoing scholarly debate [e.g., Daza and Tuck 2014]), we utilize "anticolonial" because it is a more appropriate term in this research, given it does not explicitly address physical land repatriation—though arguably that is the ultimate protection pathway. Here, anticolonial theory is understood as a continuum of ways to challenge dominant colonial systems of oppression. Within the context of our study, this continuum includes deconstructing colonial mentalities, incorporating Indigenous Knowledges (IK), building inclusive decision-making processes, and adapting colonial policies to recognize and protect inherent Indigenous rights to land and water.

In addition to anticolonial theory, "re-Indigenizing" and Critical Indigenous Research Methodologies work to *restore* Indigenous approaches to change and research (Denzin and Lincoln 2008; Brayboy et al. 2012; Eyers 2017; Lemley 2018). The "Four Rs"—relationships, responsibility, respect, and reciprocity—guide human, physical, and spiritual world interactions (Kirkness and Barnhardt 1991; Brayboy et al. 2012). Re-Indigenizing and Critical Indigenous Research Methodologies are important *restoration* frameworks for building protection pathways, and provide depth to anticolonial theory.

This research is a case study centering Indigenous water protectors' concerns within the LCR, while simultaneously exploring the limitations and potential for federal governance pathways to address those concerns. Indigenous Knowledges (LaDuke 1994; Houde 2007; Whyte 2017; Berkes 2018), understood as knowledge-action-value-spiritual constructs, provide a lens for valuing Hopi elders' concerns about *Sipapuni's* diminishing water *and* the principles of protecting *Sipapuni,* the LCR basin, and, consequently, people in the region. Against this backdrop, the questions remain: Can federal policies be employed in an anticolonial pursuit of water and sacred site protection? How do Indigenous grassroots organizers envision protection and work to re-Indigenize water management?

Methods

This research was in response to a request from BMT for support in pursuing protection for the Hopi *Sipapuni*. Our objectives were to bring research capacity to BMT, support their advocacy work, and to contribute to a broader coalition of efforts to protect the Confluence and LCR. We have been honored with relationships with specific Hopi and Diné activists and the primary objective of the research has been to be accountable to those relationships. Thus, while the relationship between research and activism is not easy (Tuhiwai Smith 2012), praxis is central to this work. Praxis, articulated by a long line of scholar-activists (Freire [2000] most prominently), connects theory, practice, reflection, and a moral framework of liberation. We intentionally pursued praxis through collaborative, reciprocal research processes while "sharing back" in culturally appropriate and accessible ways (Tuhiwai Smith 2012, 16).

To answer the research questions, we intersect critical qualitative interview methods with policy/law analyses to engender a greater understanding of extant protection pathways and ways in which those pathways align—or not—with Indigenous water protectors' visions and values regarding *Sipapuni* and the Confluence. Interview subjects came from four groups: 1) Indigenous community organizers (n=6) working to protect the Confluence region through community-based organizations BMT and Save the Confluence; 2) Federal agency employees (n=3) from GCNP, the United States Geological Survey (USGS), and the Bureau of Reclamation (BOR), engaged in Confluence related work; 3) Cultural resource management experts (n=4) from Grand Canyon tribes; and 4) a Grand Canyon springs expert (n=1). All interviews were voluntary, conducted in Flagstaff, and followed requisite Institutional Review Board protocols.

Interviews were based on Carspecken's (1996) Semi-Structured Interview Protocol and lasted between 60-150 minutes. A set of 15 questions was asked concerning: 1) the significance of various water resources in the Confluence region; 2) threats to these resources; and 3) policy options for protecting water resources. By eliciting narratives of experiences with water advocacy, policy, colonization, and the complexities therein, interviews with Indigenous water protectors and federal agency employees enable the integration of multiple perspectives and the description of processes (Weiss 1995). Numerous follow-up communications occurred for continued clarification and verification. Interviews and notes were coded using NVivo Qualitative Data Analytic software, revealing two dominant themes summarized in Figure 3. Using Carspecken's (1996) Systems analysis, these emergent themes were then analyzed using anticolonial theory as the macrolevel social theory to better understand the systemic dimensions of the interviewees concerns.

Interview Findings: Perceptions of Problems and Solutions Interwoven with Policy

The two themes emerging from interviews centered on "threats" and "protections" to the

Perceptions of colonialism's impacts and threats to the Confluence	Western "boundaried" sense of land and water devoid of spiritual meaning
	Western science hegemony in federal management of land and water resources
	Treatment of water as a commodified property lacking spiritual/cultural purpose
	Hopi and Navajo Nation (Diné) tensions stoked by colonial territorialization
	Hopi Tribal Council seen as a Neocolonial government
	Unsustainable and unregulated groundwater withdrawal in the LCR basin
Strategies for Confluence protection	Relationship building between tribes, NGOs, agencies, and stakeholders
	Advocating for inclusion of Indigenous Knowledges (IK) in resource governance
	Invoke federal trust duty to protect resources vital to a permanent homeland
	Strategic adaptation of colonial policies to achieve anticolonial protections

Figure 3. Both problems and solutions for Confluence governance emerged from interviews.

Confluence, LCR, *Sipapuni*, and water. The first theme concerns how colonization has shaped over time the degradation and continued threats to the Confluence through Western science, boundary making, driving tensions between Indigenous groups, installing puppet governments, and exploiting groundwater for capital gains. The second theme concerns developing protection strategies through relationship building, incorporating diverse perspectives in governance, taking responsibility for duties, and reframing policies for anticolonial protections.

Broadly, the interviews emphasized relationships, responsibility, respect, reciprocity, accountability, and centering Indigenous ways of knowing in ways consistent with the literature on re-Indigenizing and Critical Indigenous Research Methodologies (Kirkness and Barnhardt 1991; Denzin and Lincoln 2008; Brayboy et al. 2012; Eyers 2017; Lemley 2018). Prioritizing relationships and connection can be interpreted as a distinct anticolonial strategy countering colonization's fundamental goal of disconnecting people and place (Alfred 2017). Moreover, the interviews articulate why colonization makes water resource protection so complicated on Indigenous lands. In the following section, quotes from interviews are woven throughout the policy analysis to further illustrate the two themes.

Policy Findings: Limitations and Potential for Anticolonial Pathways Towards Protection

While many extant policies could be considered in this study, those we analyzed were selected due to Indigenous priorities that manifested in the interview sub-theme *strategic adaptation of colonial policies to achieve anticolonial protections*. As Save the Confluence community organizer Sarana Riggs reflected, "When you're looking at protection, you've got to see what you have *at hand* already. And, who are the players, who are the people involved who make it happen… [and] it's not just policies and laws but an uplift of song and prayer that gives these sacred places needed voices" (personal communication, March 2019). Thus, we examined three policies repeatedly referenced in interviews: the NHPA and Traditional Cultural Property/Place, Federal Reserved Water Rights, and the Treaty of Guadalupe Hidalgo.

The National Historic Preservation Act and Traditional Cultural Property/Place[2]

In 2011, the BOR and State Historic Preservation Officer determined the "Canyons from Glen Canyon Dam to River Mile 277 (i.e., GCNP), and the lower gorge of the LCR, are a rim-to-rim, National Register of Historic Places eligible site as a Traditional Cultural Property/Place (TCP) under Criteria (a), (b), (c), and (d)" (USDOI 2018, 8). In fall 2018 the BOR, as lead federal agency for Glen Canyon Dam management, released its Historic Preservation Plan (HPP) to comply with the NHPA

[2] In the NHPA, TCP refers to "Traditional Cultural Property." However, in this research TCP will refer to "Traditional Cultural Place." According to Joe et al. (2002), "'Properties' connotes non-Indigenous concepts of land ownership, rather than stewardship rights and privileges held in common, with inherent obligations to past and future generations" (69). Replacing "Property" with "Place" is an important distinction.

(USDOI 2018). The HPP includes and concerns the Confluence and *Sipapuni* and stands as the most current articulation of the NHPA applied to this region. Figure 4 summarizes both the potential and challenge of using these policies in anticolonial protection framings for the Confluence.

Critical anticolonial analysis of NHPA and TCP reveals the policy often favors both federal control and Western science by emphasizing archeological "mitigation" instead of cultural preservation that considers intangible/associative values and affects (K. Dongoske and M. Yeatts, personal communications, March/April 2019). In the case of *Sipapuni*, its death can be understood literally (physical-state) or metaphorically (culturally-informed concerns about its health).

While the HPP seemingly has anticolonial dimensions in prioritizing tribal consultation and inclusivity in decision-making, interviewees recognize a duality here in that any claim of harm must be proven by definitive Western science hydrology and monitoring—data which are currently nonexistent. Moreover, at present it is difficult, if not impossible, to make distinctions between natural and human generated impacts to *Sipapuni.* Policy analysis of the HPP reveals it is possible for the BOR to fund *Sipapuni* water monitoring. However, by the time groundwater withdrawal impacts are documented in a definitive "scientific" way, damage to aquifers and springs will likely be irreversible. Hopi and Diné have already seen how the arch of "objective" science bends to political pressure, in the decimation of the Navajo aquifer by PWCC (Nies 1998; Grabiel 2006). It is a repetitive story: those who bear the greatest burden also bear the burden of proof (Taylor 2014).

Further TCP analysis suggests this policy designation better reflects IK perspectives but is no magic bullet for protecting sacred places. TCP limitations partially derive from delineating protective boundaries. While tribes make the documentation for site eligibility, the State Historic Preservation Officer and BOR must agree with their suggestions. Leigh Kuwanwisiwma, who served as Director of the Hopi Cultural Preservation Office for 30 years explains, "With the many sites that we have, it's hard for us to put boundaries around sacred sites" (personal communication, December 2018). Similarly, Riggs articulates:

> "You can't rate sacred on a scale from 1-10 in Diné perspective. The Confluence is not just one aspect of one place to be saved or

Potential as Anticolonial Pathway	**Challenges as Anticolonial Pathway**
BOR considers *Sipapuni* and LCR as eligible TCPs and manages these sites accordingly	NHPA & TCP status do not guarantee protection, only a review of federal actions
HPP attempts to incorporate IK perspectives to reflect holistic recognition of water/land and recognizes IK as *equal* to Western knowledge (USDOI 2018, 8)	HPP concerns the Confluence region but whether BOR's management of Glen Canyon Dam affects *Sipapuni* is not established
Considers "intangible" or "associative" cultural values and impacts (e.g., spiritual, emotional, psychological)	Agencies often deprioritize intangible associations with TCPs while still checking the NHPA "compliance" box through physically-biased archeology methods
Facilitates inclusive process for documenting sacred sites while considering cultural sensitivity in publicizing information without affecting site eligibility	Analysis of NHPA's protection discourse versus its actions is necessary—the degree to which protection is implemented is contextual and inconsistent
HPP addresses "boundaried" issues of TCPs in the Confluence region through adaptability/flexibility	Neither the NHPA nor TCP status effectively address broader LCR watershed governance concerns
TCP designations have an important role in strategic, protective policy layering (i.e., TCPs are basis for greater protection)	*Sipapuni* and the LCR have TCP eligibility documentation from Hopi and Zuni but the State Historic Preservation Officer still has to concur with nominations

Figure 4. Relevance of NHPA & TCP designation to Confluence and *Sipapuni* Protections.

> preserved or protected. There's more to it than just that one area. That's one, basically, one grain of sand. There's a whole list of things that need to be protected, preserved, educated, all of that is Grand Canyon above and below" (Personal communication, March 2019).

Though tribes and agencies increasingly do agree on which sites should be protected, the final decision-makers are nonetheless colonial entities, demonstrating the dominance of colonial decision-making powers. Thus, compliance with NHPA via the HPP is one viable but incomplete policy option for protection of this region. At best this designation protects sites from federal actions and can be used in the layering of other policies; at worst TCP is a kind of tokenism and detraction from future protection efforts because a site is seemingly already protected. To engage this policy in anticolonial ways, Indigenous water protectors can increasingly collaborate with federal agencies to pursue groundwater studies of the lower LCR and *Sipapuni* while also reaffirming the importance of intangible values in site selection and protection.

LCR Adjudication, Federal Reserved Water Rights, and the Treaty of Guadalupe Hidalgo

Paramount in addressing interviewees concerns is a review of *In re the General Adjudication of All Rights to Use Water in the Little Colorado River System* (hereinafter, "LCR Adjudication" or "the Adjudication") in which the Apache County Superior Court of Arizona determines surface water rights to the LCR. Groundwater pumping affecting appropriable baseflow contributions to the LCR is also taken into consideration (ADWR 2009). The Adjudication has monumental implications for the LCR basin, and arguably for the availability of water at the Confluence and for *Sipapuni.* In 2016, the *Navajo-Hopi Observer* reported "over 3,100 claimants have filed more than 11,300 claims in the case" (Hopi and Navajo continue fight for water rights, para. 7) including the United States, the Hopi Tribe, NN, Flagstaff, Winslow, Holbrook, Show Low, Snowflake, Springerville, and St. John. Claims also include industrial interests such as Salt River Project and Arizona Public Service as well as numerous individual, farm, and ranch claims (Laban 2018). *In re Hopi Tribe Priority (CV 6417-201)* is a sub-trial to determine the Hopi Tribe's rights to the LCR.

The Hopi Tribe has federal reserved water rights, or *Winters* rights (*Winters v. United States* 1908), that reserve the right to water necessary to fulfill the primary purposes for which a reservation was created (Anderson 2015). The Hopi Tribe, and the U.S. on behalf of the Hopi Tribe, argue that *Winters* rights can apply to water sources not appurtenant to current reservation boundaries (e.g., the LCR, *Sipapuni*) if necessary for the purposes of providing a "permanent homeland."[3] Masayesva states, "Hopi cannot be sustained as a permanent homeland when the roots (i.e., *Sipapuni*) are severed" (personal communication, March 2019). As the Hopi place of emergence, *Sipapuni* protection is essential to the permanent homeland promise, yet limited precedent exists for such claims (Nania and Guarino 2014). While reserved rights claims can be made in the LCR Adjudication for cultural, ecological, and instream-flow uses (i.e., non-consumptive uses), including a water right related to *Sipapuni*, it is difficult to reconcile IK with Western water law quantification requirements.

In December 2015, ADWR completed the "Final Hydrographic Survey Report for the Hopi Indian Reservation" (ADWR 2015). The report is being used in the related sub-case *In re Hopi Reservation HSR (CV6417-203)* to address Hopi and U.S. water rights claims on behalf of the Tribe, including claims for "a non-diversionary right for instream flows in the lower Little Colorado River" (Ibid, 4-39). Treating water as a quantifiable "property right," however, is difficult for Hopi, who understand water as fundamentally sacred. This fact begs an important question: Can sacred waters for sacred places be quantified? Most IK frameworks would say no. One Hopi water protector explains:

> "When I think about water rights, I think to myself that it's not about the Hopi Tribe

[3] In 2001, the Arizona Supreme Court in *In re General Adjudication of All Rights to Use Water in the Gila River System & Source (Gila V)* determined that the purpose of reservations was to establish a "permanent homeland."

> having actual water rights on paper, it's about letting the water flow freely back down to where *Sipapuni* is….I'm not saying let's take all the water from these cattle ranchers and all these people who need water down there, or further up, but we have to think in a positive way to where we can work together…how can we get water guaranteed to *Sipapuni* forever, down there, because she's entitled to it. This is her water, not theirs" (Personal communication, November 2018).

In the Adjudication, the Hopi Tribe did not specify a quantity of water necessary to sustain *Sipapuni*. In response, ADWR did not propose a related water right (Ibid, 5-8) and, therefore, the Adjudication is currently not considering Hopi claims to waters in the lower LCR gorge or to *Sipapuni*.

Cultural and/or ecological instream flow claims could still potentially be amended to secure a reserved water rights solution for the Confluence and *Sipapuni*. For instance, prioritizing relationship building and reciprocity could lead to a combined claim by Hopi, Navajo, and other federal reserved water rights holders (e.g., GCNP and National Forests). Arguably the largest barrier to such a joint claim would be overcoming NN's opposition to LCR claims by Hopi, a point explained in further detail below. However, even if such a water right were to be allocated, the lack of hydrologic data still impedes the allocation of a quantifiable instream flow. Here, the dominance of Western science sustains colonial power via Western water law. While federal reserved water rights may sometimes achieve anticolonial ends (e.g., prioritizing tribal water rights with senior priority dates over states) it does so through colonial means and reaffirms the role of state governments to "give" rights. In this light, federal reserved water rights are perhaps the most powerful tool for securing tribal water rights and for denying them. Ultimately, they remain an invaluable tool for tribes (Getches 2005). However problematic or ineffective water rights may be, possessing a federal reserved right would give Hopi agency in LCR decision-making. Otherwise, without a claim, Kuwanwisiwma lamented, "The LCR Adjudication is going to erode our sovereignty more" (personal communication, December 2018).

Among BMT and other Indigenous water protectors, strong hope centers on the Treaty of Guadalupe Hidalgo[4] (hereinafter, the "Treaty") as a stronger legal path for tribal claims to the LCR than federal reserved water rights. While the use of the Treaty would be problematic at best as an anticolonial approach—using one colonizer's structure against another's—this strategy provides another example of employing state recognition-based mechanisms. Based on Aboriginal water use, the Treaty's Article VIII protections, and precedents for Pueblo water rights in New Mexico, the Hopi Tribe has argued for a "time immemorial" priority date to rights in the LCR (Clare and Mentor 2012). The fact the Hopi Tribe never signed a treaty with the U.S., but instead had Reservation boundaries imposed in 1882 by Executive Order, bolsters validity to the argument of using the Treaty's articulation of Hopi rights. However, the Treaty's boundary description of Hopi (*Moqui*) territory was vague, and unlike other Pueblo lands, there was no specific *Moqui* land grant from Spain (Kessell 2010). Nevertheless, substantial evidence exists (e.g., Whiteley 2004; Adams 2007) of historic LCR use by the Hopi, especially ranging from its confluence with the Rio Puerco to that of the Colorado. In fact, Homolovi State Park's ancestral Puebloan ruins are recognized primarily as Hopi sites; the Arizona state park *abuts* the

[4] Present-day northern Arizona came under Mexican rule after the United States of Mexico won its independence from Spain in 1821. Shortly thereafter, the ensuing Mexican-American War (1846-1848) was ended by the Treaty of Guadalupe Hidalgo and Mexico ceded most of the present-day southwest U.S., including the vast majority of Arizona. Signed in 1848, the Treaty transferred citizens' rights held under Mexico to the U.S. Articles VIII and IX required that "property of every kind…be inviolably respected" for Mexican citizens who remained in the now U.S. territory, including Indigenous peoples (Treaty of Guadalupe Hidalgo 1848). Both Mexico and Spain had paternalistically treated tribes as a protected, legal minor status. Generally, the Pueblos' rights, as regionally-established and agricultural cultures, were favored over nomadic non-Puebloan rights (Whiteley 2004; Kessell 2010). Consistent with its treatment of other treaties, the U.S. did not honor many components of the Treaty, including continuing to consider Indigenous people U.S. citizens (which did not happen until 1924).

LCR. Notwithstanding, the courts fail to recognize Hopi priority rights to the LCR.

A pivotal decision for both the *Priority* and *HSR* subcases came in 2009 when Judge Ballinger decided the Hopi Tribe did not have a right to LCR water sources "that neither abut nor traverse Hopi lands" (Minute Entry, March 2, 2009 in CV-6417, as cited in Report of the Special Master Regarding LCR Coalition's Motion 2017, 2). Despite being contested, the Court continues to uphold the decision. These decisions are based on colonial reservation boundaries that siloed the Hopi on an island within NN and gave NN jurisdiction over *Sipapuni*. Consequently, any action concerning *Sipapuni* requires NN permission. Ballinger's decision ignores the fact that Hopi are original LCR users whose traditional homelands "abut" the LCR. Hopi interviewees expressed that not having jurisdiction over their most fundamentally sacred site is disturbing and unjust and contributes to tensions between Hopi and NN. This scenario is indicative of colonial territorial acts that divide Indigenous groups to maintain control. Figure 5 highlights the key points the court "Special Master" used to rationalize the denial of Hopi water rights.

The Special Master's first point is key and refers to the 1976 Indian Claims Commission settlement in which the Hopi Tribe received \$5 million from the U.S. in remuneration for 4 million acres of lost (i.e., taken) Aboriginal lands. In the LCR Adjudication, the Court maintained that "acceptance" of the 1976 settlement extinguished Aboriginal land and water titles. However, interviewees described the settlement as an imposition of a neocolonial, undemocratic government in order to support the colonial state and market. At the time of the settlement, the Hopi Tribal Council severely under-represented the autonomous Hopi villages (ILRC 1979). Five times the number of Hopi who voted for the settlement petitioned against accepting money in exchange for taken lands. Further, the Tribe's attorney, John Boyden, was known as a controversial figure in land settlements and partitions that paved the way for mining leases—not land repatriation or "just" compensation (Nies 1998; Wilkinson 2004). Ultimately, the Hopi Tribal Council tabled acceptance of the award and, aside from Boyden paying himself 10 percent (\$500,000) of the settlement, the money was never used, for fear of legitimizing the "sale" of Aboriginal titles (ILRC 1979; Clemmer 1995; Nies 1998; Whiteley 2008). Whether the settlement amounted to a technical "sale" of land (or not) is a remaining legal uncertainty and one that begs the question of whether Aboriginal title was ever extinguished.

Nevertheless, Judge Ballinger's 2009 decision dismissing Hopi claims was upheld again on August 24, 2017 (Report of the Special Master Regarding LCR Coalition's Motion 2017, 11). This time, the Special Master affirmed the decision based on a broad coalition's motion to deny the Hopi Tribe's claims. The coalition entities include: the LCR Coalition (a coalition of cities, ranches, and water districts within the LCR watershed), City

Special Master Key Points on Hopi Rights to LCR
Hopi hold time immemorial water rights only within Land Management District 6 and excludes such rights on other tribal lands within the 1882 Executive Order Reservation or Moenkopi Island. The extinguishment of Hopi's Aboriginal title, as determined by the Commission, terminated Aboriginal water rights to those lands.
Hopi do not hold water rights with a priority date of 1848 as a result of the Treaty of Guadalupe Hidalgo, 9 Stat. 922 (Feb. 2, 1848). The Treaty did not create or establish water rights but protected existing property rights within the lands acquired by the U.S.
Hopi Tribe holds an implied reserved water right with a priority of December 16, 1882, to the Hopi Partitioned Lands within the 1882 Executive Order Reservation. President Chester A. Arthur's Executive Order of December 16, 1882, impliedly reserved water for the Hopi Tribe.
The Hopi Tribe holds an implied reserved water right to Moenkopi Island with a priority of June 14, 1934, pursuant to the Act of June 14, 1934, 48 Stat. 960.

Figure 5. Findings of the Court re: Hopi Priority (Report of Adoption 2013, 4).

of Flagstaff, Salt River Project Water Agricultural Improvement and Power District, and the NN. The decision was upheld again on March 11, 2019.

The 2009 decision and subsequent confirmations are prime examples of Western water law functioning as a colonial tool to territorialize water resources. A different ruling seems highly unlikely within the Superior Court, as that would constitute a horizontal appeal. If this decision is appealed to higher courts, it is unclear whether the Hopi priority date and territorial boundaries could be argued differently. While the priority date will predate most other claims regardless, Hopi land boundaries are drastically different when viewed through the lens of Aboriginal lands (Figure 6), historical treatment under Spain and the Treaty of Guadalupe Hidalgo, or the 1882 Executive Order. Based on court precedent, the Claims Commission "extinguishment" of Aboriginal entitlement seems unlikely to be overturned, but the settlement's validity urgently needs further legal research, as it determines Hopi's place in the present-day LCR Adjudication. If denial of any legal right to LCR waters continues when water rights are the primary mechanism for "ownership," what legal recourse will Hopi have if and when the waters of the LCR continue to run dry? If *Sipapuni* continues to diminish? The answer is very little.

Beyond the court rulings, to some Hopi interviewees the continued illegitimacy of the Hopi Tribal Council is still of concern. They described how the present-day Council does not respect or include religious elders, does not represent a majority of villages (only 5 of the 12), and is distorted in its decision-making by a government budget generated from mining royalties. In contemporary efforts to be ostensibly fair and equitable, the U.S. created a policy of government

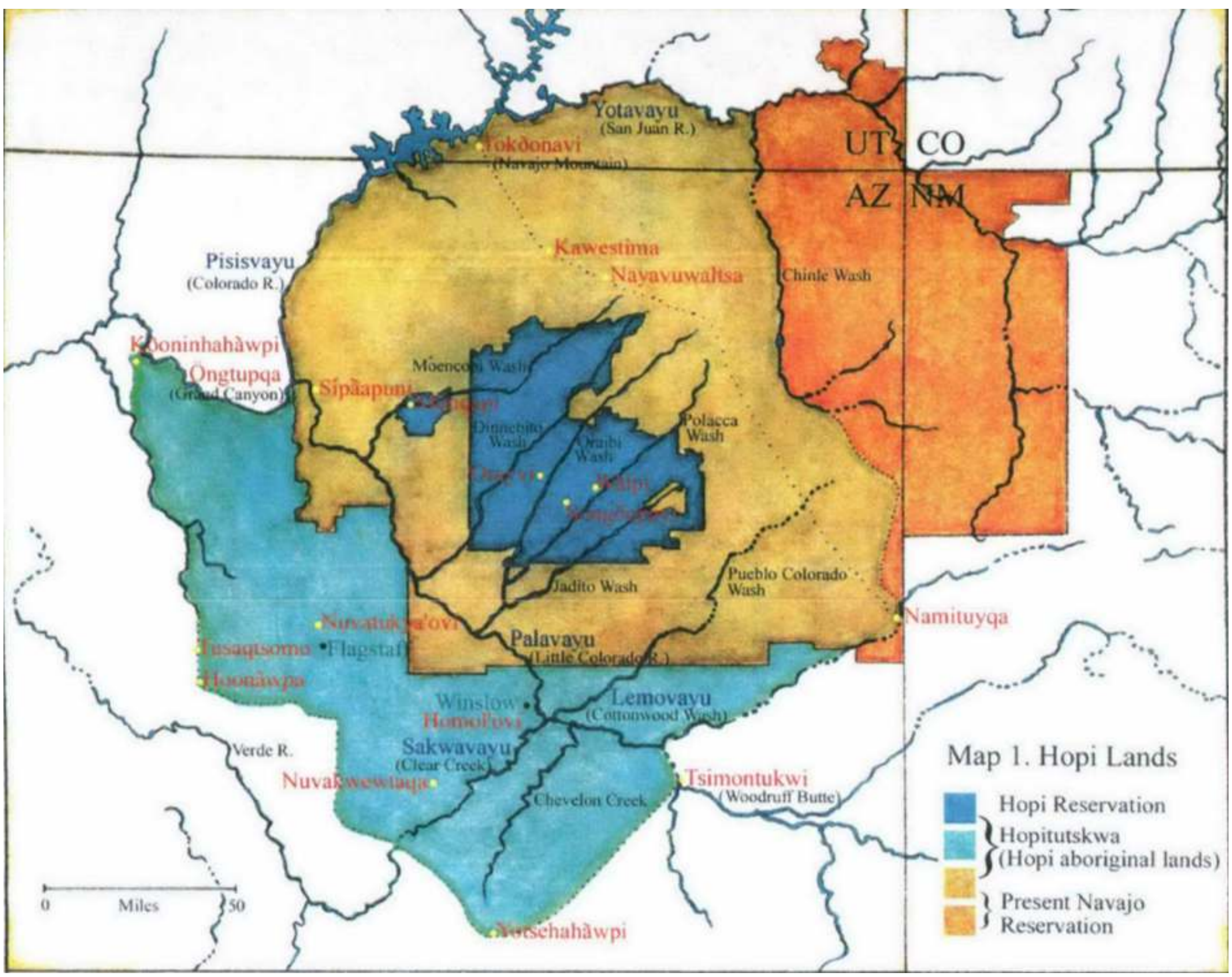

Figure 6. Hopitutskwa, Hopi Aboriginal land in relation to modern reservation boundaries (Whitely 2008, 33).

to government relations with tribes which has had the effect of restructuring Indigenous societies into miniature colonial governments. The imposition of colonial forms of government has replaced traditional governance structures (e.g., Deloria 1969; Nadasdy 2003; Coulthard 2014), and in the case of the Hopi Tribal Council, certain interviewees consider it a “failed experiment.”

Overall, the governance pathways detailed above emerged from interviewees’ concerns and suggestions. Given the complexities of protecting water in the LCR and Confluence, TCP designation is the most concrete protection at this time, as limited as it is. While it deserves further research, the use of the Treaty of Guadalupe Hidalgo as a means to secure waters rights appears unlikely to provide Hopi with greater legal standing in the LCR Adjudication. However, a combined claim from Hopi, NN, and GCNP for federal reserved water rights for instream flows in the LCR could provide more robust legal protection. Moving forward, all protection strategies must certainly be multiscalar and layered. Water does not flow within isolated boundaries and political strategies for water protection must also reflect fluidity (Cohn et al. 2019). While none of the pathways briefly described here are straightforward, they do possess potential for devising protections for the Confluence and *Sipapuni*.

Conclusion

Within the foundational contexts of water as sacred and respecting Indigenous rights, this research illuminates a case about the struggle for water and protection of the Confluence of the Colorado and Little Colorado Rivers. This case is, ultimately, about the struggle for inherent Indigenous rights and self-determination. The Confluence and the broader LCR watershed are a confluence of cultural and ecological resources, IK and Western science, colonization and Indigenous resistance. This work considers Hopi elders’ concerns that waters in *Sipapuni*, a fundamentally sacred travertine spring near the Confluence, are dying. *Sipapuni* shapes Hopi identity and fosters cultural renewal, all of which is now at stake for the Hopi. Elders’ warnings illuminate unsustainable groundwater withdrawal in the LCR basin and unjust water right adjudications. *Sipapuni* is at the hydrologic AND spiritual nexus of watershed concerns. In the matrix of multiple tribal lands, culturally complicated but significant sites, a National Park, and a watershed that drains ⅕ of Arizona, the reality of implementing multi-scalar strategies to protect the Confluence is extremely complex, but necessary. Pathways toward ensuring integrity and renewal of biocultural resources within the relatively site-specific Confluence area must include basin-scale analysis and policy intervention.

Anticolonial analyses are relevant in the examination of federal policy, water governance, and Indigenous community organizing. Any attempts to protect *Sipapuni*, the Confluence, and the LCR must examine if and how such efforts either continue or challenge the colonial legacy of severing Indigenous people from their homelands and culture in the name of conservation or compliance. While it is perhaps incongruous to assess anticolonial dimensions of federal policy tools, the critique is still needed as a component of systemic anticolonial strategies. A comprehensive anticolonial protection pathway arguably starts with deconstructing “colonial mentalities.” This can be done by incorporating IK as knowledge-action-value-spiritual constructs equal to Western science and then building genuine, collaborative, and inclusive decision-making processes that prioritize Indigenous sovereignty and self-determination. The next step requires recognizing that Indigenous rights to land and water are inherent, while understanding advocacy strategies must simultaneously adapt colonial policies to achieve anticolonial ends. The final step entails progressing toward repatriation of Indigenous lands (i.e., physical decolonization). Anticolonial pathways further support re-Indigenizing water management through a heavy emphasis on the role that relationships, responsibility, respect, reciprocity, and accountability play in interactions with the human, physical, and spiritual world.

There is tension between using federal policies as anticolonial pathways to protection and how Indigenous grassroots organizers envision re-Indigenizing water. Our goal was to examine both governance pathways and Indigenous organizers’ perspectives in order to better understand the limitations and potential for protecting the Confluence, LCR, and *Sipapuni.* The short answer is that both federal governance strategies and re-Indigenizing strategies exist in a dynamic, interdependent relationship. Federal policies and water law pathways are needed to protect the LCR, Confluence, and *Sipapuni.* Indigenous community organizing is needed to challenge and change the limitations of these inadequate colonial tools. Protection pathways simultaneously need both colonial tools and anticolonial approaches to protect *inherent* Indigenous rights—better said as inherent Indigenous *relations* (Dhillon 2018).

Moving forward, it is yet to be seen if land and water management can be responsive to Indigenous grassroots efforts in the Confluence region and shift trajectories to better serve re-Indigenizing. Indigenous and non-native peoples alike are *all* distorted by historic and contemporary colonization. We all suffer from its separation of people and place, but we do not all suffer equally. We must reflect on how our efforts continue such separation, such continued colonization, if we are to save what is sacred in the Confluence, the LCR, and, ultimately, in ourselves.

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Dissolved Uranium and Arsenic in Unregulated Groundwater Sources – Western Navajo Nation

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Abstract: Concentrations of dissolved uranium (U) and arsenic (As) above drinking water standards in unregulated water sources pose various human health risks. Although high natural background concentrations may occur in some environments (Runnells et al. 1992), anthropogenic contamination concerns are especially troublesome on the Navajo Nation (NN), where past U mining activity may have contaminated water supplies. This research investigated U and As groundwater contamination issues in unregulated wells in the western portion of the NN. Objectives of this research were to provide insights to human health risks by assessing the spatial extent and seasonal variability of U and As concentrations while effectively communicating the potential contamination risks to the local Navajo people. Eighty-two unregulated wells were sampled in 2018; nine of these sources exceeded the maximum contaminant level (MCL) for drinking water standards for U (30 µg/L), and 14 exceeded the MCL for drinking water standards for As (10 µg/L). U and As levels were highest in the southwest portion of the study area and seasonal variability was observed in a subset of wells, especially shallower hand dug wells and hand pumps. The results were compiled into a report that was presented to NN chapters included in the study as well as the Navajo Department of Water Resources and the NN Environmental Protection Agency. Implications for regional water quality patterns can help to direct policy recommendations for well monitoring, water use, and remediation targets.

Keywords: *water quality, tribal, health, well monitoring*

The Navajo Nation (NN) has over 300,000 tribal members, and approximately half of the population reside on the Reservation, which spreads over parts of Arizona, New Mexico, and Utah (Figure 1) (Navajo Division of Health 2013). Additionally, the NN has some of the world's largest uranium (U) deposits on their lands (DeLemos et al. 2007). U mining occurred on the NN from the early 1900s until 1986 (Fettus and McKinzie 2012). Navajo communities with past mining legacies have been exposed to increased levels of contaminants from mining operations (Eichstaedt 1994). There are over 500 abandoned U mine (AUM) sites and over 1,200 mine features spread throughout the NN. Mine features include pits, waste piles, and trenches. Contamination of groundwater from U mining can occur due to erosion of tailing piles and from open pit mining below the water table that produce mine waste water (US EPA 2007). Through increased exposure to water and oxygen, mining activities increase the mobilization of elements such as U and arsenic (As); therefore, the risk of contamination of natural water sources is greater in mining areas (Hoover et al. 2017; Credo et al. 2019). Arsenic is a natural occurring contaminant that is elevated in groundwater in the southwestern United States due in part to desorption reactions with metal oxides, dissolution reactions, a concentration effect due to high evaporation rates in arid zones, and mining activity (Smedley and Kinniburgh 2002). Higher As and U concentrations may occur together because both are more soluble in their oxidized form and can be co-precipitated in the same minerals. Thus, they are often found together in anomalously high concentrations associated with U mining (Smedley and Kinniburgh 2002; Mkandawire and Dudel 2005; Hoover et al. 2017). In addition, regions surrounding mines will have higher background concentrations, because rocks may occur with concentrations of U too low to be considered profitable to mine or because there are deposits that have yet to be discovered and mined. Given the dangers associated with U and As exposure, it is important to determine what communities may be at risk.

Areas with natural mineral deposits can have high levels of dissolved metals due to acid rock drainage (ARD). ARD, caused by the weathering and oxidation associated with all sulfide minerals, is a natural process which mobilizes metals and must be considered when creating remediation goals (Kwong et al. 2009). A subset of ARD is acid mine drainage (AMD) which occurs when mining activities increase the acidity of waters by exposing 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 (Nordstrom 2015).

The quality of water from private wells, which is not regulated by a government agency, creates concerns for public health. Twenty-three % of private wells in the United States exceeded a human-health benchmark for one or more contaminants (DeSimone et al. 2009). Unregulated

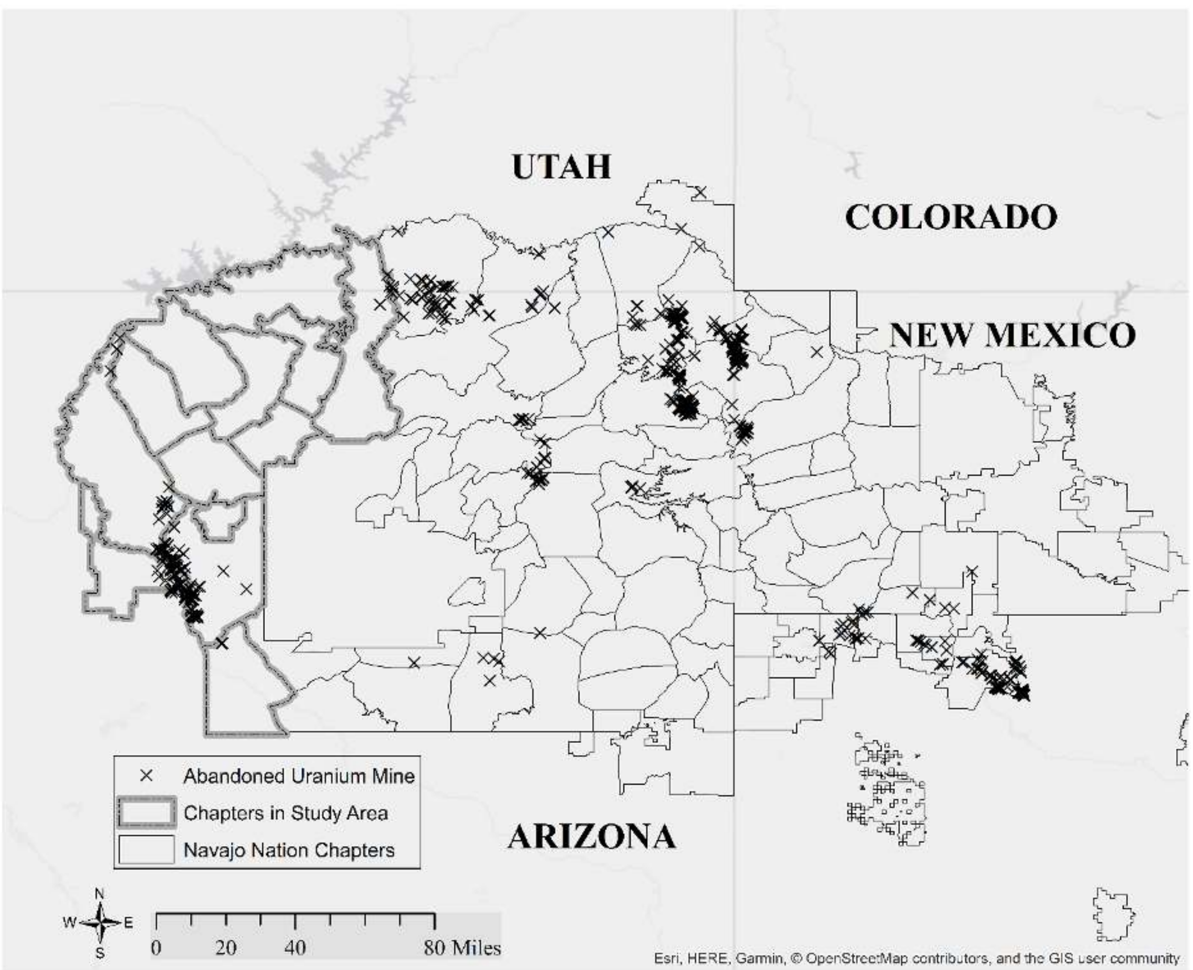

Figure 1. Entire Navajo Nation with chapters, agencies, and abandoned uranium mines.

wells typically have more contamination issues than regulated wells because they may not be as deep, may be located in different aquifer or geologic zones, and may be less soundly constructed than municipal wells (Johnson and Belitz 2017). Also, unregulated wells are not regularly tested for contaminants and often lack water treatment systems (Malecki et al. 2017).

However, 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 NN where approximately 30% of homes lack access to municipal water supplies and rely on hauling water to meet their needs (US EPA 2018). Because many Navajo people live in low-density areas, the cost to benefit ratio of developing water infrastructure is unfeasible (US DOI 2015). Historically, livestock has 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 originally installed for livestock use. There are approximately 900 windmill wells throughout the NN (NNDWR 2011). Data on the water quality of these unregulated sources are limited, especially for the western portion of the NN. In the middle and eastern portions of the NN extensive work has been done to collect water quality data and compile past data collected as shown by the 2017 Hoover et al. research.

The NN is within the Colorado Plateau region where the climate is largely controlled by orographic effects and elevation. Areas below 1370 m (4,500 ft) are semiarid. The average precipitation is 20 to 30 cm per year. However, some lowland areas may receive less than eight cm of precipitation per year. A majority of the NN is in a rain shadow where most 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) (Cooley et al. 1969).

In the western portion of the NN, rocks from the Cretaceous Dakota Formation and below are present. However, regional erosion patterns have resulted in progressively older rocks being exposed at the surface in the southwest portion of the NN (Peirce et al. 1970). Recharge of the aquifers occurs in upland areas, which divides the land into five separate hydrologic basins: Black Mesa, San Juan, Blanding, Henry, and Kaiparowits. Water that is recharged in the upland areas moves downward towards the major rivers and tributaries (Cooley et al. 1969).

The main sources of groundwater for the NN come from the Navajo (N) aquifer, the Coconino (C) aquifer, and shallow alluvium aquifers (Cooley et al. 1969). The N aquifer is an important groundwater source in areas north of the Little Colorado River and water quality is considered relatively good except in areas where past U mining and milling occurred (ADWR 2009). Formations of the N aquifer include the Jurassic Navajo Sandstone, Kayenta Formation, and Lukachukai Member of the Wingate Sandstone. These formations are hydraulically connected and act as a single aquifer (Eychaner 1983). The N aquifer receives recharge in areas near Shonto where Navajo Sandstone is exposed at the surface. In other parts of Black Mesa the N aquifer has overlying confining layers which limit recharge (Lopes and Hoffmann 1997). Groundwater that is recharged near Shonto flows radially in the southwest direction to Tuba City, as well as to the south and east (Eychaner 1983).

The C aquifer is an important groundwater source south of the Little Colorado River. North of the river the C aquifer is too deep to access and the high level of salinity (total dissolved solids) makes it undesirable to use for a drinking water source (ADWR 2009). The C aquifer includes the Pennsylvanian and Permian Upper and Middle Supai Formations, the Permian Coconino Sandstone, and the Permian Kaibab and Schnebly Hill Formations (Bills et al. 2016).

Human health risks from living close to AUM sites have been documented and include kidney diseases, hypertension, and other chronic diseases (Hund et al. 2015). However, information on the health impacts from past mining is lacking for tribal communities. The small population sizes, absent or ineffective policies, and a lack of infrastructure in tribal communities have created problems in understanding the full health impact of past mining activities (Lewis et al. 2017). While research is limited, important studies have been conducted. For example, the Navajo Birth Cohort Study is a long-term, collaborative research project that examined how U exposure affected pregnant Navajo women and their infants. Exposure risks were assessed via biomonitoring, home assessments, and surveys. This study was important to inform individuals with higher risks of the dangers they faced, as well as to develop future policies to mitigate the health risks (Hunter et al. 2015).

The Safe Drinking Water Act sets the maximum contaminant level (MCL) for U at 30 μg/L (US EPA 2000). Human health effects of chronic U exposure include kidney disease and various cancers (ATSDR 2013). The level of uptake and toxicity of different U compounds is still not well understood and requires further research (Bjørklund et al. 2017). Long-term As exposure can lead to skin problems, cardiovascular disease, and lung, bladder, liver, kidney, and skin cancers due to its toxic and carcinogenic properties (ATSDR 2007). The MCL for As in the United States is 10 μg/L (US EPA 2001). Concerns about As contamination issues have been documented world-wide in countries such as China, Pakistan, Bangladesh, India, Vietnam, Mexico, Poland, Argentina, and the United States (Smedley and Kinniburgh 2002; Ng et al. 2003; Nelson et al. 2005; Naseem et al. 2012; He and Charlet 2013; Shakoor et al. 2015; Verma et al. 2015; Chabukdhara et al. 2017). Up to 100 million people globally may face health risks caused by As contamination (Ng et al. 2003).

The NN 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 NN Water Quality Program (NNWQP) is operated under the NN Environmental Protection Agency (NN EPA) and is responsible to ensure the water quality standards are enforced. The NNWQP states that the domestic water supply must not exceed 30 μg/L for U and 10 μg/L for As. In addition, As must not exceed 200 μg/L for livestock water. There is no listed maximum for U in livestock water (NN EPA 2007).

A pathway of exposure to contaminants can exist in drinking water from unregulated sources. As mentioned previously, the lack of access to regulated water in their homes causes about 30% of Navajo households to depend on hauling water to meet their needs (US EPA 2018). 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 non-tribal communities near the NN is 190 gallons per day. The per capita use for the NN is 10 to 100 gallons per day and largely depends on the availability of water resources (NNDWR 2011). 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 will remain an important objective for research on the NN.

Understanding the spatial variability of groundwater contamination issues is critical for future resource management. Further, improving the capacity of tribal nations to mitigate health risks and to manage their natural resources in culturally appropriate ways is critical for sustainable future resource management (Lewis et al. 2017). Objectives of this research are to provide insights on human health risks by assessing the spatial variability of U and As concentrations in unregulated groundwater on the western portion of the NN and to communicate contamination risks to the local Navajo people.

Methods

Study Area

The NN is comprised of five agencies each made up of tribal chapters, similar to states made up of counties. The study area focused on twelve chapters in the Western Agency of the NN (Figure 2). Seven of the chapters are located within the western AUM region and the remaining chapters were included in the study based on community requests to test water in those chapters. U mining occurred in the western AUM region from 1951 to 1963, and the U.S. Environmental Protection Agency (US EPA) has identified 126 AUM structures in the area correlating to that time (US EPA 2007).

The study boundaries include the following chapters of the Western Agency in the NN: Bodaway-Gap, Cameron, Coalmine Canyon, Coppermine, Inscription House, Kaibeto, LeChee, Leupp, Navajo Mountain, Shonto, Tonalea, and Tuba City. There are 82 unregulated wells or water sources identified and tested within these chapters. Water samples from wells in this area have been collected and analyzed for U and As since 2003 by the Ingram Lab at Northern Arizona University.

The study area is sparsely populated, with Tuba City having the largest population size of the chapters. The population sizes for the chapters

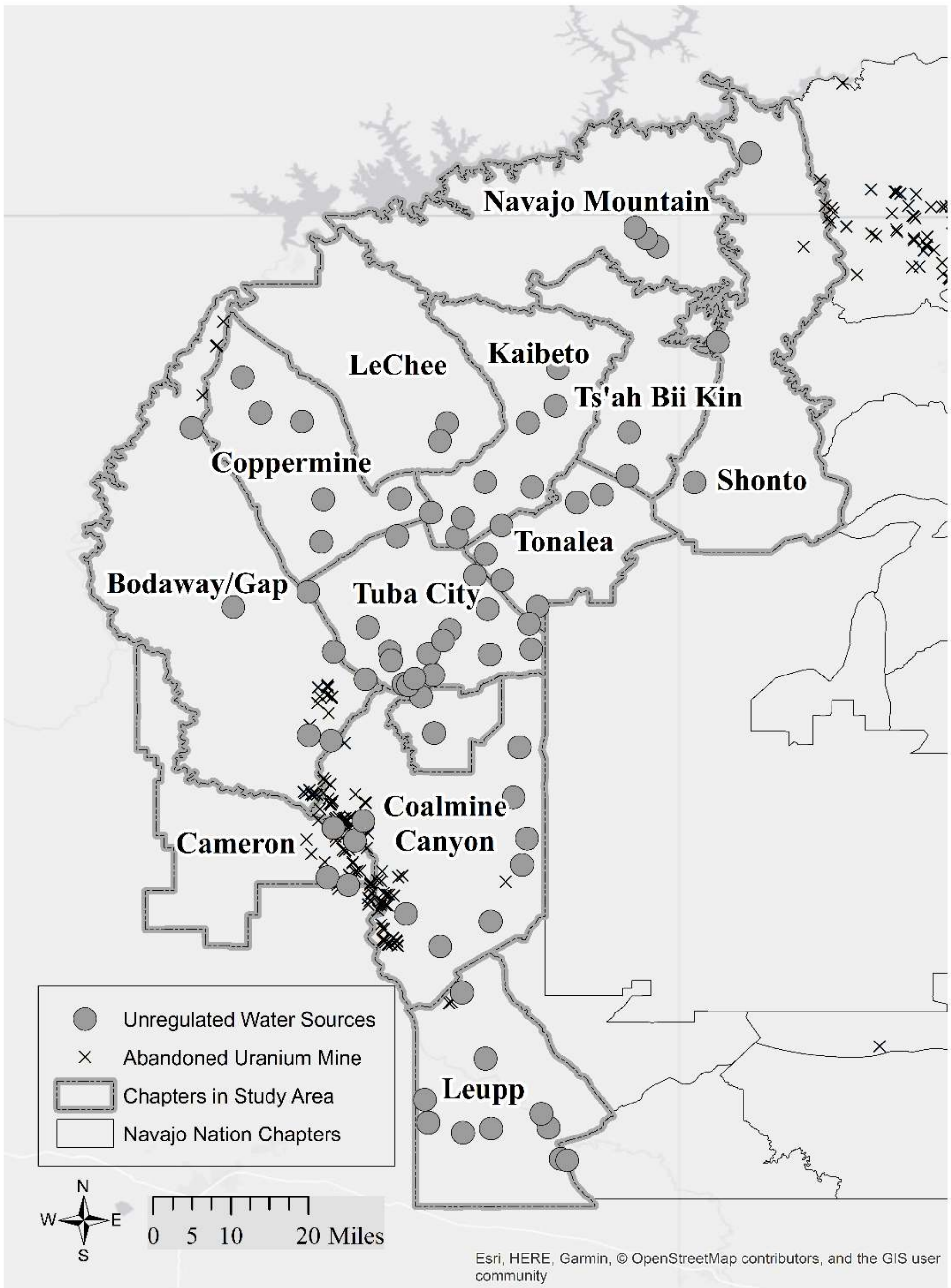

Figure 2. Western Navajo Nation, unregulated water sources, and abandoned uranium mines.

ranged from 542 to 9,265 as shown in Table 1 (U.S. Census Bureau 2010). The population density for the NN is much lower than the United States overall, with only 6.33 persons per square mile as compared to the U.S. average of 345 persons per square mile (Navajo Division of Health 2013).

Chapter Resolutions for Environmental Testing

To ensure that a consensus existed for this research to be conducted, it was important to engage communities at different levels (chapter and agency). Chapter Resolutions were requested and approved to gain permission to carry out this study in the Navajo Mountain and Tuba City Chapters. Additionally, pre-existing chapter Resolutions from the Leupp and Cameron Chapters provided approval for the Ingram Lab Group's previous water sampling. A general Resolution from the Western Agency was requested and approved at the NN Western Agency Meeting in June of 2018.

Field and Laboratory Methods

Fieldwork methods included locating unregulated wells using GPS; measuring field parameters including, pH, specific conductance, temperature, and oxidation-reduction potential (ORP); and collecting water samples. Water samples were collected in 2018 at different times of the year to evaluate seasonal variability. Water samples were filtered with 0.45 μm membrane filters (Whatman 0.45μm PVDF). Samples for cation and metal analysis were acidified in the field with ultra-pure nitric acid (VWR Aristar Ultra nitric acid) to store metals and metalloids in a soluble state. The subset of samples that had carbon and nitrogen analyses performed were filtered in the field with glass microfiber filters (Whatman Glass Microfiber Filters GF/C Diameter 47mm) into glass vials and care was taken to ensure no head space was left, since the interaction with oxygen could alter the results. Specific conductance, pH, ORP, and temperature were recorded in the field with a portable Thermo Scientific Orion 4-Star Plus meter. Calibration of the meter occurred directly before every sampling event for conductivity, pH, and ORP, and the calibration was routinely checked while in the field. For specific conductance and pH, a three-point calibration was performed with pH and conductivity standards. For the ORP, a one-point calibration was performed with Zobell's solution, which is a potassium ferric-ferro cyanide solution with a known ORP (Eh) value. Field notes and photos were taken at every site. One field blank was collected at a random site for each sampling trip.

Water samples were analyzed for dissolved U and As using US EPA water analysis methods (6020B and 200.8) via inductively coupled plasma-mass spectrometry (ICP-MS), Thermo Fisher Scientific X-Series 2 ICP-MS. Usage of internal standardization was to correct for instrument drift and matrix effects during the data collection. For the water analysis, multi-element calibration standards were prepared containing 0, 0.1, 0.5, 1.0, 2.0, and 5.0 μg/L of the analytes, with an internal standard of 1.0 μg/L of iridium-193. The analysis was confirmed by analyzing the Standard Reference Material 1640a, which has certified concentrations of U and As. To ensure the quality of the data, other quality assurance/quality control (QA/QC) measures were followed, including analyzing blanks, analyzing calibration check standards, and the use of an internal standard (iridium-193).

Calibration standards were used to produce calibration curves for each analyte. The instrument signal for the analyte of interest and the internal

Table 1. Summary of populations of the chapters in the western portion of the Navajo Nation (U.S. Census Bureau 2010).

Chapter	Population
Bodaway-Gap	1,704
Cameron	1,122
Coalmine Canyon	691
Coppermine	590
Inscription House	1,252
Kaibeto	1,963
LeChee	1,660
Leupp	1,611
Navajo Mountain	542
Shonto	2,124
Tonalea	2,595
Tuba City	9,265

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 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 µg/L for each sample. The squares of the correlation coefficient values, R^2, were assessed with each calibration. R^2 values of 0.999 or better were deemed sufficient to utilize the calibration.

For each analysis, the instrument was switched from vacuum to operation mode. Once operating, the instrument was warmed-up by pumping water for 15 minutes, followed by 30 minutes in 2% nitric acid. This warm-up time allowed for the determination of contamination in the nitric acid prior to analysis. It additionally provided time for the instrument parameters to be optimized, maximizing analyte signal and increasing stability of readings at the detector. To maintain stability of reading, approximately 100 sweeps of three replicates were processed at the detector per sample.

Once the tuning was complete, the calibration standards were analyzed, first including a reagent blank, followed by the National Institute for Standards and Technology (NIST) Standard Reference Material (SRM) 1640a for trace elements in natural water, and then the diluted unknown samples. The SRM 1640a was used to check the validity of the calibration curves and the reproducibility in sample preparation prior to analysis. After every 15-20 unknown samples a check standard was analyzed to check instrument signal.

Results

The U and As data collected in 2018 were combined with past data collected by the Ingram Lab Group to examine the spatial variability. The data were entered in ArcMap Version 10.5 to create U and As concentration maps (Figures 3 and 4). These maps help to visualize the spatial variability of U and As. Additionally, the maximum, minimum, median, and mean for U and As determined for each of the 82 water samples are provided in Table 2. The highest levels of U and As were found in the southwestern portion of the Coalmine Canyon Chapter. Nine unregulated water sources exceeded the U MCL of 30 µg/L and fourteen exceeded the As MCL of 10 µg/L. Figure 5 shows the exceedances for the similar wells tested with water samples collected over dates from April to December 2018. The plot provides the MCL for U and As, along with the levels of U and As determined in the water sources. For example, the U levels between 124 and 128 µg/L at the top of the figure are the same well tested three times.

The highest levels of U were found in the southwestern portion of the study area (Figure 3). This area correlates with the location of a majority of the AUM sites in the study area. Mining activity may be responsible for these elevated levels; however, since pre-mining baseline levels are unknown it is impossible to determine the source. Since mining occurred in areas with high U levels these results may be due to natural sources. More spatial variability occurred for As (Figure 4) compared to U. The highest levels of As occurred in the southwestern portion of the study area, similar to U, but As levels also varied in water sources in and around the Tuba City Chapter.

The field data revealed that the water was basic and had a wide range in conductivity values (Table 2). The pH values ranged between 7.22 and 9.78. The secondary MCL (SMCL) for pH is below 6.5 and above 8.5 (US EPA 2015). Twenty-nine water sources had pH levels above 8.5. Specific conductance is a measure of how many ions are present in water and can be used to estimate the amount of total dissolved solids (TDS) (Geddes et al. 2014). The SMCL for TDS is 500 parts per million (ppm) (US EPA 2015). To estimate the amount of TDS in water the conductivity value must be multiplied by a factor between 0.55 and 0.90, which is empirically determined and beyond the scope of this study (Geddes et al. 2014). Conductivity values ranged between 78 µS/cm and 11,980 µS/cm. Using the conservative conversion factor of 0.55, any conductivity values above 910 µS/cm would exceed the SMCL of 500 ppm for

TDS, which could result in deposits, staining, or salty tasting water (US EPA 2015). There were 23 water sources with conductivity values above 910 µS/cm. The highest conductivity values were found in the Leupp Chapter and the southwestern portion of the Coalmine Canyon Chapter.

The Navajo Department of Water Resources provided a well database which had aquifer information and well depth for many of the water sources in this study. The aquifer information was used to create a map (Figure 6) to visualize the trends. A majority of the wells pump water from

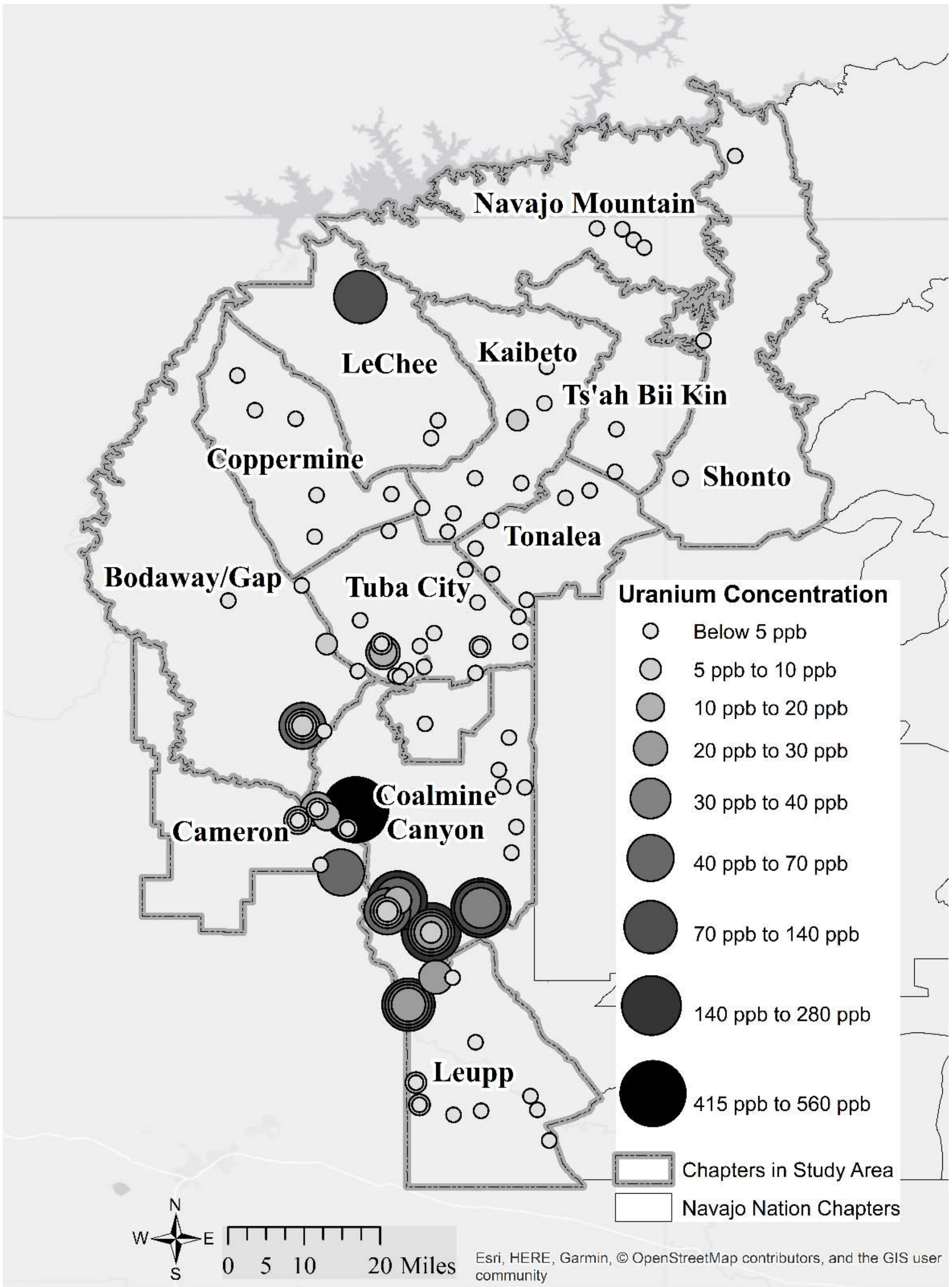

Figure 3. Uranium concentration in parts per billion for the western portion of Navajo Nation.

the N aquifer. One well in the Navajo Mountain Chapter was completed in the Wingate Sandstone which is beneath the Navajo Sandstone but is hydraulically connected; therefore, it is considered part of the N aquifer (Figure 1). In the southern portion of the study area, specifically the Leupp Chapter, most wells pump water from the C aquifer. There was also a subset of wells in the southwestern portion of the study area that access water from the Chinle Formation, the Shinarump Member of the Chinle Formation, and the Moenkopi Formation which lies on top of the Coconino Sandstone layer.

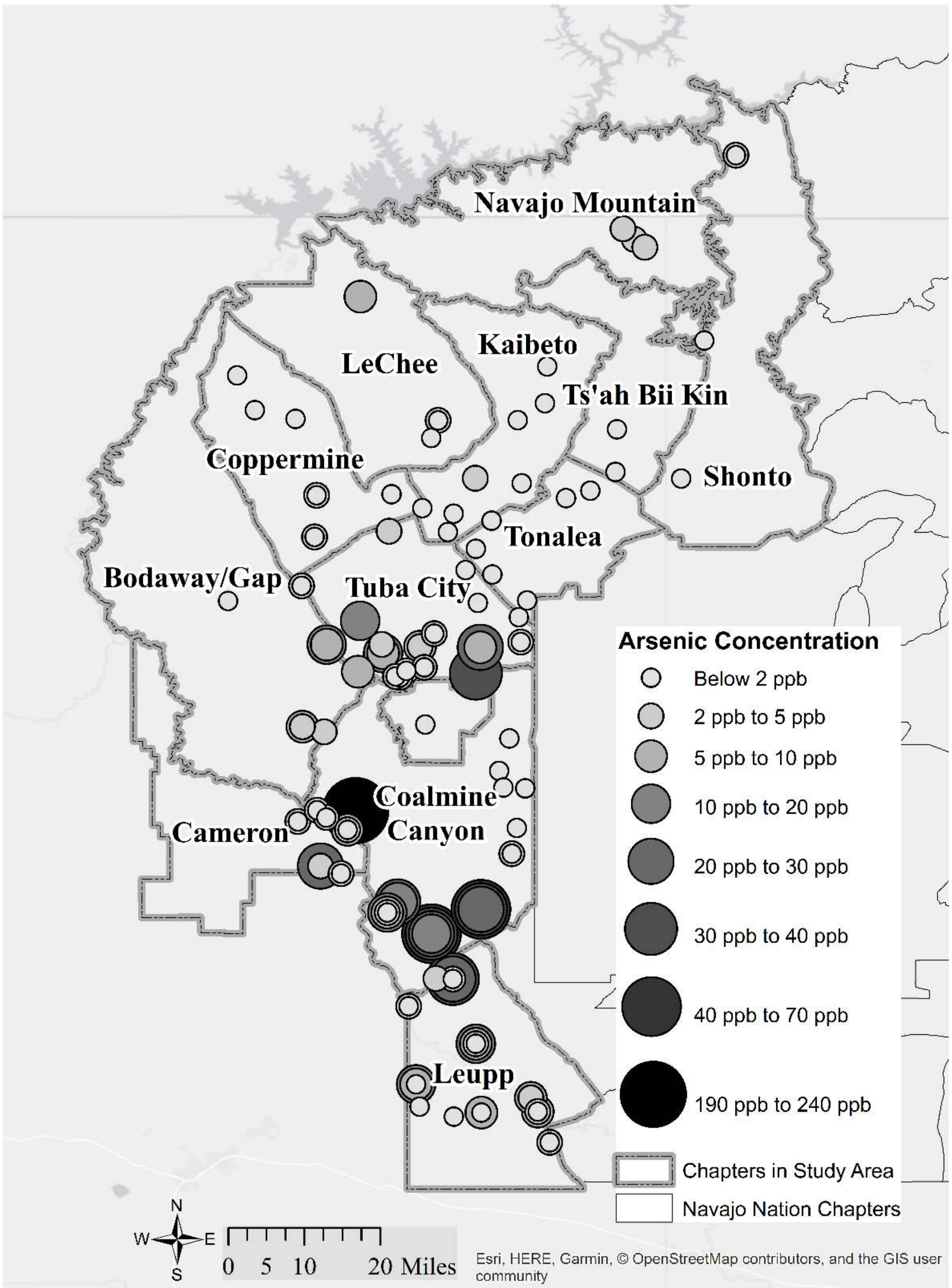

Figure 4. Arsenic concentration in parts per billion for the western portion of Navajo Nation.

Table 2. Summary of field data collected in 2018 for groundwater in the western portion of the Navajo Nation and the overall U and As results for the 82 samples.

	Minimum	Maximum	Median	Mean
Temperature (°C)	7.1	31.3	21.2	18.9
pH	7.22	9.78	8.27	8.25
Conductivity (µS/cm)	77.6	11,980	415	540.7
Oxidation-reduction potential (volts)	0.17	0.63	0.45	0.44
U (µg/L)	BDL	560.2	2.46	2.3
As (µg/L)	BDL	234.4	2.08	2.76

BDL = Below Detection Limit (U=0.001 µg/L; As=0.030 µg/L).

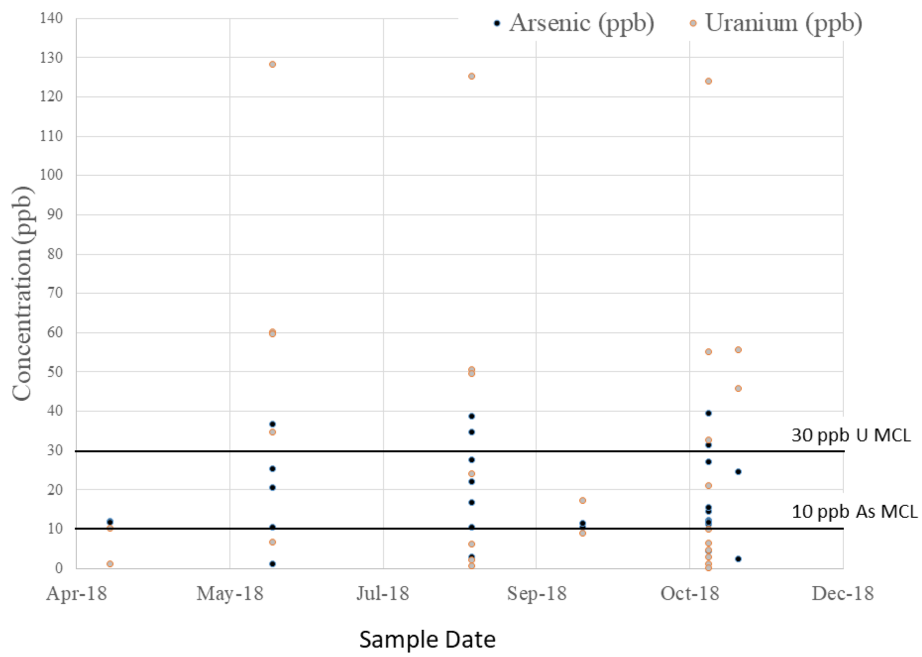

Figure 5. Arsenic and uranium levels determined from April to December 2018 compared to the maximum contaminant level (MCL) values shown as horizontal lines (As MCL = 10 µg/L; U MCL = 30 µg/L).

These layers are generally thought of as confining units and likely only produce very small amounts of water. A portion of the water sources did not have any corresponding aquifer information in the well database.

Some overall trends of the groundwater quality from the N and C aquifers became evident while doing this research. The N aquifer had lower conductivity levels and lower concentrations of ions compared to the C aquifer. The highest concentrations of U and As were found in wells with unknown aquifer information; however, nearby wells were located within the Moenkopi and Chinle Formations (Figure 6). While the highest levels of U and As were found in wells in the same region where past mining occurred, it is difficult to attribute these concentrations to mining activities alone. For example, one well had high levels of U and As but was not near an AUM. The closest mining operation was several miles to the north, but it was in a canyon, therefore, it is down-gradient of the well. Additionally, several wells had relatively low levels of U and As and were very close to AUMs. The complete dataset and a

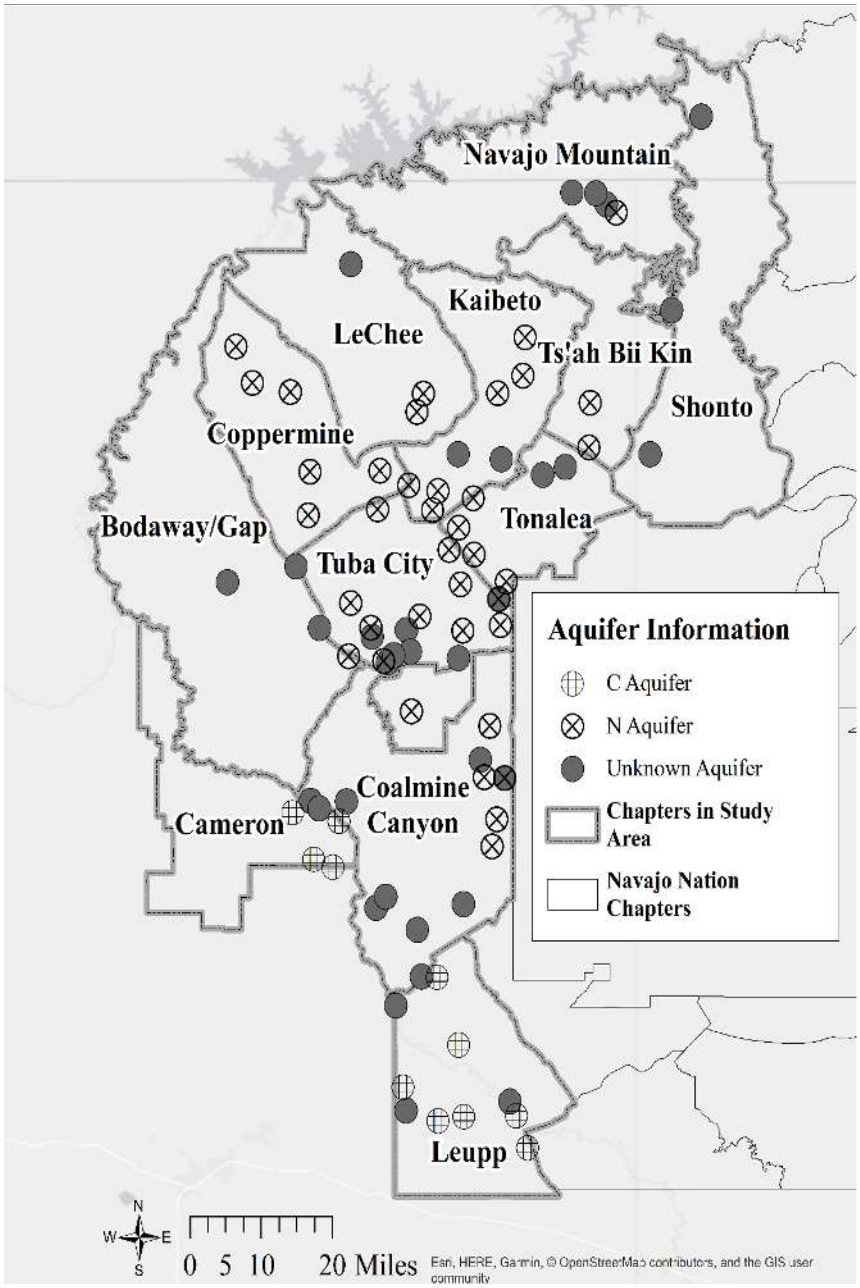

Figure 6. Aquifer information provided by the Navajo Department of Water Resource's Well Database for unregulated wells tested in 2018 by the Ingram Lab Group.

more in-depth analysis of all the data collected can be found in Jones 2019.

Discussion

Importance of Communicating Results

Engaging community members while designing the research plan, as well as disseminating the results back to the community members, were integral to the design and communication of this project. The community members provide information on the location and use of the wells; this information guides both the field collection and dissemination to the community. Various health risks of the contaminants were discussed, and requests from the community for testing of specific wells improved the study. The final report given back to the local people included maps of the well locations and concentrations of dissolved U and As. The report interpreted the results for each chapter in layman's terms. A summary of the report was provided in the Navajo language as well, and dissemination was effective due to the invaluable help of chapter officials. Understanding the steps and procedures that are needed to do research on the NN was extremely important. The Resolutions that were approved helped to engender trust that this research was respectful of Navajo customs.

Unregulated water sources can cause human health issues and communicating the risks that Navajos face in drinking from these sources remains a top priority. However, language and cultural barriers may inhibit effective communication. Researchers have worked to incorporate the Navajo peoples' perspectives to provide culturally significant communication methods (DeLemos et al. 2009). Maps can provide clear and effective ways to communicate the environmental and human health risks. Gaining feedback from Navajo community members concerning the efficacy of these maps will engender more culturally appropriate forms of communication.

A report was created with the 2018 data and copies were given to all the chapters in the study area as well as to the Navajo Department of Water Resources, the NN EPA, and the Navajo Tribal Utility Authority. Additionally, the researchers provided in-person presentations of the results to many of the chapters in the study during their monthly community meetings as well as at the Western Agency quarterly meeting. At these meetings, copies of the report were distributed to the meeting attendees, and community members had the opportunity to ask questions and talk to the researchers individually. This report was created to add to the knowledge about water quality issues for the western NN. While the report does not consider all water quality issues or possible pollutants, it can be used to direct future studies to determine where safe drinking water sources exist.

Implications for Regional Water Quality Patterns

The main source of water for the western portion of the NN comes from the N aquifer; however, increased withdrawals from the C aquifer have been proposed to supply the Navajo people with an alternative water resource (Leake et al. 2005). Seepage of contaminated mine groundwater to surface water introduces a pathway of exposure. The movement of shallow groundwater sources is influenced by precipitation and topography while deeper groundwater is more influenced by fracturing and fault zones in geologic units (Bartolo et al. 2017).

Pre-mining baseline studies to establish if natural geological sources of U and As are responsible for water contamination issues are not available for the study area. For other areas where baseline studies exist, the focus is on stream sediments and soils. The change in geochemical factors in water over time is not usually considered. However, temporal sampling is important to evaluate how geochemical factors of water can vary with seasonally. For example, biological activity and sorption rates vary due to temperature and precipitation intensities and amounts affect water flowpaths and reaction times (Levitan et al. 2014).

Determining background levels of metal concentrations is important in mining regions since remediation of these sites to levels below pre-mining levels is difficult or impossible. Natural background concentrations may be above what is considered safe for drinking water; therefore, remediation of groundwater to levels considered safe to drink may be unfeasible. When baseline studies do not exist, one method to determine background levels is to compare levels of mined areas to close by areas which were not mined (Runnells et al. 1992).

Limitations

Other wells likely exist in the study area that were not tested, since the locations of those wells were unknown. Further, it was not known which wells were commonly used by people for their drinking water; therefore, human-use surveys would be helpful for future research. Past students' work was limited to certain wells; therefore, large gaps in the data existed. This study included a larger number of wells, but temporal change could not be studied since no long-term data exist for many wells.

Large fluxes in concentrations may be due to evaporation, precipitation, and groundwater pumping rates (concentration and dilution factors). Most of the unregulated water sources tested were windmills, which pump water into storage tanks when the wind is blowing. The storage tanks can be open on top or covered. The uncovered storage tanks allow for a greater amount of evaporation which would increase the levels of U and As found (due to concentration). Additionally, the shallow dug wells can have a large amount of evaporation occurring. The effect of evaporation and the concentration of contaminants would be greater during the hot, dry summer months. Dilution of contaminants can occur from heavy rains during the late summer months or from increased pumping of the groundwater when there is sufficient wind to power the turbine.

Water sampling methods followed how local Navajo people collected their water. Because the water was coming from holding tanks, the well could not be purged for the recommended time to ensure that the water was coming from the aquifer. The water also had time to interact with air while in the holding tank; therefore, properties of the groundwater may have changed during the time it spent on the surface. Additionally, the well construction was unknown, and there could have been leakage from an overlying aquifer, or deposition from blowing dust, which would alter concentrations. These study limitations make it hard to say if the results are truly representative of the aquifer water quality.

Conclusion

This research combined physical science with community engagement, which is critical to achieve solutions to environmental challenges. Field and chemistry work were essential to provide the data. However, social interactions, such as community presentations and discussions, were critical to make the data relevant. The relationship between researchers and community members is also important to consider. This research focused on improving relations between the two groups and creating an open dialogue that allows for solutions to problems. The results from this research can be useful to provide data for comparison to future water quality testing, for determining particularly problematic mining areas, and to determine the existence of possible natural sources of dissolved U and As. However, wells with open holding tanks provided an uncertainty in the results.

Collaboration with stakeholders was essential for this research. The Resolution process to gain permission to sample the water sources helped to make connections with stakeholders which proved to be useful for other parts of this project. Connections with community members helped to locate additional wells that the local people wanted tested. The dissemination of the results was assisted by collaborating with community officials. Therefore, it was only through collaborations with multiple stakeholders that this research was possible.

The final recommendations that were made to the Navajo people included adding signage to wells that exceeded the MCLs of U and As to warn people of the risks. It was also recommended that wells that were very low in U and As be considered for addition to the regulated water system. Closing the wells was not recommended since these water sources are also used for livestock water and were still considered safe for that purpose. Maps representing water sources with toxic U and As concentrations, along with alternative cleaner water sources, may provide effective forms of communicating risks. Water is limited for the Navajo people and the protection of water quality must remain a priority into the future. By working in collaboration with the Navajo communities and their leaders, the results from this study can be utilized by the NN to develop strategies for water utilization on their lands.

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Arsenic Concentrations in Ground and Surface Waters across Arizona Including Native Lands

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Abstract: Parts of the Southwestern United States report arsenic levels in water resources that are above the United States Environmental Protection Agency's current drinking water limits. Prolonged exposure to arsenic through food and drinking water can contribute to significant health problems including cancer, developmental effects, cardiovascular disease, neurotoxicity, and diabetes. In order to understand exposure risks, water sampling and testing have been conducted throughout Arizona. This information is available to the public through often non-overlapping databases that are difficult to access and in impracticable formats. The current study utilized a systemic compilation of online databases to compile a spreadsheet containing over 33,000 water samples. The reported arsenic concentrations from these databases were collected from 1990-2017. Using ArcGIS software, these data were converted into a map shapefile and overlaid onto a map of Arizona. This visual representation shows that arsenic levels in surface and ground water exceed the United States Environmental Protection Agency's drinking water limits for many sites in several counties in Arizona, and there is an underrepresentation of sampling in several tribal jurisdictions. This information is useful for water managers and private well owners throughout the State for determining safe drinking water sources and limiting exposure to arsenic.

Keywords: *arsenic, groundwater, surface water, Arizona, monitoring map, water quality*

Arsenic contamination represents a growing public health concern in numerous countries across the globe (Mukherjee et al. 2006; Uddin and Huda 2011; Alarcón-Herrera et al. 2013; Huang et al. 2015; Ayotte et al. 2017; Hsu et al. 2017; Malloch et al. 2017; Saint-Jacques et al. 2018; Zeng et al. 2018). It has been responsible for some of the most devastating natural mass poisoning incidents in recent times, according to the World Health Organization (WHO) (Flanagan et al. 2012), and represents a looming threat as concerns about water security and water shortages increase (IPCC 2013, 2014). Its potency for damage to health prompted the WHO in 1999 to lower maximum contaminant levels (MCL) from 50 μg/L or parts per billion (ppb) to 10 ppb and recommend emergency corrective measures be taken in waters that exceed 50 ppb (Smith et al. 2000). Following this policy change, most governments adopted similar regulations globally (Shankar et al. 2014; Nigra et al. 2017).

Arsenic exists in two common forms, organic and inorganic, and this characteristic determines its toxicological potential (Dani and Walter 2018). Organic forms of arsenic, such as monomethylarsonic acid (MMA) and dimethylarsinic acid (DMA), are commonly found in aquatic fish and other consumable sea products and are generally viewed as relatively non-toxic (Husain et al. 2017), although this view is under debate (Moe et al. 2016; Wei et al. 2017). This non-toxic designation is attributed to the fact that MMA and DMA are both metabolic products produced by the liver during natural arsenic metabolism, and ingestion of these products typically results in normal excretion by the organism (Vahter and Concha 2001). Inorganic arsenic, in relation to contamination and toxic health effects, is broken into its pentavalent, arsenate, and trivalent, arsenite, forms (Thomas et al. 2001). Both arsenate and arsenite contaminate ground and surface drinking water sources and can be taken up by plants, such as rice (Hughes et al. 2011; Chung et al. 2014). Inorganic arsenic can be metabolized by organisms; however, it bioaccumulates in various organs such as the liver, kidneys, heart, and lungs causing progressive damage with chronic exposure (Arslan et al. 2016). Arsenic is recognized as a potent carcinogen and is associated with vascular damage, which can lead to congestive heart failure (Martinez et al. 2011; Moon et al. 2012). Additionally, studies have demonstrated that arsenic acts as a potentiating agent with other toxins exacerbating their detrimental effects (Singh et al. 2011; Tyler and Allan 2014).

While arsenic's previous use in industry poses a possible legacy contaminant in parts of the globe, its application has been diminishing and its natural occurrence represents the primary environmental source to contaminate air, food, and water resources (Ribeiro et al. 2000; Mandal and Suzuki 2002). For example, tube wells drilled in Bangladesh in the 1960s and 1970s by the United Nation's Children Fund (UNICEF) went deeper than previously drilled wells to access cleaner water sources not contaminated by microbial organisms (Sen and Biswas 2013); deep wells have provided arsenic laden water to parts of Vietnam for more than a hundred years (Winkel et al. 2011). The aquifers in these deeper wells have a different surrounding geologic structure, and the mineralite matrix was associated with heavy arsenic concentrations, which led to subsequent contamination of these new wells (Hoque et al. 2017; Rahman et al. 2018). A report by the United States Geological Survey (USGS) in the early 2000s revealed similar geologic conditions which could lead to contamination of water by naturally occurring arsenic across many parts of the United States (Welch et al. 2000). A combination of rich iron-sulfur bearing rocks, agricultural backgrounds, and extensive mining history increases the potential for arsenic contamination in the Southwestern United States. Mining operations in the Southwest result in increased risk of contamination by disturbing underlying bedrock and iron-sulfur rocks; as ore is brought to the surface, this increases the surface area of these rocks, which may increase arsenic mobilization into the environment (Focazio et al. 2000; Etschmann et al. 2017). Waste and tailing piles represent an added source for contamination, increasing the potential for concentration of arsenic contaminants (Lim et al. 2009; Larios et al. 2012; Laird et al. 2014).

Because of water treatment to meet drinking water standards, arsenic in Arizona does not pose a significant concern for urban centers; however, much of the state is designated as rural or frontier regions (Gordon 1987; U.S. Census Bureau 2010). Citizens in these regions still rely on private wells or water hauling practices, which are unregulated and unmonitored, and are vulnerable to unchecked contamination by arsenic. Both the Verde Valley and the Hopi Tribe have faced litigation and legal ramifications for exceedances in their water from arsenic (Foust et al. 2004; Wildeman 2016). For these reasons, numerous separate studies and databases are publicly searchable, and show arsenic levels across the state (see references- National Water Quality Monitoring Council (NWQMC); U.S. Environmental Protection Agency (USEPA)). These databases are now combined within the NWQMC site, and the USEPA site is no longer available. However, a recent study investigating regional water quality on the Navajo Nation in Arizona demonstrates that the use of these databases, combined with new sampling, can provide information regarding water quality such as arsenic concentrations above the regulatory drinking water limit across a landscape (Hoover et al. 2017, 2018; Jones et al. 2020). The Navajo Nation represents the largest contiguous Native American reservation in the United States, has an extensive history of environmental injustice and environmental contamination issues associated with uranium mining, and is primarily rural or frontier in designation (Lewis et al. 2017). The purpose of this paper is to combine water quality and arsenic concentration data on the water in

Arizona from various databases and scientists into a single location. This information is important for identifying which populations and communities are at risk of consuming arsenic contaminated drinking water, especially for those reliant on unregulated sources.

Methods

Retrieval of Datasets

Datasets were collected through the methods summarized in Figure 1. Data were downloaded in May 2017 from https://ofmpub.epa.gov/storpubl/dw_pages.querycriteria, which is no longer available through the USEPA online sites, and https://www.waterqualitydata.us/portal/, where the USEPA data may have now migrated. Search criteria for the geographic location was entered as Arizona and then more specifically broken down by county and or tribal lands. Data from all Organization Types and Station Types were used. The Date Range was set as January 1, 1990-May 1, 2017. Water was chosen as the "Activity Medium" and all "Intents and Communities" were used. "Arsenic" and all synonyms were chosen as the "Characteristic" and all "Warehouse Data Sources" were used. Once the results were generated, they were downloaded and converted into Microsoft Excel files.

The location information and corresponding arsenic levels had to be combined into a single file for results downloaded from https://www.waterqualitydata.us/portal/. To do this conversion, the Monitoring Location Identifier was matched on each of the documents. A copy of the Results file was saved in order to avoid corrupting the original information. The sample type (groundwater or surface water), latitude, and longitude were then added to the copy of the Results file for each individual county. The date of the sample was also changed to a recognizable date format using the formula =DATAVALUE.

Condensation by County

After combining the Water Quality Database site location and arsenic level information into single files for each county, all of the information for each county from both websites was merged into a single Excel document that was used to create the shapefiles in ArcGIS. In order to ensure quality was maintained, the background color of six to ten line items was changed per county. Random spot checking was also conducted by comparing the merged file to the originally downloaded data.

Organization and Formatting

When the county samples were merged into a single Excel document, the website containing the original information was included for each sample site. Additionally, the location information for each sample was included, specifically the county where the sample was taken, latitude, longitude, and whether the sample was taken from groundwater, surface water, or unspecified. The date the sample was taken, the original numerical value of the concentration of arsenic, the original units, and the converted value and units were also included. Each sample was converted to ppb. After all of this information was entered, the file was saved in comma-separated value (CSV, comma delimited) format.

Conversion into Shapefiles

ArcGIS version 10.4 software was used to make the shapefiles. The CSV file was converted into an XY table with Longitude as X and Latitude as Y (this information comes from ESRI technical support: How to import XY data tables). The XY table is then uploaded as a shapefile to the map of Arizona. The map of Arizona was loaded from the ESRI online database and tribal reservations were delineated (Figure 2; CAPGISadmin 2017; Central_Arizona_Project 2019; Esri 2020; MPD_GIS 2020). Once loaded as a shapefile, it was converted to a layer. The symbols were identified by quantity and broken up into the following three categories based on concentration in ppb: 0.0-10.0, 10.1-100.0, and greater than 100.0. The color became darker and the size larger as the value increased.

Upon completion of the map of the entire state of Arizona, there were 33,099 samples represented. The previously listed information (see above) per sample is viewable in the attribute table for the newly created layer in ArcGIS (http://www.arcgis.com/home/item.html?id=191c7abbce0445409a190522ccb3db2c).

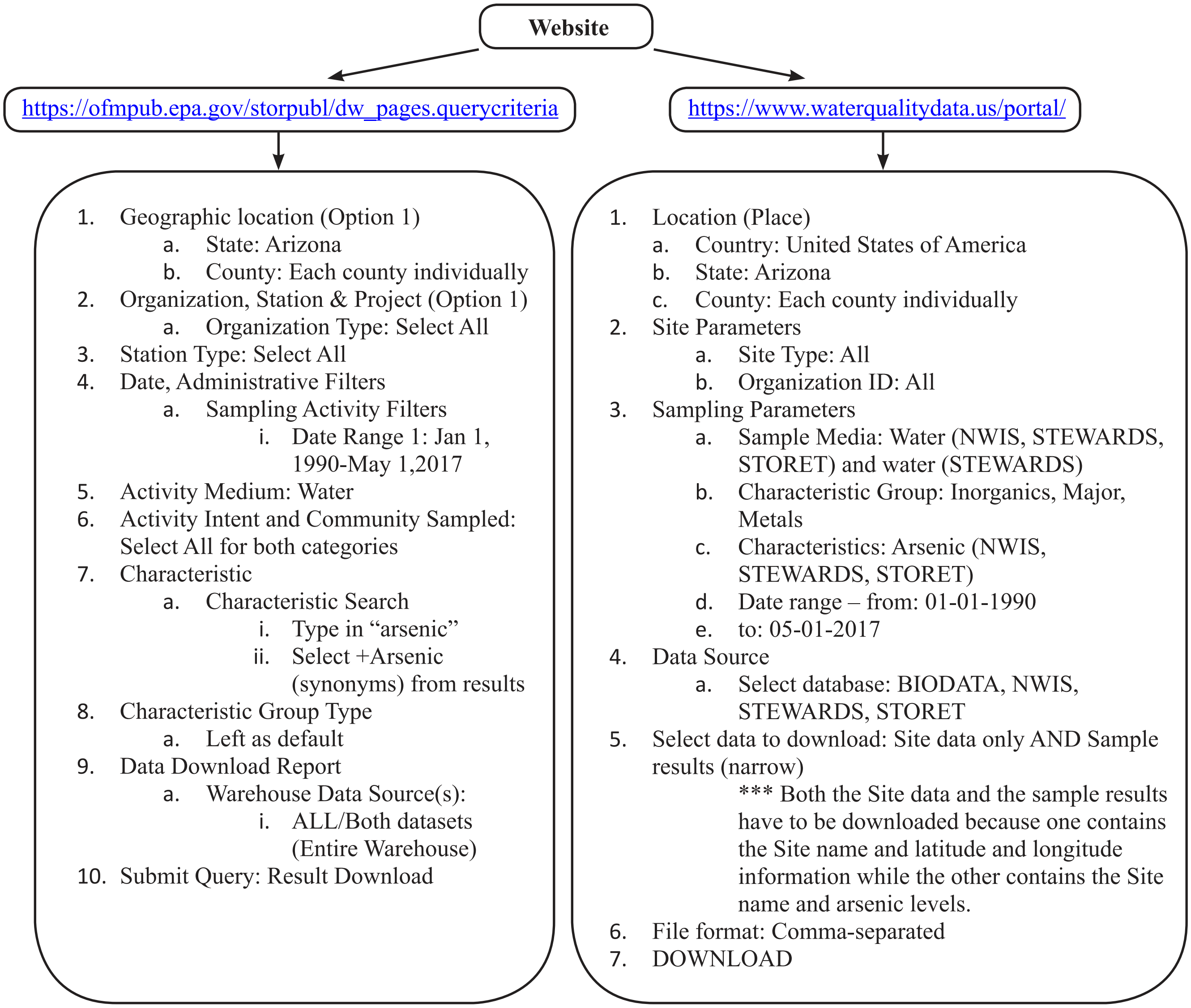

Figure 1. Flowchart demonstrating the procedures used for querying each website for downloading data regarding arsenic measurements in ground and surface water in Arizona.

Data Analysis and Reporting

In order to determine the number of samples per county with a measured arsenic concentration over 10.0 ppb, the 33,099 samples were separated by county and broken up further by concentration level. The number of samples with an arsenic concentration of 10.1 ppb or above was divided by the total number of samples reported for that county in order to get the percentage of reported samples over 10 ppb using the formula below where *P%* is percentage, *X* the portion of total samples in the concentration category, and *Y* the total number of samples in the category (equation 1).

$$\frac{P\%}{100} = \frac{X}{Y} \qquad (1)$$

Similar analysis was also conducted for arsenic levels on tribal lands. These analyses are reported in further detail in the Results section.

Results

The compilation of data from 33,099 ground and surface water samples provides a clear picture of the extent of known arsenic levels throughout the state of Arizona (Figures 3-6; surface water, groundwater, and sites where the water source was not specified, respectively). Sixty-four %

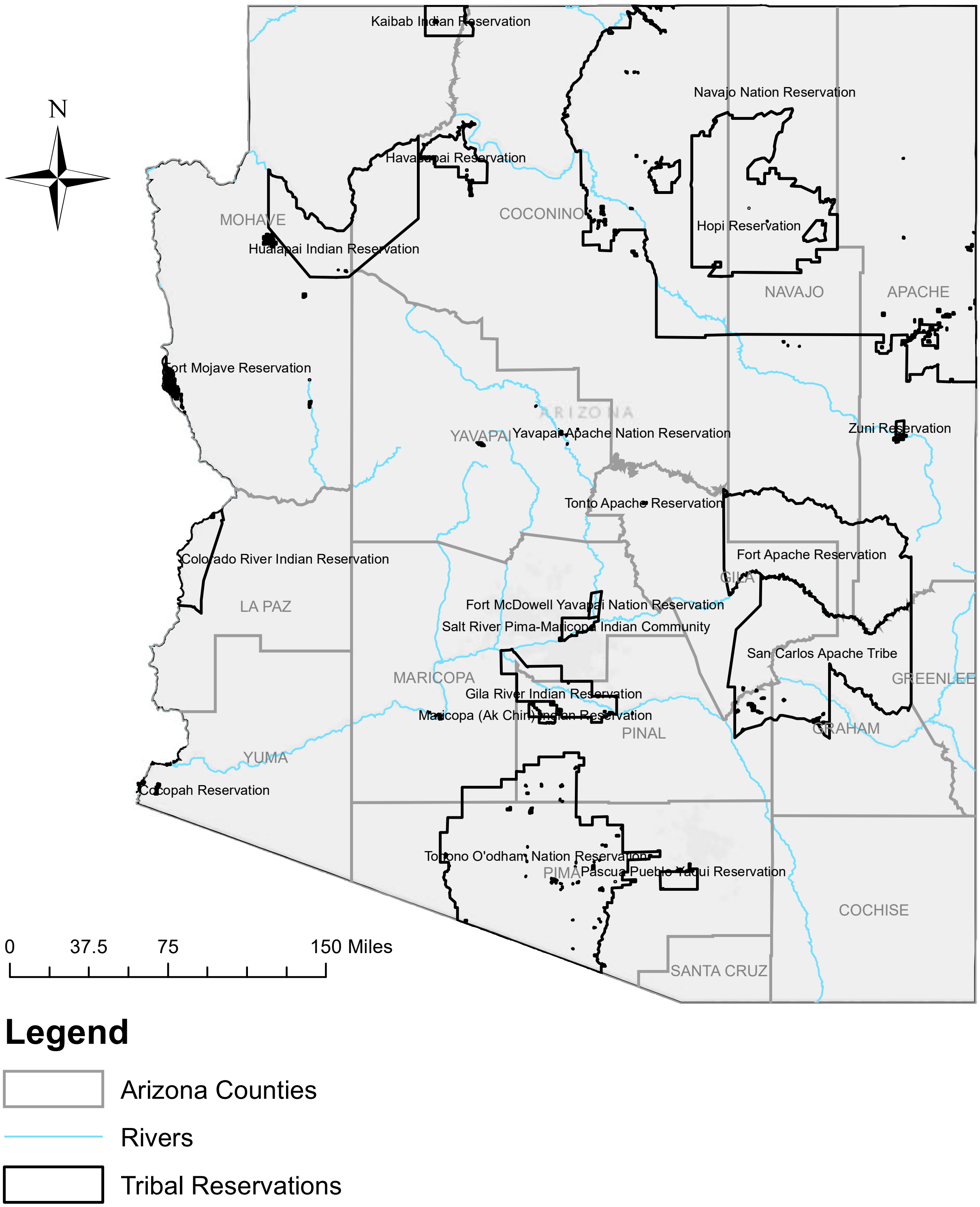

Figure 2. Map of Arizona with tribal names and jurisdictions outlined.

(21,194 samples) of the total samples taken did not specify where they were from, while 6.4% were from groundwater and 29.6% were from surface water. Many samples came from repeated site sampling at the same location over the course of the timeframe evaluated; therefore, the number of sites represented on the map appears to be fewer than the total sampled, especially for the surface water sites. For the sites where the type of sample was "unspecified," the information may have been recorded when the sample was taken, but has not been made publicly available. For several of these unspecified sites, samples were taken from areas with little or no surface water, so it may be possible to assume the sites were sampled from groundwater resources. Any area with no indication of arsenic sampling on the maps is a result of there being no data indicated in the searched databases for GIS coordinates in that region. Regions where there are no shapes on the maps either have not been sampled or samples were not provided to the queried databases suggesting that further sampling may be useful especially for the evaluation of groundwater.

Across counties, many ground and surface water samples demonstrated arsenic levels above the regulatory safe drinking water limit of 10 ppb as put forth by the USEPA. The results indicate that 20.7% of all the samples taken throughout the state measured over 10 ppb for arsenic in the water (Table 1). More than 40% of samples from Pinal and Yavapai Counties have arsenic concentrations over 10 ppb (Table 1). The county with the overall lowest concentrations is Greenlee. Several of the tribal jurisdictions also had samples that exceeded 10.0 ppb, especially Fort McDowell. For the most part, sampling on tribal lands is limited and in some cases is either non-existent or unavailable through the searched public databases (Table 2).

Discussion

The geologic profile and climate of Arizona lend itself to naturally occurring valuable mineral deposits and fertile agricultural lands. Unfortunately, both of these factors plus the large and primarily rural nature of Arizona contribute to issues securing clean water resources that are safe for human consumption (Cordy et al. 2000). The arsenic water quality information represented in the USEPA and National Water Quality Monitoring Council databases demonstrated water resources that exceeded the USEPA MCL of 10 ppb were widely distributed across the state, with most exceedances located in the central and southern regions (Figures 3-6). The frequency of contaminated wells in Arizona at 20.7% exceeded the national average of 12%; however, several states including Illinois, Maine, Minnesota, and Nevada have a high percentage of exceedances similar to the levels found in Arizona (Uhlman et al. 2009; Ayotte et al. 2011, 2017). The USGS points to the geologic substrate across Arizona as the explanation for an elevated background concentration of arsenic in water resources, which explains the statewide contamination (Ryker 2001). Areas that have experienced previous mining or significant ground disturbances, including deep water exploration, demonstrate clusters of elevated arsenic concentrations exceeding drinking water regulatory limits, such as those seen in Yavapai and Pinal Counties (Anning et al. 2012).

All of the maps demonstrate a lack of information regarding sampling of arsenic levels in water resources within most tribal jurisdictions. This lack of representation in these databases does not demonstrate an absence of arsenic in water resources across these regions, but rather an absence of either sampling by federal agencies and/or a lack of centralized information being publicly available. These Native American Nations are sovereign entities recognized and separate from the federal government that maintain their own utility services, including water monitoring programs (U.S. Department of the Interior 2006; Washington and van Hover 2011). The most sampling has occurred on the Navajo and Hopi lands, where water quality issues, especially related to widespread arsenic and uranium contamination occur (Brugge and Gobble 2002; Hoover et al. 2017, 2018). Unfortunately, while water quality information exists for some of these Nations (TerraSpectra Geomatics et al. 2000; Orescanin et al. 2011; Hoover et al. 2017, 2018), for many, if the data exist, it requires strict approval by the various tribal governments to publish them in a public location (Kickingbird and Rhoades 2000). An added barrier to such publication is the

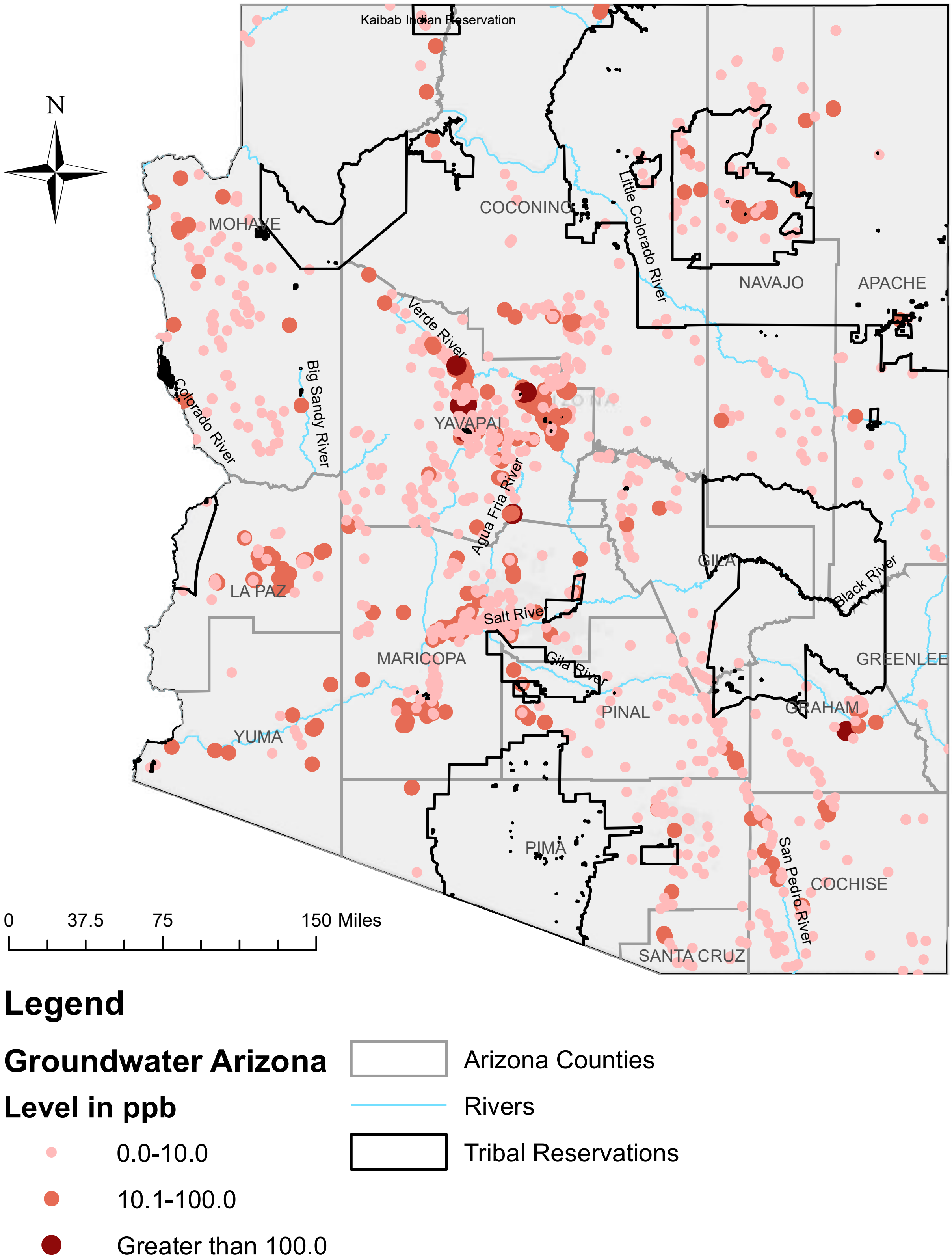

Figure 3. Map of Arizona representing arsenic levels in ppb for samples taken from groundwater resources between 1990 and 2017. Increasing circle size indicates higher arsenic concentrations.

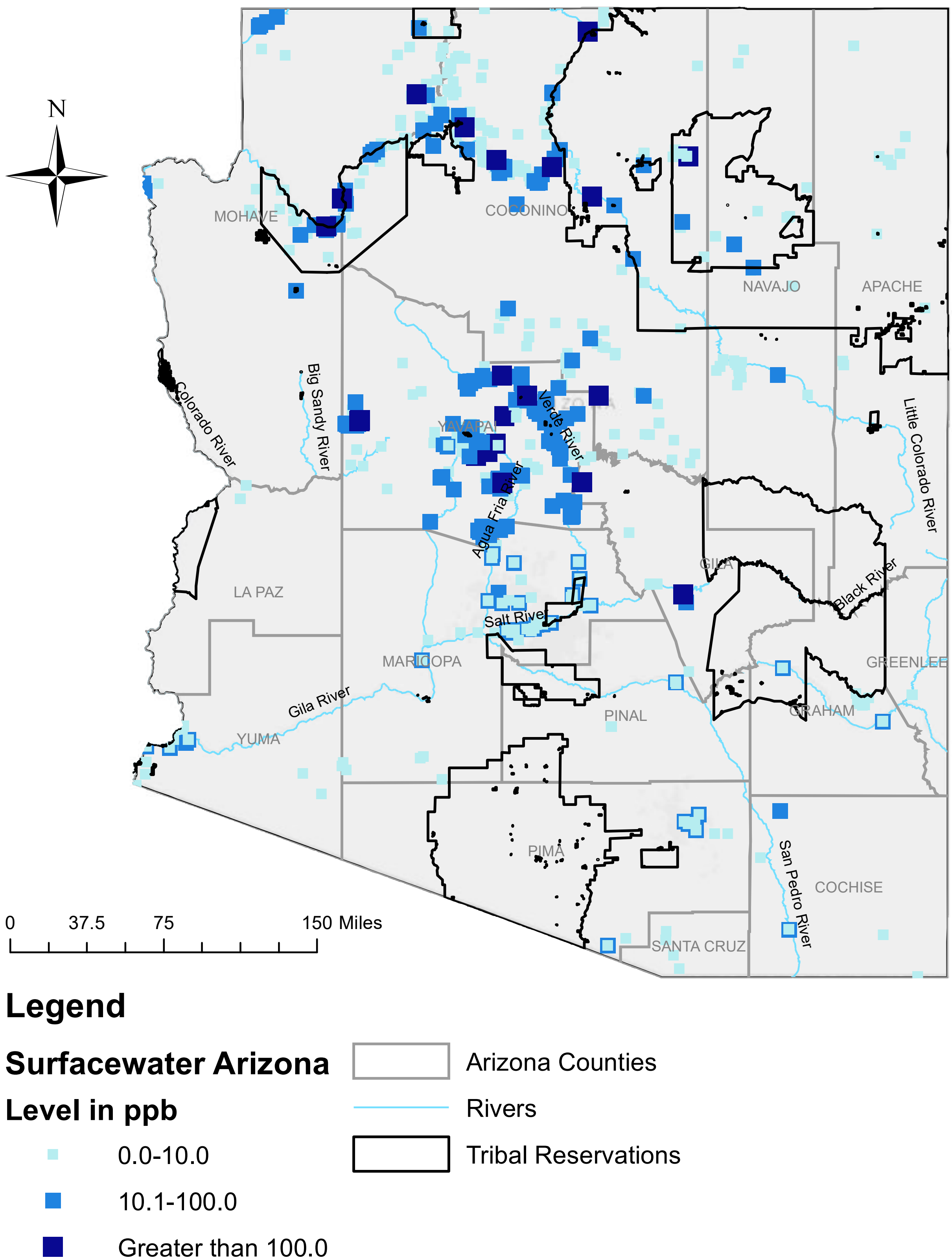

Figure 4. Map of Arizona representing arsenic levels in ppb for samples taken from surface water resources between 1990 and 2017. Increasing square size indicates higher arsenic concentrations.

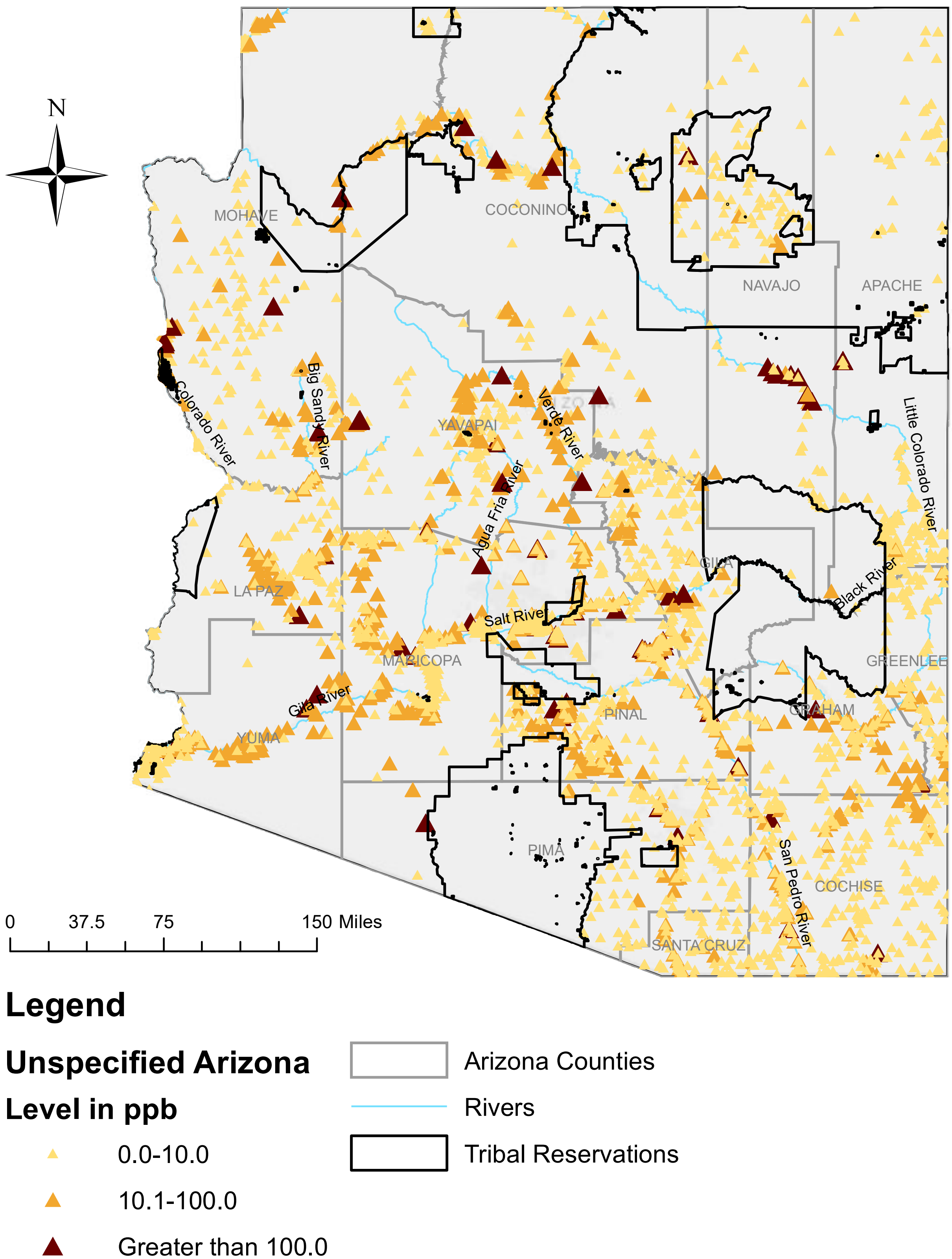

Figure 5. Map of Arizona representing arsenic levels in ppb for samples that did not have the type of water resource provided and were taken between 1990 and 2017. Increasing triangle size indicates higher arsenic concentrations.

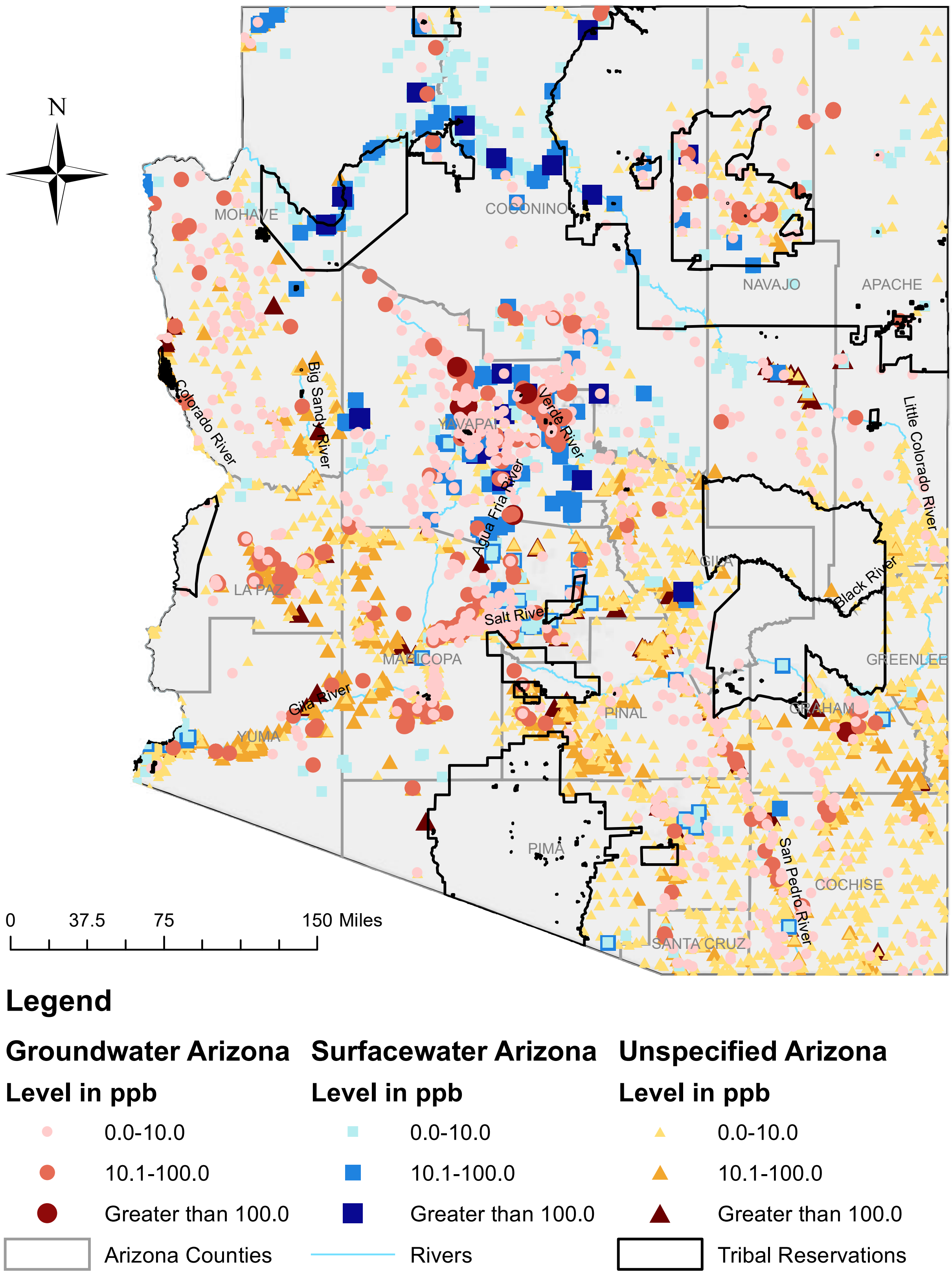

Figure 6. Map of Arizona representing arsenic levels in ppb for all samples taken between 1990 and 2017. Marked places on the map are the same as for Figures 3-5.

Table 1. The distribution of samples across concentration ranges of arsenic and the % of samples that are above the USEPA drinking water limit (10.0 ppb) for each Arizona County. Percentages highlighted in red represent those counties with the highest % of samples above USEPA drinking water limits.

	Apache	Cochise	Coconino	Gila	Graham	Greenlee	La Paz	Maricopa	Mohave	Navajo	Pima	Pinal	Santa Cruz	Yavapai	Yuma	Total for Arizona
Square Miles	11,218	6,219	18,661	4796	4641	1848	4513	9224	13,470	9959	9189	5374	1238	8128	5519	113,997
Total Number of Samples	1407	1511	3712	2870	1162	1164	794	6774	1622	782	1411	1801	720	5705	1664	33,099
# of Samples 0.0-5.0 ppb	169	235	1618	555	559	114	207	1246	437	259	230	182	66	463	883	7,223
# of Samples 5.1-10.0 ppb	25	43	151	286	159	16	278	1954	233	49	312	240	103	432	304	4,585
# of Samples 10.1-50.0 ppb	20	78	267	226	90	33	137	1393	339	74	78	718	41	2227	183	5,904
# of Samples 50.1-100.0 ppb	11	17	38	31	7	1	9	113	20	26	50	92	3	127	3	548
# of Samples > 100.0 ppb	32	4	26	52	3	0	2	26	22	36	3	56	0	136	4	402
% of Samples > 10.0 ppb	**4.5**	**6.6**	**8.9**	**10.8**	**8.6**	**2.9**	**18.6**	**22.6**	**23.5**	**17.4**	**9.3**	**48.1**	**6.1**	**43.6**	**11.4**	**20.7**

Table 2. The distribution of samples across concentration ranges of arsenic and the total number of samples for each Arizona tribal jurisdiction.

	Cocopah Reservation	Colorado River Reservation	Fort Apache Nation Reservation	Fort McDowell Yavapai Nation Reservation	Fort Mojave Reservation	Fort Yuma Indian Reservation	Gila River Indian Reservation	Havasupai Indian Reservation	Hopi Reservation	Hualapai Indian Reservation	Kaibab Indian Reservation
Square Kilometers	26.1	1202.1	6814.8	100.9	136.6	182.1	1514.4	714.4	6560.8	4155.9	491.5
# of Samples 0.0-10.0 ppb	4	1	12	71	12	0	75	4	284	75	35
# of Samples 10.1-100.0 ppb	2	0	1	86	2	0	3	2	55	61	2
# of Samples > 100.0 ppb	0	0	0	0	0	0	0	0	2	11	0
Total Number of Samples	**6**	**1**	**13**	**157**	**14**	**0**	**78**	**6**	**341**	**147**	**37**

	Maricopa Ak Chin Indian Reservation	Navajo Nation Reservation	Pascua Pueblo Yaqui Reservation	Salt River Pima Maricopa Reservation	San Carlos Apache Reservation	Tohono O'odhan Nation Reservation	Tonto Apache Reservation	Yavapai-Apache Nation Reservation	Yavapai-Prescott Reservation	Zuni Reservation
Square Kilometers	84.9	62563.9	5.7	221.2	7580.7	11535.4	0.3	2.6	5.7	1879.9
# of Samples 0.0-10.0 ppb	33	1246	0	35	132	1	0	0	69	0
# of Samples 10.1-100.0 ppb	1	38	0	20	19	0	0	4	11	0
# of Samples > 100.0 ppb	0	1	0	0	0	0	0	0	1	0
Total Number of Samples	**34**	**1285**	**0**	**55**	**151**	**1**	**0**	**4**	**81**	**0**

hesitation of some tribal governments to associate a location identification with any specific problem, which may lead to social or local stigmatization for continued monitoring (Sharp and Foster 2002; Manson et al. 2004). Last, resources for testing may be limited.

The information presented in this study strictly focused on the extent of arsenic contamination in water supplies across Arizona from readily available databases. The lack of information regarding water resource characteristics, sampling practices, and other hydrogeochemical information were not presented and therefore do not allow comment on how these factors could influence arsenic contamination or mobilization. Though these limitations do not paint a complete hydrogeochemical profile of water in Arizona, they provide a collected map that displays arsenic contamination and details counties where arsenic is prevalent. The map additionally demonstrates whether water resources are likely to be contained in surface or groundwater, which allows regulatory and governmental agencies to take steps to locate and possibly mitigate input into these resources.

As Arizona, and much of the Southwestern U.S., prepares for another year of limited precipitation and drought conditions, the question of clean and safe consumable water is important. A recent study from Sonora, Mexico demonstrates a clear link between arsenic levels in wells used for drinking water, urinary arsenic levels in children, and hazard risk for negative health outcomes (García-Rico et al. 2019). Such studies demonstrate the importance of understanding the potential risk of arsenic exposure especially for those populations who may not always have access to municipal water resources.

Spurred by worsening drought conditions, in 2017 the Governor of Arizona authorized the Arizona Department of Water Resources to conduct studies that detail the extent of water security and purity (MacEachern 2017). Tribal governments, such as the Navajo Nation, have already adopted similar policies and contingency plans to address this growing concern (Navajo Nation Department of Water Resources 2003). Decreased precipitation and snowmelt recharge in combination with increased water consumption from growing population centers and resource extraction represent a significant stressor to water resources (Maupin et al. 2014; Eden et al. 2015). These factors could act to concentrate arsenic as the amount of water in these systems drop and present another looming concern for public health and safety. The collective maps in this study provide another resource for legislators, regulators, and community members to face the challenge of providing safe drinking water to Arizona and limit public health risks.

Conclusions

This study demonstrates that many ground and surface water resources in Arizona have levels of arsenic above the current drinking water limits. The data also demonstrate a lack of data available for many of the Native American jurisdictions throughout the state. Many populations in rural areas throughout the state rely on well water and do not have access to the water treatment available to municipal customers. These maps may provide information for local water resource managers to evaluate both the need for more arsenic sampling and for providing information to water users regarding their water quality. This need is especially important for many of the tribal regions throughout Arizona.

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Change Rippling through Our Waters and Culture

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Abstract: It is well established that climate change is already causing a wide variety of human health impacts in the United States and globally, and that for many reasons Native Americans are particularly vulnerable. Tribal water security is particularly threatened; the ways in which climate changes are damaging community health and well-being through impacts on water resources have been addressed more thoroughly for Tribes in coastal, arid, and sub-arctic/arctic regions of the United States. In this article, Crow Tribal members from the Northern Plains describe the impacts of climate and environmental change on local water resources and ecosystems, and thereby on Tribal community health and well-being. Formal, qualitative research methodology was employed drawing on interviews with 26 Crow Tribal Elders. Multiple determinants of health are addressed, including cultural, social, economic, and environmental factors. The sense of environmental-cultural-health loss and despair at the inability to address the root causes of climate change are widespread. Yet the co-authors and many other Tribal members are actively prioritizing, addressing, and coping with some of the local impacts of these changes, and are carrying on Apsáalooke [Crow] lifeways and values.

Keywords: *climate change, Native American, human health, water resources, Crow Tribe, Apsáalooke, solastalgia, traditional ecological knowledge*

There is widespread consensus that climate change is already causing a wide variety of health impacts in the United States and globally, and that some population groups – including Native Americans – are more vulnerable than others (Ford 2012; Gamble et al. 2016). The U.S. Global Change Research Program states "Vulnerability is the tendency or predisposition to be adversely affected by climate-related health effects. It encompasses three elements – exposure, sensitivity, and adaptive capacity – that also interact with and are influenced by the social determinants of health" (USGCRP 2016, 103). Rural Native American communities may have increased exposure due to greater time spent ranching, farming, hunting, fishing, gathering, and/or participating in other outdoor work, activities, and traditions. Low socioeconomic status, health disparities, political factors, geographical isolation, older homes, degraded infrastructure, declining ecosystem health and services, and reliance on subsistence foods are additional factors increasing exposure and lowering resilience in many Native American communities (Cozetto et al. 2013; Gamble et al. 2016). Spiritual and cultural values and practices may both increase exposures and provide expertise to increase resilience. A review of climate change impacts on Native American health in the U.S. Global Change Research Program's 2016 Report summarized them under the themes of food safety and security, water security, loss of cultural identity, degraded infrastructure, and other (USGCRP 2016). Reviewing impacts of climate change on Tribal water security, a comprehensive nationwide study (Cozetto et al. 2013) describes impacts (a) to water supply, management, and infrastructure; (b) to culturally and nutritionally important aquatic species; and (c) to Tribal rights and sovereignty over water and other natural resources. Additionally, the authors discuss the impacts of droughts, floods, and other extreme climate events on ranching, agriculture, soil degradation, and land loss (Cozetto et al. 2013).

These reports, as well as the majority of the peer-reviewed literature, provide numerous examples of health impacts of climate change to Alaskan Native and Canadian Inuit communities as well as to Tribes in the Southwest, along the western and Gulf coasts and around the Great Lakes (e.g., Weinhold 2010; Brubaker et al. 2011; Ford 2012; Cozetto et al. 2013; Gautam et al. 2013; Lynn et al. 2013; Maldonado et al. 2013; Redsteer et al. 2013; Willox et al. 2013; Shamir et al. 2015; Gamble et al. 2016). However, there is far less published from Tribes in the Northern Great Plains (Cozetto et al. 2013; Doyle et al. 2013). A review of climate change and indigenous health notes that while the broader factors shaping vulnerability are important to understand, the effects of climate change will depend upon a variety of local factors; therefore "[t]his diversity in how climate change will play out locally reinforces the importance of place-based and population-specific studies" (Ford 2012, 5). Ford calls for focusing on geographic gaps in current research, and subsequently identifies research priorities, starting with:

> *Indigenous conceptualizations on* [sic] *and approaches to health* need to be articulated and central to research if we are to focus on relevant health risks and capture the complex, culturally mediated interaction among social, biophysical, and biomedical determinants of vulnerability (Ford 2012, 5).

This article seeks to address this geographic gap and research priority by providing a Northern Plains case study of the impacts of climate change on local water resources and ecosystems, and thereby on Tribal community health and well-being. As Crow Tribal Elders and young adults, we provide our understanding of how these changes are impacting our people's health, broadly speaking, based on our formal qualitative analysis of interviews we conducted with 26 Tribal Elders.

The Apsáalooke [Crow] Community

According to our migration story, the Apsáalooke people split from the Hidatsa in the late 1400s, under the leadership of Chief No Vitals, and by the late 1400s we were settled in the plains and mountains of what is now southcentral Montana and northern Wyoming (McCleary et al. 2000). The Tribe's first encounter with Europeans is believed to have been in 1743, when a group of Apsáalooke met French Canadian trappers at a confluence of rivers near present day Hardin, Montana. In 1840, a wave of three severe smallpox epidemics afflicted the Tribe, reducing the population from about 10,000 to only 2,000 by 1850. The first Fort Laramie Treaty was signed in 1851, stating that the Tribe controls more than 33 million acres of land in what is now southern Montana and northern Wyoming. The second Fort Laramie Treaty in 1868 took three-fourths of Apsáalooke land, a wicked loss, leaving the Tribe with only 8 million acres in present-day Montana. Further losses of land in 1872 and 1882 treaties and Congressional Acts in 1891 and 1904 reduced the Crow Reservation to its present 2.3 million acres (McCleary et al. 2000; MT OPI 2017). In 1883, the Government boarding school was relocated to Crow Agency, and parents were threatened with the loss of their food rations if they refused to send their children to the boarding school (MT OPI 2017). There are innumerable community stories about how this school and the Catholic boarding schools mistreated and traumatized Crow youth (personal communication, J.T. Doyle January 21, 2020). In 1958, the U.S. Government bought the Tribe's rights to the Bighorn River for the building of the Yellowtail Dam (MT OPI 2017); when the dam was completed in the 1960s, the upper river valley was entirely flooded. The Federal Government still controls the dam and profits from the electricity generated; for many Tribal members this was yet another bitter loss. (For more on Crow history, see Hoxie 1995.)

We are still here today. Our Reservation, located in southcentral Montana, encompasses the center of our Tribe's traditional territory, including three mountain ranges and three large river valleys. Approximately 8,000 of the 14,000+ Tribal members reside on the Reservation, primarily along the rivers and creeks. The majority of communities, including the "capital" town of Crow Agency, are situated in the Little Bighorn River Valley (Figure 1). Many cultural traditions continue to be practiced and the Crow language is still widely spoken by people 30 and over, with some families and a new immersion school continuing to pass the language on to younger generations. Water is one of the most important natural resources to the Crow community and has always been held in high respect among Tribal members. River and spring waters are still used in many ceremonies (Knows His Gun McCormick et al. 2012), and until plumbing was installed in rural districts in the 1960s, served as the primary domestic water source for rural Crow families. Tribal Elders say they "grew up along these rivers," spending their summers playing in the water and along the riverbanks, and still today the rivers are home to children throughout the hot summer days. Local riparian ecosystems are vital to deer, elk, five species of berry shrubs, important medicinal plants, and other species vital to subsistence hunting and gathering, food security, and cultural identity. Additionally, riparian tree species such as cottonwood, water birch, willows, chokecherry, ash, and more continue to be collected for traditional practices and ceremonies. As we live today in a country that has been our ancestral

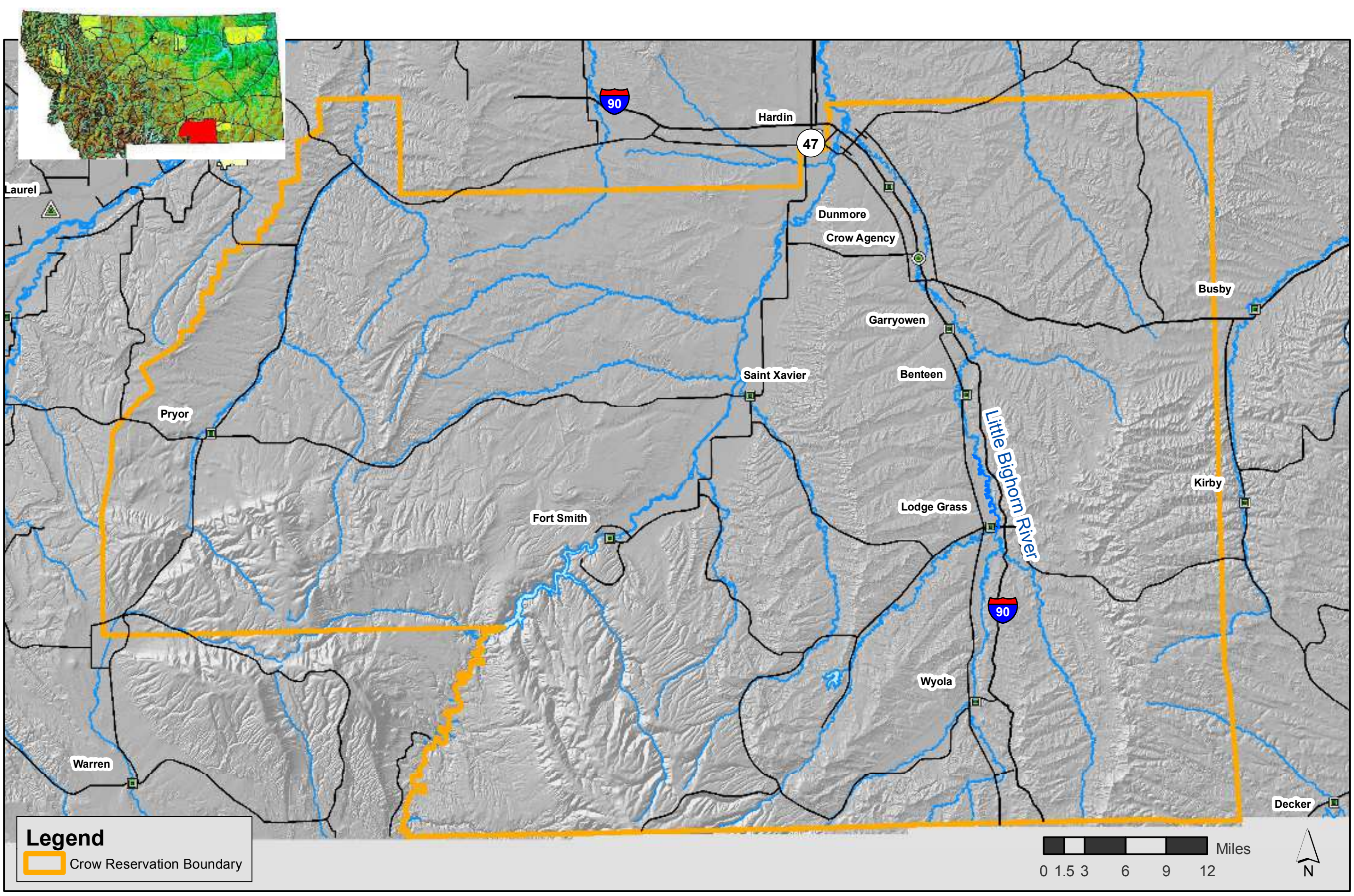

Figure 1. Map delineating the Crow Reservation (in yellow). The Reservation is southeast of Billings, MT, with the Reservation's southern border on the Montana-Wyoming state boundary. (Map prepared by Eggers; inset courtesy of Doyle et al. 2013; U.S. Department of Agriculture 2013.)

homeland for many centuries, our community – especially our older generation – retains significant traditional ecological knowledge.

The Reservation remains largely rural, with an economy based primarily on jobs and royalty from mining of the Tribe's extensive coal reserves (MT OIA 2019). Ranching, the Indian Health Service Hospital, the Bureau of Indian Affairs, Little Big Horn College (LBHC), local schools, and service industries provide other employment opportunities (MT OIA 2019). There is extensive irrigated and dry land agriculture as well as feedlots, however all are operated almost entirely by non-Tribal members. Smaller ranching operations, both Tribal and non-Tribal, are common, especially in the Little Bighorn River Valley. With the expansion of agriculture in the 1960s, Elders note that the river water quality deteriorated: whereas rivers used to "clear up" after spring runoff, they now remain murky all summer long. Populations of local frogs and river mollusks starting declining (Doyle et al. 2013). Rural families switched from collecting river water for domestic use, to relying on newly installed home wells. Recent research initiated by the Crow Environmental Health Steering Committee (CEHSC) at LBHC and conducted with University partners, has documented high levels of fecal contamination in the Little Bighorn River, including pathogenic microorganisms (Hamner et al. 2014; 2018).

Uranium was first discovered in the Pryor Mountains adjoining the Crow Reservation in 1955; within a year 315 claims had been staked and mining initiated (Patterson et al. 1988; Kerschen et al. 2003). The U.S. Department of Energy subsequently produced a Technical Report on these uranium resources (Hart 1958). Mining for both uranium and vanadium was conducted until the early 1980s, including in the headwaters of the Bighorn River Valley (Patterson et al. 1988; Eggers et al. 2015). These mines are now abandoned, and the federal agencies owning the lands have closed these areas to the public due to the radiation risk (French 2003). Many home wells in the lower part of that valley are now contaminated with uranium above the Environmental Protection Agency (EPA) drinking water standard (Eggers et al. 2015; 2018; EPA n.d.), but whether and to what extent mining has contributed to this contamination is unknown.

Changing Climate Conditions on the Crow Reservation

Organized as a grassroots group of diverse Tribal members and a non-native partner, the CEHSC conducted a community wide assessment of environmental health risks in 2005. Through this process, we came to a consensus that waterborne contaminants and pathogens constituted the greatest environmental health risks to our people, and we have been working together to understand, communicate, and mitigate these risks ever since (Cummins et al. 2010; Doyle et al. 2013; Eggers 2014; Hamner et al. 2014; Eggers et al. 2015; McOliver et al. 2015; Doyle and Eggers 2017; Doyle et al. 2018; Eggers et al. 2018; Hamner et al. 2018; Richards et al. 2018). Our Committee includes Tribal members from Elders (some with graduate degrees) to young adults, including graduate students. The older members began discussing how winters have become much milder with far less snow, leading to discussions of how climate changes were already impacting Tribal water resources and hence Tribal health. This resulted in research to determine what climate data from Western science would tell us in comparison to our anecdotal understanding from conversations with fellow Tribal members.

We learned that local environmental knowledge and Western science concurred that total snowfall has been declining for decades, winters are becoming milder and summers hotter, and that total annual precipitation is declining (Doyle et al. 2013). Spring runoff in the Little Bighorn River, central to our Reservation, appears to be coming earlier in the year, with more frequent severe spring flooding yet overall reduced total discharge. Forest fires are becoming more frequent (Doyle et al. 2013). In informal conversations with fellow Tribal members about climate change impacts, we realized that our people have a wealth of complementary local knowledge about our water resources, aquatic life, animals of all sorts, plants, soils, and weather patterns that is unique and has never been recorded by Western science. We reported previously on these anecdotal observations (Doyle et al. 2013), while realizing we needed to undertake a structured research study of the impacts of climate change on our water sources and ecosystems, and hence on community well-being. Here we describe what we have learned, based on a formal qualitative analysis of new interviews with a diverse and geographically representative group of Crow Tribal Elders.

Methods

Working together as the CEHSC, we developed survey questions based on co-author knowledge, as well as the original, informal discussions with other Crow Tribal members and our earlier analysis of Western climate data (Doyle et al. 2013). In absence of a Crow Tribal Institutional Review Board (IRB), we submitted this study to the Montana State University Bozeman IRB, which deemed it exempt. Potential interviewees, representing the six Districts of the Reservation, were identified by consensus of our CEHSC, and invited to participate. We used purposive sampling to ensure a broad range of perspectives. Sample size was determined to be sufficient based on adequate geographic representation and diversity of life experiences. All interviewees, men (n=14) and women (n=12), reside within the boundaries of the Crow Indian Reservation in southcentral Montana. After providing informed consent, participants answered 28 open-ended interview questions about perceived changes in local weather patterns and ecosystems throughout their lifetime, and the impacts of these changes on Tribal well-being. Interviews lasted no more than an hour and participants received a stipend for their time. Two Crow co-authors – one trained in qualitative research design and the other a Tribal Elder – conducted the interviews. The interviews were audio recorded and transcribed by two of the Crow co-authors.

Interviews were analyzed using thematic analysis (Braun et al. 2018). Five CEHSC members read through and open coded all 26 interviews, compared codes, and developed themes. Two of the Crow CEHSC members then refined the codes and applied them to the interviews and met again to confirm coding strategies. Discrepancies were reviewed and resolved through in-depth discussion. Analysis of transcripts produced themes related to changes in weather patterns, the resulting impacts on wildlife, water, plants, animals, and ecosystems, and the effects these interrelated changes have had on Crow Tribal cultural practices and community well-being.

Results

Traditional Indicators of Changes in the Weather and in the Seasons

Participants described many different indicators they use to predict changes in weather and seasons. Some participants talked about predictors they use to tell the changes in weather. Other participants talked about the distinct actions they observe in the plants and animals around them, which help them predict upcoming changes in the weather or mark the changes in season. Several noted that these traditional indicators are no longer reliable or may not even be available:

> *Birds will start to gather and start heading south to warmer weather. Bees are not as active which means the temperature is starting to cool off. You can tell by the amount of sunlight in the day that it is going to get cooler when the sun sets early. When the deer start to group together, the weather is getting cooler. Leaves falling are an indicator that it's getting cooler. In the spring, when the cheat grass grows that's an indicator that spring is coming.*
>
> *Bees can tell you what the weather is going to be like. They do certain things when certain weather is coming. Their chemicals acting with the chemicals in the atmosphere, it allows them to behave accordingly and get prepared.*
>
> *Birds used to help indicate the weather but birds are hardly coming back nowadays. The thunder and lightning would give warning of rain but now it just rains out of nowhere and there is no warning.*
>
> *When there is a halo around the moon we're going to have storm and rain for that month. Some indicators have changed with climate change. You can use the plants to indicate the changes but because the changes are so rapid and inconsistent the plants are unable to detect or predict the weather that is to come.*

Climate Change

Participants described the changes they have noticed in the weather throughout their lifetime, especially in precipitation, temperatures, and predictability. There was widespread agreement that winters are milder and shorter in duration, with far less snowfall than there used to be. Now winters generally start later in the year: trees are losing their leaves later in the fall and snowfall is coming later. When they were younger, there was snow cover on both mountains and prairies winterlong, with deep snowdrifts. Now the prairies are more often brown – lacking snow cover altogether – throughout the winter. Interviewees explained:

> *Winter is coming later. Snowfall is coming later in the fall. The freezing period for the fall is coming later so the leaves are falling later as well. Warmer temperatures in the fall.*

> *When I was a child back in the '70s the snow was very deep every year to where I remember there was snow drifts every year and they were at least 3-6 feet high. We used to build tunnels in them every year when we were kids. Nowadays, in the winter, we don't see that drift that high. Nowadays, the snow drifts are about 6 inches to a foot high.*

Temperature. Temperatures used to stay below freezing throughout the winter – as kids, ice skating was a winterlong pastime. Now winter temperatures are milder with fewer periods of subzero temperatures. Spring is coming earlier:

> *I think that the winters are different. There's fewer days that are subzero that I would observe. It seems to me that I used to count on a month of subzero weather maybe six weeks especially in January and February. And not before Christmas or not before the holiday or the new year.*

> *Snowpack in the mountains is melting sooner so you are able to go into the mountains in June when they would usually go up in July.*

Winter Weather. Winter weather has become unstable and unpredictable, with periods of thaw. Elders commented on this in various ways:

> *Weather patterns have changed.*

> *It's cold at the wrong times.*

> *We are seeing more dramatic events in our weather. There is rapid change and no consistency in our rivers.*

Snowfalls sometimes turn to rain, even into thunder and lightning storms, a new phenomenon. One Elder related:

> *One of the most dramatic changes was during the Tobacco Society ceremony in May.*[1] *They experienced four different changes in one day. It was sunny, windy, rainy, and snow. All four very extreme and this happened during the ceremony. They had never seen something like this, said it was unreal.*

River Ice. Many Elders commented on how the rivers used to freeze solid, with thick ice for ice skating. During ice break up in springtime, there used to be massive ice jams, with risks of severe flooding. Ice break-up was a culturally significant event, the Crow term is *buluxchiatacha* and it was the signal for the Old Warrior Society to meet. Now, the rivers hardly ever freeze, and when they do, the ice is too thin for skating:

> *Ice break-up is a rare commodity. I recall a time when they would float down the river on ice chunks that were about nine inches thick and the size of a car hood. Ice jams haven't occurred for years. The ice break-ups don't happen like they used to and if they do, the timing is off.*

One Elder remarked how these huge ice chunks would scour the river bottoms, then melt away on the banks of the rivers – and wondered if without this process, there is now more sediment in the river bottom gravels, in turn affecting the fish and other river life?

Spring Floods. Severe spring floods are happening more often, with major floods causing extensive damage in 1978, 2007, and 2011:

> *…that floodwater came through their houses, and that house is condemned. For people that is such a hardship because we just don't have to money to relocate. So they just had to let their house dry out and move back in, even with the same carpet. So that was a community health concern.*

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[1] The authors do not wish to explain Apsáalooke religious traditions in this article. Readers interested in learning more are referred to Linderman 1932; Medicine Crow 1992; Frey 1993; Snell 2000; McCleary 2012.

Precipitation. There was a consensus among the Elders that there is less precipitation now than in the past. Other participants talked about how there is less water in the rivers and more contamination today when compared to growing up, making it impossible for their families to use the river during the summer months. Grasses and cattails are not growing as high as they once did. For instance, participants noted:

> *We used to get squalls all the time. The old people used to follow the rivers when they flow but the water has decreased. It only rains in the mountains and not in the valleys anymore.*

> *The rainfall is very inconsistent and is throwing off the growth of the plants. The [ceremonial] tobacco seed is growing later than when it's supposed to be.*

> *We're losing the annual precipitation that we enjoyed in the years that have gone by. All we can do is just have memories and hope that eventually the cycle will come back to that time when we had ample moisture and we were at leisure with plant life, berry picking, root gathering and other ceremonial activities that go on here year after year.*

> *Where they had the sundance, the ground never used to hold as much heat as it does now. The ground was moist but now it is dried out and has a lot more dirt.*

Springs. Many Elders remarked that springs they are familiar with have decreased in flow or dried up altogether. One Elder remarked that some mountain springs are now originating further downslope than they used to, perhaps because the water table has dropped.

> *The spring behind our house went out during the hot spell of 1988. The spring fed a pond that is dried out now. The groundwater and spring levels have depleted. We are using the annual precipitation and getting less snow that recharges our springs. A place where berry picking was noted by one of our chiefs, Crazy Head, that spring no longer exists.*

> *There were special warriors who had medicine to look for places to camp. They would always make sure that their camps had water, either waterholes or springs. Some of these places where they camped no longer have water.*

Summer Heat. Nearly all participants observed that summers are hotter and are lasting longer than in the past. One participant put it this way:

> *We have a few days of hot weather in March, then some in April but the hot weather comes in June and lasts until September, it's longer, the heat, it appears to me to be longer and hotter… more uncomfortable.*

Wildfires. Interviewees observed that wildfires are starting earlier in the spring and are more frequent and widespread. The majority thought fires were more severe than they used to be, but not all agreed. Some are concerned that where the ground is really scorched, plants will not fully recover and there will be less forage for the deer. As one Elder summarized it:

> *There are more fires now days and they're more severe and more widespread and they do more damage. To me it's all obvious and apparent that we in fact are in global warming… When it rains, the mudslides wash away everything…*

Mammals. Participants noticed changes in the presence of wild animals in their area. Most are seeing fewer deer, elk, and antelope, with a couple exceptions. Two people remarked on declining deer health:

> *Heard of hunters finding some type of disease inside the deer that they killed. Unknown what it was.*

> *The deer are not as healthy as they once were. The meat is in smaller portions and is not as lean. They are also decreasing in size.*

Elders also commented on decreases in small mammal populations, including raccoons, badgers, skunks, fox, and squirrels. Several people noted that there are fewer road kills than there used to be.

Birds. Almost all the Elders talked about the loss of bird species, collectively mentioning decreases in sage grouse, prairie chickens, mourning doves, bluebirds, woodpeckers, magpies, wild turkeys, snipes, ducks, and even robins. The owl they knew has disappeared and different species of owl are coming in.

One big thing I noticed is that the dove that we used to have here it had its own song and I always really liked that song. I could hear it and other birds in the morning… their different sounds all blended together in one big ol' symphony. It was just a great thing to me. But that dove is no longer here…

Prairie chickens [sage grouse] used to be more plentiful. I remember when I was a little guy we used to cruise around and see them all the time… they would be just right alongside of the road, eating or doing their thing. I don't see them around much anymore the way we used to.

Fish. Fish populations have also declined, with participants noting:

They don't eat fish like they used to anymore; you can barely find them anymore.

Decrease in the amount of fish you would catch when you go fishing.

Because the streams are lowered, the population isn't able to bounce back the way it used to.

One person commented that there is increasing "moss at the riverbed" [a local reference to algae]. An Elder who used to fish regularly for food as a young man, remarked that he started catching fish with sores, so he quit fishing.

Riparian and River Life. Many participants talked about how they have witnessed a significant decline in frogs and other riparian species compared to their childhoods. For example:

When we were little we used to catch and release frogs and that was part of our activity at the river… there would just be tons of frogs in those little water holes next to the river, and turtles and salamanders… We used to see who could find the most… there was about five or six of us playing that game where we could each collect our own frogs… But now when I go over there, the frogs are still there but they're not all along the river like they used to be… you kind of have to hunt them out.

Decrease in frogs. You don't hear them as much anymore. There used to be small clams in the rivers but you don't see those anymore. You don't see the small lizards that used to be around the rivers.

Insects. In response to an open-ended question about any changes in insect populations, many respondents noted declines in bee populations:

There aren't as many wild bees anymore. The weather change can be contributing to the loss of these insects.

Decrease in bees, decrease in pollination of gardens.

One interviewee added that "There are more grasshoppers. The temperatures are warmer and dryer for them to thrive."

Plants. Nearly all participants discussed decreases in availability and changes in the phenology of culturally important plants, mentioning bitterroot, wild turnips, wild onions, and especially berry species and medicinal plants such as mint, bear root, Echinacea, and sweet sage. Buffaloberries were traditionally harvested after the first frost, as they are sweeter then, but now the berries deteriorate before frost comes. Some suspect that the midwinter thaws are damaging the many species of berry shrubs. Russian olive, spotted knapweed, and other invasive plants are contributing to the decline of important native plant species.

There used to be a bunch of patches of raspberries and now they only know of one or two patches. And now they won't tell me where they're at. They said, 'They're rare and I'm not going to tell you, they're mine.' The chokecherries weren't as delicious, they weren't as sweet. None of them are as sweet as they used to be. That might have something to do with the decrease in bees… or the frost and thawing period, or it could be the late precipitation. Because if you are not getting the water then you are not growing as early in the season…

You don't see a lot of these plants like we used to. There are less and less berries that my grandma used to pick. Everything is living so with climate change everything is confused.

Buffaloberries were not ready to be picked when we went to go picking during the harvest *season we know of. Chokecherries bloomed late in the season as well.*

I don't remember a year where there just weren't any [choke]cherries. I would say late '80s. There might've been a year when there was a slight [harvest]. And then more recently it's like every other year. If you don't get in there and get a lot you could easily have a year where you won't have any. I have been down to like no jars [of chokecherries].

When my family was younger, we did a lot of just going around in the mountains, a lot of hunting and camping. Now that I am older and my kids have their own families, they're camping and I'm not so much. So I am thinking I won't see so much change. When I get next to the rivers, what I am doing is usually searching for things. Like I am looking for mint or I am picking berries of different kinds. Or maybe I am looking for wild onions and carrots and things. And those things changed, they've changed a lot. I feel like I can hardly ever find mint where I would use to find it a lot. And that is really usually along water ways. So there is a difference in growth. Why? I don't know. But why plants move around so much, I just don't know. But I do think that it probably has to do with water and the season of time when the water is available. There are places where I used to constantly go for certain things that I have had to look for new places because things just aren't growing where they used to... [Interviewer: So do you find them?] Not always. I've felt like . . . well you know at the sundance we go and look for mint. There is plenty of cattails. That's never a problem and you go look for mint or even sweet sage. Not just any old sage but sweet sage, sometimes you just have to go a tremendous distance to find it… The last time I went looking for mint to any extent was in the Wolf Mountains and I am very familiar with the Wolf Mountains. That's if I was going to go to the mountains, that's where I would go for walking, for picking, just exploring, hunting. Things change.

Ceremonially important plants including cottonwood trees and lodgepole pine are also on the decline and many are harder to find. Lodgepole is harvested for teepee poles:

Good teepee poles are hard to find. The poles are dried out so they are harder to peel. We used to go to the Pryor Mountains and each year we would go deeper and deeper [into the mountains] because the poles are getting more scarce.

People mentioned multiple factors contributing to these losses and changes: less precipitation; declining springs for riparian species; warmer temperatures including winter thaws damaging the berry shrubs; pesticides and loss of pollinators; greed for money (obtained by selling wild plant foods); loss of knowledge as to how to harvest plants properly so they will regrow; and increases in invasive plants.

Mint tea grows near springs so it is disappearing with the springs. Most of our plants only grow in certain locations now. Wild turnips are decreasing. Chokecherry tree is a vital plant to grow; it is a food we rely on and it initiates other ceremonies that we do like the Tobacco Society and adoption ceremonies.

Impacts of Climate Changes on Community Health

Participants shared many concerns with health issues related to the changes in lifestyle as a result of increased spring flooding, contamination of the rivers, increased wildfires, milder winters and hotter summers, and loss of cultural practices.

Milder Winters. There is a widely held community understanding that the milder winter temperatures are no longer cold enough to kill disease and this is resulting in increased illness in the community:

Winter temperature and snow kills bacteria so now with warming temperatures or warming homes the bacteria can thrive. People are getting sick because the bacteria and illnesses aren't being killed.

Spring Flooding. Before the severe spring flood of 1978, there had only been one disastrous flood in living memory, in the 1920s. Then disastrous floods hit again in 2007 and 2011, causing widespread home damage and financial distress, with many lacking the resources to repair the damage:

> *There was financial distress from homes being destroyed by the floods, people not being able to relocate. They had to let their houses dry out and they moved back into their homes.*

> *The flood caused a lot of destruction to the Little Bighorn River and surrounding areas. It caused a lot of health problems for people. Financial distress on people who couldn't relocate or rehabilitate their homes.*

Rivers. The rivers have long been sacred to the Crow community, the source of domestic and ceremonial drinking water, vital to many ceremonies, the center of summer life for children. Nearly all interviewees commented on the connections between deteriorating river water quality and quantity, and the many resulting negative impacts on community health. People have lost river water as a source of home and ceremonial drinking water, many have even stopped swimming in it and several mentioned they have quit fishing.

> *Industry, farming, power plant, pollution… all these changes have affected the river. The poisons and pollutions that get into the water systems have increased, it never used to be like this when we were younger. We don't ingest the water anymore, just splash the water on my face and body. Toxins could be in the water.*

> *We can't swim in our rivers anymore. Have to boil the water if you are going to use it, because of contamination.*

> *This has affected our health because kids are not able to swim in the rivers as much or drink the water as it could cause health problems. They aren't able to go outside and play like they used to when it gets hot.*

> *We still have our sweat[lodge] because the Crows believe that the Creator gave us 100 gifts and said that these are the gifts I'm giving you so that you can survive as Apsáalooke people. Those gifts have been dwindling down until we only have maybe ten and so. One of the gifts that the Creator [gave] was the sweat so that we can continue to be Apsáalooke people and if we held on to those then our people will not perish, we will always have Crow people. That is our belief so we always have a sweat… Part of that is when we use the sweat we get water from the river cause it's right close to the river bank and we still do that today… we pour the water on the rocks and we bath in it but the one thing we don't do that we used to, is we don't drink the water, we do not drink the water. If it's like for ceremony, like when we build a new sweat[lodge], then we will drink some of the water but it's not like the continuing usage we had when we built a sweat every time. Now we only use it when we do it for ceremonial purposes but all the other times we use tap water that we bring and drink from that.*

Summer Heat and Wildfire Smoke. Several participants mentioned the impacts of increased summer heat on health. For instance:

> *When it gets hot, people are irritated so it makes people unhappy.*

> *People aren't able to go outside as much so it causes health problems.*

> *Warmer temperatures can cause heat exhaustion.*

One participant observed that wildfire smoke is especially hard on people with asthma.

Culture and Loss

Participants talked about their beliefs and how this guides their ways of knowing. Some participants talked about the oral stories they heard growing up and how this has helped them engage with what was going on around them. Other participants talked about the ceremonies they witnessed growing up as well as the old ways of knowing versus current Western lifestyles. These changes have impacted the community and people's knowledge, the depth of conversation among individuals as well as how aware they are of what is going on around them. Losses of cultural practices and beliefs were described by many:

> *They used to camp but they haven't camped in a while. People aren't interested in it anymore or they don't have the time to do it anymore.*

> *The campsites were different back in the buffalo days. They don't advertise where their*

traditional campsites are because people vandalize too much. People don't have respect for our traditional places like we used to.

We don't pray for these things when we use them so they are not coming back like they should be. We are dominated by European society so we don't use them as much anymore. People are relying on Western medicine so they don't need these anymore.

We went to go check on the plants and foods that we used to harvest and everything had disappeared. Young people aren't attuned to these changes so they don't know.

The loss of culture, of the close traditional connection to the land, especially in the younger generations, is exacerbated by climate change and environmental deterioration; these multiple losses interact in contributing to poorer health.

Maybe I'm an old timer. Maybe older generations before have said this about the younger generations. Our younger people are addicted to video, audio, cell phones. They don't sit down and eat breakfast and dinner together… that real strong element of our tradition and culture – I see it kind of going away… We're losing all of the good stuff that we think about with culture, society, family, and tribe – a lot of that is being lost.

Families are not going outdoors as much as they used to anymore and it's causing health problems such as diabetes and obesity. People are eating more and more processed food and not the food that they harvest. Families aren't doing things together any more so they aren't having these things taught to them. We are not eating as healthy and being active like we used to anymore.

Discussion

The results of this formal, qualitative research study confirm and strengthen the consensus heard earlier from our conversations with fellow Tribal members and from our analysis of Western science climate data (Doyle et al. 2013): snowfall is declining and winters are milder, increased spring flooding has been devastating for many families, summers are hotter, and wildfires are increasing in frequency, and the impacts on local animals and plants are many. Going beyond our earlier work, we have gained a deeper insight into community understanding, beliefs, and practices and the complex challenges we face in coping with and adapting to multiple environmental and climate change impacts on our water sources, animal and plant life, ecosystems, and our people. In particular, climate impacts on our waters and well-being are both direct and indirect: less snow and rainfall, more frequent severe spring floods, with earlier and apparently declining total spring runoff, and worse summer droughts. Deep soil moisture is not replenished as it once was, resulting in long-term drier conditions for plant growth, some mountain springs moving downslope, and perhaps reduced river recharge. Important riparian plants such as mint have become less available. Drier fuels are contributing to more frequent wildfires, in turn reducing air quality. Reduced river flow with deteriorating water quality especially impacts our traditional practices, outdoor summer recreation for our children, and our river-dependent public water supply in Crow Agency.

Community members recognize that changes in climate are exacerbating the many other ongoing factors which contribute to environmental change: pollution – especially water pollution from agriculture, ranching, mining, and home wastewater; invasive plant species; pesticides and loss of pollinators; commoditization of traditional plant foods and medicines leading to overharvesting (especially by non-native residents); and the dominance of Western culture and loss of Crow knowledge and traditional values leading to inadequate or nonexistent stewardship.

Many Elders made observations which parallel and enrich data from Western science. In Crow culture, the appropriate times to do certain things have long been, and still are, tied to specific seasonal changes, hence we continue to be very observant of our environment. This traditional knowledge and Western science complement each other and bringing them together tells a more complete story. For instance, the comments about deer in poorer health or with obvious disease, echo Montana and Wyoming chronic wasting disease (CWD) maps which show CWD has been found in free ranging cervids on all sides of the Crow Reservation (Thuemer 2015; MT Fish, Wildlife and Parks 2019). Although testing of deer and elk meat is available to Tribal members, the authors could find no on-line information about CWD occurrence within the Reservation boundary. Currently, there are no carcass movement regulations in place on either the Crow or neighboring Northern Cheyenne Reservations, as there are in other parts of Montana under state government jurisdiction. This is a serious issue for us, as many families rely on subsistence hunting of deer and elk and are beginning to question the safety of this vital food source.

The increase in "moss" [algae] in the rivers, coupled with the observation that fish with skin sores are being caught, suggests bacterial infections in fish associated with nutrient pollution of the rivers (Johnson and Carpenter 2008). Both agricultural fertilizer and unregulated draining of septage into local rivers could be contributing to nutrient pollution. Elevated nitrate in home wells in the Bighorn River Valley – where extensive irrigated agriculture takes place – has already been identified (Eggers et al. 2018). Families whose wells tested above the maximum contaminant level for nitrate were educated about the risks and provided with free home water coolers (Eggers et al. 2018), but our rivers are not being tested nor monitored for elevated nitrate.

When we initiated this study and started to recruit participants, we found that some people see the acknowledgement of climate change as conflicting with their hopes for restoration of the Tribe's former income level from coal tax revenue. The severe downturn in our Tribe's economy from major reductions in coal mining for electricity generation has caused tremendous financial distress for many if not the majority of Tribal families. One outcome is that it has become difficult to discuss and plan for alternate economic development paths and for adaptation to climate changes already impacting us.

In the interviews, nearly all participants described a sense of loss related to changing climate and environmental conditions on our land, where generations of families have lived and have gathered for celebrations and traditional ceremonies. They shared their observations about surrounding wildlife, noting that they have seen less and less of familiar wildlife around, and sometimes see new wildlife. Participants shared their experiences of how their use of nearby rivers, familiar plants, and animals has changed throughout their lifetimes and in comparison to the previous generations. They talked about the loss of culturally significant plants, such as bear root, mint, and berries, how they are harder to find and harvest. Sometimes they are competing with wildlife for the picking and other times there is no harvest of berries or medicinal plants where they have found them in the past. Other participants talked about the changes they have noticed in the river as compared to previous years growing up. Changes in the river have changed the land and that has ripple effects throughout our lives. The sense of loss, tragic loss, is pervasive.

Other Native American researchers have identified impacts on spiritual, mental, and physical health when the environment is contaminated and traditional foods or water sources are unsafe for consumption (e.g., Donatuto et al. 2011; Cozetto et al. 2013; Willox et al. 2013). This widespread anguish is akin to what some have called solastalgia, described as "the distress that is produced by environmental change impacting on people while they are directly connected to their home environment" (Albrecht et al. 2007; Tschakert and Tutu 2010). Other studies are also finding that climatic and environmental change can have profound impacts on human well-being through multiple pathways (e.g., Bourque and Willox 2014; Gifford and Gifford 2016). Indeed, the American Psychological Association and collaborators recently published an entire report entitled "Mental Health and our Changing Climate: Impacts, Implications and Guidance" (Clayton et al. 2017). For us, and perhaps for many other indigenous people, the changes are not simply unfamiliar alterations in our home environment causing discomfort – *they are direct threats to our ability to carry on the traditional practices which define us as a people.*

It is history repeating itself in an even more insidious way. We lost the majority of our lands through treaties and Congressional acts. We lost generations of raising and educating our own children through federal boarding schools starting in the 1880s. We have since lost the Upper Bighorn River to Yellowtail Dam, agricultural and recreational lands to non-Tribal members, much of our traditional diet – the list goes on. Now, even though we live in our traditional territory, the changes in climate are changing our homelands all around us, and this time there is no single enemy to fight.

In just the past couple years since these interviews were conducted, community conversations around climate change have become different. We hear more and more comments that the sudden and extreme weather events we are now experiencing are abnormal, they are not in the living memories of the older generations. For those younger than 40, however, the current weather patterns are their "normal." These extreme weather events are very hard on our communities, but when the topic is raised there are comments of "there is nothing we can do about it" and fearful silence. We hear that kind of despair more and more often.

As the CEHSC, we are working to support rural families' access to safe drinking water, to increase community understanding about the health risks from contaminated surface and groundwater, to develop and provide a water quality course at our local Tribal College, and to develop a Geographic Information System for the Reservation to include environmental data (especially water quality data). We prioritize mentoring Crow undergraduate and graduate students in our environmental health research and mitigation projects. For instance, one of our co-authors recently earned his Master's degree in environmental science with a geospatial emphasis; another is currently working on her doctorate in soil and water sciences. Most of us collaborate with the local Guardians of the Living Waters program to engage Crow youth in understanding and protecting our waters from a multidisciplinary perspective, including Crow history and traditional values and practices (Milakovich et al. 2018; Simonds et al. 2019a, 2019b). Some of us work on community economic development with another Tribal grassroots organization, Plenty Doors Community Development Corporation (see references). We have recently initiated a new partnership with a local foundation, seeking strategies and funding to reduce environmental impacts on and improve the health of our rivers so that we can maintain essential traditional practices for the well-being of our people. We carry on diverse cultural traditions in our personal lives, and are passing these on to our children, grandchildren, and great grandchildren. Our younger co-authors also emphasize the need to research, document, and preserve more of Crow culture as another way of allowing youth to learn from older Tribal members. Collectively and individually, we are finding ways to address these issues and give back to our Tribal community.

Conclusion

Through these interviews and subsequent discussions, we have gained a better understanding of all the environmental, historical, economic, and cultural factors which interact to increase our vulnerability to the impacts of climate change on our waters and ecosystems, and hence on our Tribal community health and well-being. We are using what we have learned to identify, prioritize, fund, and implement strategies to cope with and adapt to the changes impacting our Tribe.

Regardless of these many challenges, we still manage to practice our beliefs and traditions, such as berry picking, hunting, getting tipi poles, "feeding" the river, holding sweats and sundances, and following the clan system. We strive to live a traditional Crow lifestyle, in spite of assimilation and conditioning to incorporate Western thinking into our way of living. We care for our Elders and youth, and have a collective responsibility to pass on our beliefs and traditional knowledge to our next generation, so they can carry on our culture and traditions in a good way. We must maintain the gifts we have from our Creator, which sustain us and are what make us Apsáalooke.

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Impacts of Coal Resource Development on Surface Water Quality in a Multi-jurisdictional Watershed in the Western United States

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Abstract: This study focuses on water quality and quantity impacts from natural resource development on watersheds originating on Crow tribal lands in southeastern Montana. Field research analysis will focus on the surface water quality in three adjacent watersheds. This study will determine impacts to water quality from reclaimed coal mine spoils surface runoff and produced water discharge from coal bed methane wells within the watersheds. A secondary research objective is to determine a baseline assessment of surface water in watersheds prior to proposed mine development, particularly on tribally owned and allotted tracts. Historical data from state agencies will also be compared to data collected within watersheds on tribal lands. Water quality impacts from mining development may be more pronounced than that of coal bed methane as the reclaimed mining sites have demonstrated lasting impacts on the nearby surface water quality in the study area. Historical and current samples have demonstrated increased sodium absorption ratio and sodium levels downstream of a mine site in a tributary to the primary watershed. A sample from a pond in another reclaimed mine site contained the highest sodium adsorption ratio levels of all surface water samples. Coal bed methane development impacts may have been transient in the primary watershed surface water based on sample results. Historical oil and gas development appears to be impacting surface water quality within the southernmost watershed. Analysis has shown the increasing degradation of water quality in watersheds downstream and across the state boundary of Montana into Wyoming where natural resource development has occurred.

Keywords: *water quality, water resources, coal mining, sodium absorption ratio, coal bed methane, tribal land, Powder River Basin*

This study assesses the impact of coal mining and coal bed methane (CBM) development on surface water quality. The headwaters of our study watersheds are located within the boundaries of the Crow Indian Reservation. Part of the motivation for this study is to provide baseline, surface water quality data in advance of potential CBM or other coal mining activities proposed for the area; specifically, the Crow Reservation in Montana, on tracts owned by the tribe and individual tribal members. The sampling area will extend beyond the reservation to include areas with current gas extraction as well as reclaimed coal mines.

Another motive for completing this study is that the impacts on the reservation are understudied in terms of policy and water quality impacts. The watersheds represent a unique regulatory regime as they lie within the jurisdiction of the Crow Tribe and the states of Montana and Wyoming. The policies from each jurisdiction are rarely assessed together in regard to the overall impact on the water management and resulting water quality of the watershed.

The Montana Bureau of Mines and Geology (MBMG) completed a water quality study when coal mines were initially developed in the Tongue River Basin during the 1970s (Hedges et al.

1998). Specific sampling sites were chosen that coincided with sites previously sampled by the MBMG in September 1977 on Youngs Creek and September 1972 on Little Youngs Creek (Hedges et al. 1998) to make a longitudinal assessment and determine if water quality has changed between the mid-1970s and 2016. Tanner Creek data represent samples collected in 1975. Analysis includes comparing the profile of these watersheds to adjacent watersheds that have experienced development.

Site Description and Background

During the time of the MBMG study, several coal mines were being developed east of the reservation boundary including the Decker Company mines in Montana and the Ash Creek Mine to the south in Wyoming (Figure 1). At the time, the Shell Oil Company had developed mine-project plans within the Crow Reservation boundary and submitted a mine permit application (USDOI BIA 1981). Additional data on coal aquifer locations and depths are in the final environmental impact statement of this permit application (USDOI BIA 1981), however, the majority of the surface water data were cited from the MBMG 1977 study. For this study, the Shell Oil plans for mine development were used to estimate the extent of mine development in the Tanner Creek and Youngs Creek watersheds.

The Cloud Peak Energy Company had identified three potential mine coal deposit tracts; Squirrel Creek, Tanner Creek, and Upper Youngs Creek project areas, based on the locations within the watersheds. Each tract lies entirely within the Crow Indian Reservation (Figure 2) and had a separate option to lease. The project area was referred to as the Big Metal Mine. The Department of Interior Bureau of Indian Affairs (BIA) has approved Cloud Peak's Exploration Agreement and Option to Lease Agreement with the tribe. In 2013, the tribe received $2.25 million upon signing the agreements and an additional $1.5 million upon the BIA approval of the agreements. The tribe was to receive approximately $2 million per year for the five-year option period (CPE 2013).

The Navajo Transitional Energy Company had purchased several mines from Cloud Peak Energy Company in 2019 after the company had filed for bankruptcy. Assets purchased from the bankrupt company include the Spring Creek Mine and the mining rights to the Big Metal Mine project. The current status of the Big Metal Mine project or any new exploration and lease agreement is unknown as of the end of 2019.

The coal layers within the basin located in the Tongue River Member of the Fort Union Formation lie shallow enough to the surface for coal strip mining development (Wheaton and Donato 2004). The active coal mines in this region of the Powder River Basin are developed as surface strip mines. The coal beds that were targeted by Cloud Peak and Shell Oil, i.e., those on the Crow Reservation, lie at higher elevations than the other regional mines. These coal beds outcrop throughout the target and study areas among the foothills and alluvial valleys of the study watersheds.

Proposed Coal-Related Development and Geology

Study sites are located in the larger Powder River Basin of Wyoming and Montana, which include both active coal-related fossil fuel extraction activities and undeveloped areas for which water quality can be compared. The coal beds within the Powder River Basin have been developed in this region of Montana and Wyoming. The Powder River Basin has supplied 40 percent of the domestic coal production (USEIA 2017). The active coal developments in Montana within the study area are the Decker and Spring Creek Mines (Figure 1).

The Ash Creek Mine was developed and mined through 1978 within a portion of Little Youngs Creek watershed in Wyoming (Figure 1). The mine was inactive after 1978 and the developed portion of 140 acres was later reclaimed in 1996. The Ash Creek Mine project area was amended to include a larger portion in Wyoming extending south and east to the Ash Creek watershed. The amended project was renamed Youngs Creek Mine and permitted in 2010 by Wyoming agencies including the state of Wyoming Department of Environmental Quality.

Powder River Basin CBM Reserves

A vast amount of CBM reserves are stored in coal seams throughout the Powder River Basin.

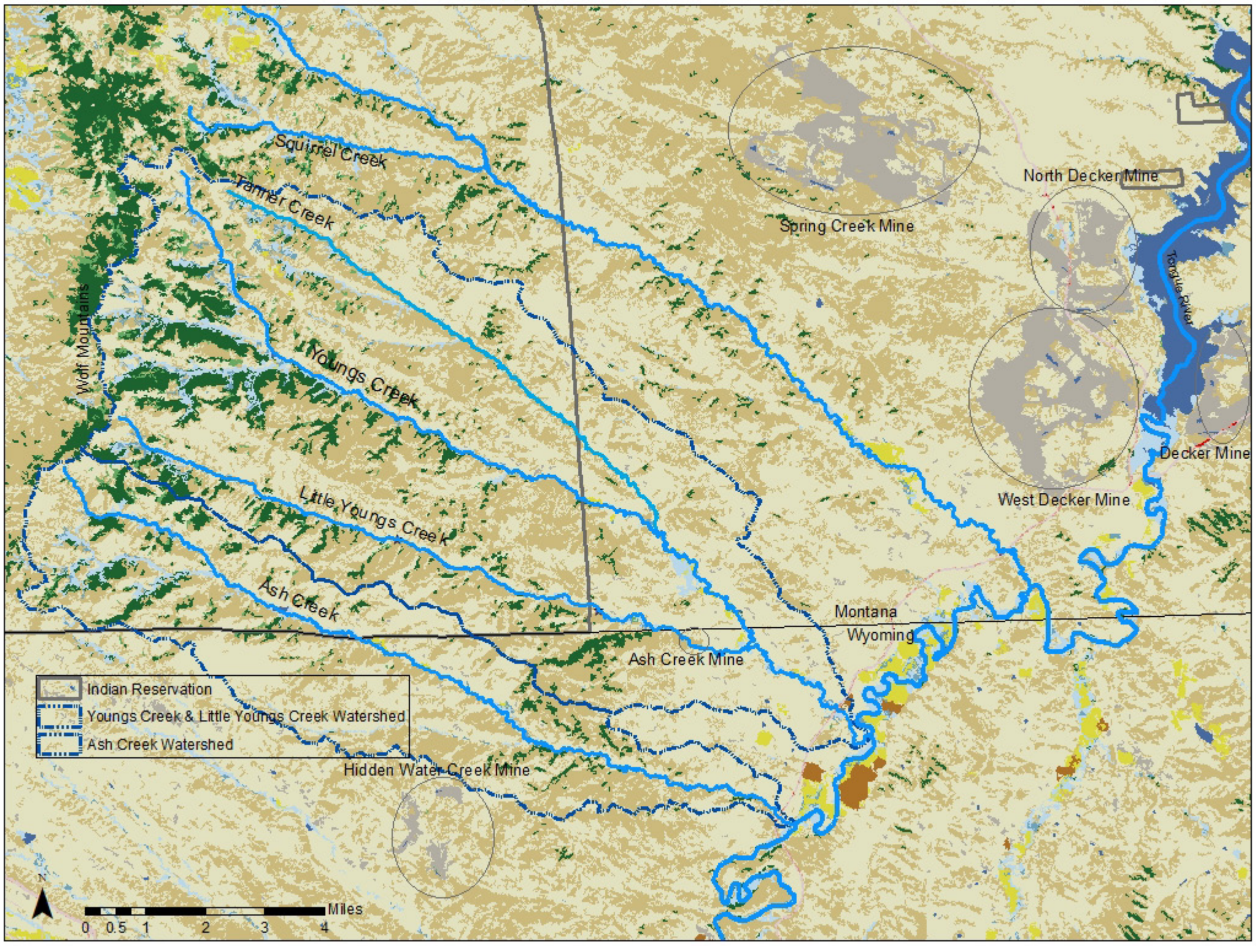

Figure 1. Study area watersheds and mine locations.

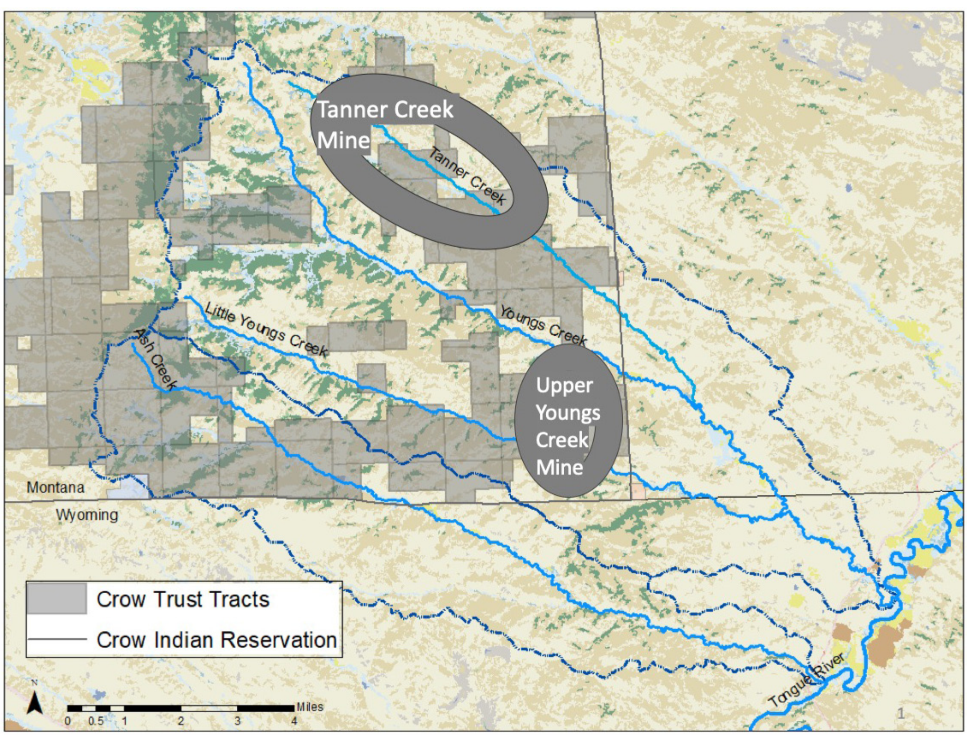

Figure 2. Potential coal mine sites.

Due to the geological setting, fewer reserves are located in Montana coal seams than in Wyoming. The Montana portion of the basin contains an estimated 0.86 trillion cubic feet (TCF) of CBM gas (Wheaton and Donato 2004), while the Wyoming portion of the basin had produced 4.18 TCF through 2010 within the Powder River Basin (USEPA 2010). In Montana, CBM development is limited to 19.3 kilometers (12 miles) north of the state line and between the Wolf Mountains to the west and the Powder River to the east. Active CBM development was located east of the Tongue River Reservoir as of 2017 but had previously extended to the Crow Reservation boundary (MDNRC BOGC 2017).

Background and Relevant BioGeochemical Processes: Coal Seam Aquifer Water Quality

Within the study area, coal bed waters will favor the dominance of the sodium cations. Bicarbonate will be the dominant anion with typical total dissolved solids (TDS) levels ranging from 1000 to 2500 mg/L. Depending on the flow influences present in the coal seam aquifer, levels of TDS will be highly variable. In order to release CBM, the coal seam aquifer is dewatered producing large volumes of produced water. The sodium adsorption ratio (SAR, described later) values of coproduced waters in Montana can be greater than 30. The dominance of sodium-bicarbonate waters associated with CBM coproduced waters is of particular concern in monitoring water quality in the study area.

In the study area, several processes occur in the coal seam, creating conditions for the generation of methane. These include the reduction of sulfate, removal of calcium and magnesium, and the increase in bicarbonate as the dominant anion (Lee 1981). These conditions allow for the biogenic production of methane in coal seams in this portion of the Powder River Basin (Van Voast 2003).

CBM Regulation: Sodium Adsorption Ratio

Coal bed methane produced waters are monitored using SAR as the primary indicator for water quality. SAR limits for the Tongue River are 3 for irrigation season and 5 during the rest of the year (ARM 17.30.670). The SAR of samples collected are calculated from the following equation (U.S. Salinity Lab 1954):

$$\mathrm{SAR} = \frac{\mathrm{Na}}{\sqrt{\frac{(\mathrm{Ca+Mg})}{2}}}$$

where sodium (Na), calcium (Ca), and magnesium (Mg) are measured in concentrations of milliequivalents per liter.

The U.S. Environmental Protection Agency (EPA) produced an environmental impact report on CBM produced waters, listing the additional contaminants of potassium, sulfate, bicarbonate, fluoride, ammonia, barium, iron, arsenic, and radionuclides (USEPA 2010). However, the agency delisted CBM produced water from the agency regulation in 2014 (USEPA 2014).

Prior to 2010, operators were allowed to discharge produced water from CBM wells directly into stream drainages in Montana and Wyoming (MCA 82-11-175). In 2010, Montana prohibited the direct discharge of CBM produced water into stream drainages. Wyoming has separate produced water standards, and continued permitting direct discharge into stream drainages for beneficial use (USBLM 2003).

The Bureau of Land Management (BLM) considers aquifer waters with levels of TDS less than 10,000 ppm as 'useable water' within federal and tribal land (43 CFR pt. 3160). The EPA considers waters with the same TDS levels to be classified as underground sources of drinking water (USDW). All of the waters in the coal bed aquifers within the study watersheds would be considered USDW and usable sources. This classification as a useable water source may influence the BLM and state agencies regulation of CBM produced waters designated for beneficial use.

Climate and Land Use

The study region is considered semi-arid and receives relatively low levels of precipitation, ranging from 30 to 38 cm (12 to 15 inches) per year. Lands located on the Crow Reservation within the study area are largely uninhabited and primarily used for pasture and grazing lands. There are a few residences on fee lands located along Youngs Creek based on land records (Montana Cadastral 2017), site visits, and personal observation. The land topology is varied with foothills and creek drainages with increasing altitudes upstream to the northwest toward the Wolf Mountains.

Surface Water and Groundwater Quality

Initially, headwaters of a stream would have lower SAR levels, as the dominant cations in surface fed waters are calcium and magnesium (Davis 1984). SAR levels would increase with distance downstream as ground waters contribute increasingly to the stream flow. Groundwater contributing sodium dominated water would increase SAR in stream flows.

Where surface flow from precipitation as snowmelt dominates in the headwaters, TDS concentrations will be lower. Groundwater will contribute to stream flow further downstream thereby increasing TDS concentration (Hedges et al. 1998). TDS concentration will also be lower in streams during high flow rates.

Prior to any energy related development in these watersheds, surface waters were classified as calcium-magnesium bicarbonate type water (Hedges et al. 1998). This is consistent with streams that are surface water fed. Tanner Creek has more highly mineralized waters than Youngs and Little Youngs Creeks (Hedges et al. 1998). Youngs Creek and Little Youngs Creek have TDS concentrations ranging between 200 and 400 milligrams per liter (mg/L) (Hedges et al. 1998). The Tongue River has an average TDS concentration of 440 mg/L (Hedges et al. 1998).

Groundwater quality of the alluvium in Youngs Creek and Tanner Creek at the mouth of each stream represents higher TDS levels than surface water with TDS concentrations of 1500 mg/L (Hedges et al. 1998). By comparison, Little Youngs Creek alluvium contained less than 1000 mg/L TDS. Groundwater primarily contains sulfate anions in each watershed.

Historical SAR levels measured in the Tanner Creek and Youngs Creek watersheds are 0.4 - 0.5 and 0.1 - 1.0, respectively, during low flow periods (Hedges et al. 1998). CBM produced water discharges to surface waters are monitored to limit the resultant SAR level of the Tongue River. Waters with high SAR levels are limited from land application as sodium may damage soil and crops (Hanson et al. 1999). Analysis will focus on the SAR levels of samples as this served as the primary monitoring criteria and limiting factor for produced water discharge in all watersheds.

The primary objectives of the study are to determine impacts to water quality, if any, associated with reclaimed mines and produced water discharge or land application from CBM wells. Although there are potential impacts on groundwater, this study focused on surface waters due to difficulties in sampling groundwater. The study focuses largely on the Tanner Creek, Youngs Creek, Little Youngs Creek, and Ash Creek watersheds, with a few auxiliary sampling points outside of these watersheds. The tributaries draining the developed sites flow directly into the Tongue River.

Methods

Determining Sampling Points

Like previous studies (Hedges et al. 1998), sampling points have been based at locations that were generally accessible from nearby roadways, such as outlets of roadway culverts, stream crossings, and clearings in brush and tree covering. Sampling points were also located at the confluence of tributary streams, and at the mouth of each stream. Sampling points were generally located within roadway right of way areas. Our study was limited to surface water because groundwater was generally not as accessible. Sampling sites were chosen near MBMG 1977 sample sites.

Water samples in Youngs Creek, Little Youngs Creek, and Ash Creek were collected in September 2016. The September sample collection was scheduled to coincide with the 1977 MBMG study during the watershed low flow period. The majority of the Upper Tanner Creek watershed was found to be dry during this sample time with stream flow found at the lowest reach of the creek. There were a few bends in the creek with standing water in the lower most 3.2 km (2 mi) of the creek, above the confluence with Youngs Creek. Two ponds located near the headwaters of Tanner Creek were sampled in the month of June.

The water was sampled during a low flow period in September when runoff would be at minimal levels. The low flow rate would lead to higher expected overall TDS with less flow contribution from surface water that exhibits lower TDS. Youngs Creek was flowing through the entire stream length. Little Youngs Creek and Ash Creek were also flowing in the most upstream sampling sites to the downstream confluence sites.

Several sampling locations were selected based on proximity to prior resource development. Locations nearest the Tongue River Reservoir, immediately outside of the eastern edge of the North Decker Mine area were selected to target waters discharged from the mine site. One location near the reservoir displayed a State of Montana Department of Environmental Quality discharge permit number posted at the site of a discharge point. This point discharged directly into the Tongue River Reservoir through a culvert under Highway 314. Samples were taken from this outfall in April 2016.

Another sampling location was selected at the site of a reclaimed coal mine south of the Ash Creek watershed in the reclaimed Hidden Water Creek Mine in Figure 1. The site was developed with several coal mine pits across the drainage area that flows into the Tongue River south of Ash Creek. There is a pond located in one of the reclaimed pit areas. The standing water was sampled during a period of low flow in September. The pond did not appear to flow into a connecting drainage at the time of low flow.

These sampling locations were accessible in open, unfenced areas where signage is posted regarding the permit designation and reclamation status. The permit and reclamation status can be researched and tied to documentation of land use and water quality data. The samples taken in each watershed are indicated in Figure 3.

Because the area had been previously studied by both the oil and gas industry and the MBMG, there were many, readily accessible auxiliary data. For example, well logs and CBM well production data in Wyoming are available online at the Wyoming Oil and Gas Commission on the State of Wyoming website (WOGCC 2017). Additional data provided by MBMG include CBM well production and associated produced water, as well as locations of CBM infiltration ponds. CBM well production data are available from the Montana Oil and Gas Commission (MDNRC BOGC 2017).

Density of CBM Wells

The CBM wells in Montana and Wyoming were developed in clusters, typically each well targeting different coal bed formations. Wells were co-located and drilled primarily in the Dietz 1-3, Carney, and Monarch formations, and occasionally in the King and Roberts formations. Each well developed in a separate formation produces varying levels of gas and water. Some formations in co-located wells did not produce gas or water. The density of the CBM wells per section is outlined. There were also several dry wells listed in the CBM fields that are not included in this analysis.

Chemical Analysis

Parameters of water quality measured include major cations and anions. Cation and anion measurements detailed the geochemical signature of the stream waters. Water samples were collected at each location by grab sample, then filtered and preserved for analysis. Samples were analyzed at the Cornell University, Department of Biological and Environmental Engineering, Soil and Water laboratory. Anions were analyzed by ion chromatograph. Cations as dissolved metals were analyzed by inductively coupled plasma mass spectrometry. Samples collected in September 2016 were sent to a commercial laboratory in Montana to measure TDS.

Results

The results section focuses on the cation and SAR data, as the criteria were indicators for permitted CBM produced water discharged to stream drainages (ARM 17.30.670). Cation and SAR values for each watershed are listed in Tables 1-3. The density of CBM wells per section or square mile in Montana and Wyoming is shown in Figure 3 and outlined in the supplemental information. All of the wells in this area are listed as capped or inactive as of 2013 (MDNRC BOGC 2017).

Cation Levels/SAR/TDS

A spring above Tanner Creek within the watershed had the lowest total measured concentrations of all water samples and also exhibited the lowest levels of calcium, magnesium,

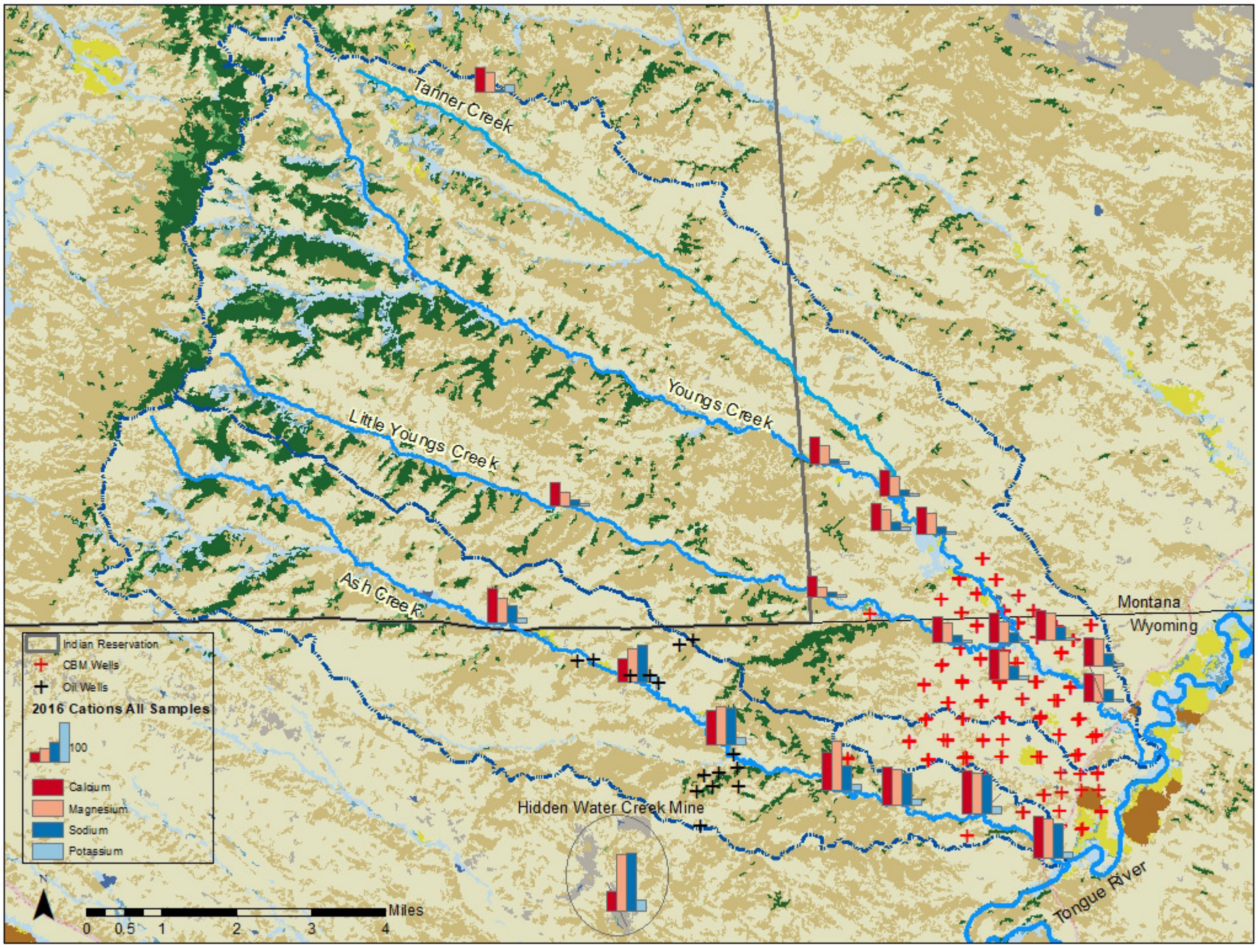

Figure 3. Surface water 2016 cation data with CBM oil wells and mines. The sample concentration value as indicated in the legend is scaled for 100 parts per million.

and sodium. The spring had a slight level of sulfate above 5 mg/L **(**Figure 3). A stock pond in the Tanner Creek watershed did not have sulfate present within the detection limit, and indicated higher levels of calcium, magnesium, potassium, and sodium than the spring pond. The stock pond and the headwaters of Tanner Creek were dry at the time of September sampling, supporting the idea that it is a surface water fed pond.

A pond in the reclaimed mine site of Hidden Water Creek showed elevated levels of sodium and magnesium and moderate levels of calcium. This sample had the highest SAR level of all collected samples, consistent with the presence of sodium, calcium, and magnesium. Measured SAR concentration levels for all samples are indicated in Figure 4.

There were four sampling sites on Youngs Creek that corresponded with the MBMG 1977 sites. On Little Youngs Creek, three sampling sites corresponded with the 1972 and 1977 sites. A paired t-test of sample data compared site-by-site indicates a slight decrease in SAR levels particularly in the Youngs Creek sites at p-value of 0.06 (Table 4).

Discussion

Comparison to MBMG Data: Changes in Land Use and Water Quality Since 1970s Data Collected

Just as the sampling points were generally accessible by roadway or more accessible due to natural features of the stream, these locations were also readily accessible to livestock grazing in adjacent pasturelands. In the summer months, livestock, mainly cattle, were found watering at

Table 1. Youngs Creek, Little Youngs Creek, and Ash Creek water quality results.

	Youngs Creek (n = 7)	Little Youngs Creek (n = 5)	Ash Creek (n = 8)
Sodium	12 - 36 mg/L	12 - 34 mg/L	45 - 105 mg/L
Chloride	2 - 3 mg/L	2 - 3 mg/L	3 - 45 mg/L
Sodium Adsorption Ratio	0.28 - 0.69	0.34 - 0.66	0.49 - 1.84
Magnesium	47 - 74 mg/L	25 - 73 mg/L	52 - 129 mg/L
Potassium	6 - 9 mg/L	5 - 9 mg/L	8 - 21 mg/L
Calcium	70 - 80 mg/L	54 - 80 mg/L	62 - 117 mg/L
Sulfate	0 - 113 mg/L	0 - 105 mg/L	0 mg/L
Date Sampled	9/2016	9/2016	9/2016

Table 2. Reclaimed and developed sites water quality results.

	Hidden Water Creek – Reclaimed (n = 1)	MPDES Outfall North Decker Mine (n = 1)	Tongue River Reservoir (n = 1)
Sodium	154 mg/L	159 mg/L	21 mg/L
Chloride	21 mg/L	20 mg/L	4 mg/L
Sodium Adsorption Ratio	2.47	2.10	0.63
Magnesium	149 mg/L	136 mg/L	26 mg/L
Potassium	29 mg/L	24 mg/L	3 mg/L
Calcium	52 mg/L	209 mg/L	43 mg/L
Sulfate	0	0	0
Date Sampled	9/2016	4/2016	6/2016

Table 3. Tanner Creek Watershed water quality results.

	Tanner Creek Spring (n = 1)	Tanner Creek Pond (n = 1)
Sodium	1.3 mg/L	6 mg/L
Chloride	1.4 mg/L	2.1 mg/L
Sodium Adsorption Ratio	0.08	0.14
Magnesium	5 mg/L	52 mg/L
Potassium	17 mg/L	22 mg/L
Calcium	13 mg/L	67 mg/L
Sulfate	4.6 mg/L	0
Date Sampled	6/2016	6/2016

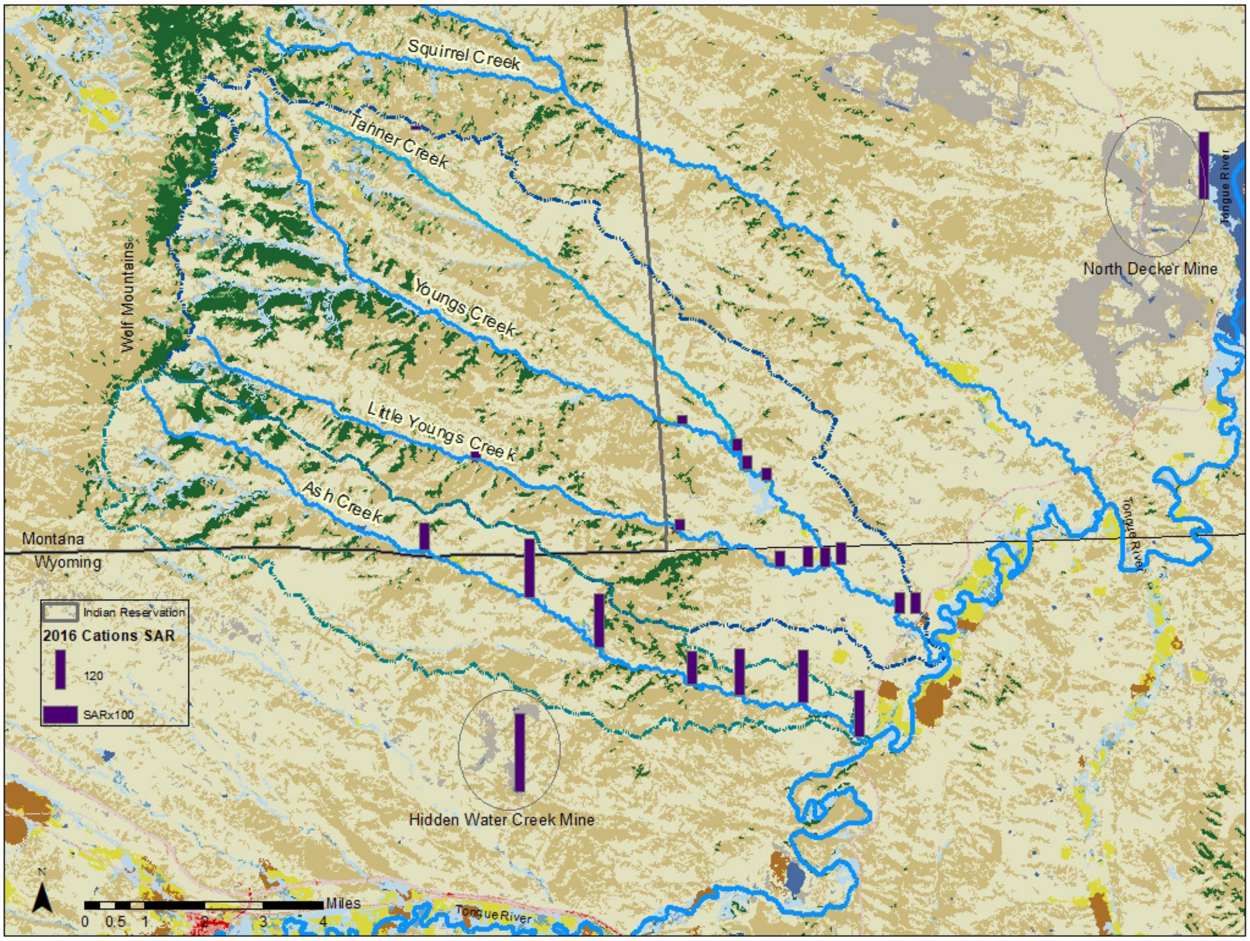

Figure 4. Surface water 2016 data SAR levels.

most sampling locations throughout Tanner and Youngs Creeks.

Cation and SAR levels of Youngs Creek did not differ significantly from initial levels taken in 1977. The land use activities may have changed the Youngs Creek channel in some downstream areas where irrigation canals run throughout the creek fed alluvial valley, based on topographic and aerial maps (Montana Cadastral 2017). These areas are downstream of the confluence of Little Youngs Creek and Youngs Creek and upstream of the mouth of Youngs Creek.

Indications of CBM and Oil and Gas on Water Quality

Water quality impacts from CBM development may be transient. As Youngs Creek experienced the most development with the highest concentration of well density and closest distance to CBM wells, the flow rate of the stream is high enough to resist impacts of produced water. Youngs Creek has a historical average annual flowrate of 0.26 cubic meters per second. The impacts of CBM produced water may have been exhibited at the time of well production but the stream water quality is similar to values recorded in 1977 prior to well development.

Active CBM wells in Wyoming were permitted to discharge produced waters directly into surface water drainages. This water, when not discharged directly into stream channels, is often held on site, in infiltration basins. Water in these basins that does not infiltrate or evaporate is usually channeled through culverts or other overflow structures into adjacent streams. Infiltration ponds for CBM wells were shown to impact groundwater quality (Healy et al. 2008). Depending on the well sites, infiltration of the produced water may have affected the water table directly below the pond site. The produced water would have elevated SAR levels and would raise the SAR levels in the groundwater.

Ash Creek did not experience the same amount of CBM development, however, the watershed has a higher concentration of oil and gas development than the other watersheds in the study area. Contaminant and indicator levels appear to be elevated within the Ash Creek drainage downstream of the Montana border into Wyoming. There are operating oil wells along the creek in addition to several now abandoned CBM wells. The concentration of oil wells along Ash Creek range from one to seven wells per section (WOGCC 2017). The oil and gas wells are located in formations at greater depths than the coal bed seams.

Background and historical data are limited for the Ash Creek watershed due to the location in Wyoming and lying outside of the study area of Montana agencies and databases. The majority of the Ash Creek watershed sampled is within the state of Wyoming. A few USGS data sets from the 1970s may capture effects of the drilling of the oil wells in the watershed (USEPA 2017). Comparatively, the Ash Creek watershed indicates higher levels of chloride, sodium, and SAR indicators than the Youngs Creek watershed.

Mining Impacts

The Ash Creek Mine site was dewatered beginning in 1976, then was reclaimed and dewatering ceased in 1995 (Meredith et al. 2011). The water produced during the dewatering process was likely discharged to infiltration ponds or to nearby streams which would include Little Youngs Creek. The Ash Creek Mine site appears to impact the nearby surface water quality on Little Youngs Creek. A MBMG sample from 1977 taken downstream from the mine site on Little Youngs Creek shows high levels of sodium, sulfate, chloride, and SAR values (Figure 4). The site exhibited the greatest levels of sodium for 1977 data on Youngs Creek and confluence with Little Youngs Creek at 103 mg/L and a SAR level of 2.2. This sample would have been taken during the operational period of the Ash Creek Mine. Samples taken downstream of the reclaimed mine site also show elevated sodium and SAR relative to upstream samples. The mine site has been demonstrated to influence Little Youngs Creek as instream flow is lost within the reclaimed mine site (Hedges et al. 1998). CBM wells were not developed in the Ash Creek Mine site and few

Table 4. Paired t-test for 1977 and 2016 water quality data.

	Difference Mean	SE	df	t-value	p-value
Calcium					
Youngs Creek	9.8 mg/L	2.75	3	3.56	0.0189
Little Youngs Creek	18.9 mg/L	4.63	2	4.07	0.0277
Magnesium					
Youngs Creek	-2.3 mg/L	4.93	3	-0.46	0.3384
Little Youngs Creek	0 mg/L	7.56	2	0	0.5
Sodium					
Youngs Creek	-9.1 mg/L	5.78	3	-1.57	0.1072
Little Youngs Creek	-23.3 mg/L	23.09	2	-1.01	0.2094
Potassium					
Youngs Creek	-0.2 mg/L	0.72	3	-0.23	0.4164
Little Youngs Creek	0.2 mg/L	1.42	2	0.16	0.4438
Sodium Adsorption Ratio					
Youngs Creek	-0.2	0.08	3	-2.12	0.0609
Little Youngs Creek	-0.5	0.51	2	-1.04	0.2038

Note: The mean of difference reported represents 2016 data minus 1977 data values.
SE = standard error; df = degrees of freedom.

wells in the Little Youngs Creek watershed were located upstream of the sampling point at Little Youngs Creek culvert.

Water quality impacts from mining development may be more pronounced than that of CBM due to significant coal seam dewatering and the alteration of the coal bed aquifer during mining development. The reclaimed mine spoils will change the character of the saturated groundwater and surface runoff. As seen with the sample from a pond in the reclaimed area of the former Hidden Water Creek Mine, surface water runoff may have increased SAR. The pond was not connected to a flowing stream, at least not in an obvious way, which would also contribute to the increased level of contaminants found in standing water, i.e., concentration via evaporation. The mine site would be less hydrologically connected to natural groundwater flow paths, therefore, the standing pond water would likely originate from the surface runoff within the site.

The spoils aquifers of reclaimed mines can have higher TDS than adjacent coal aquifers. The spoils aquifers will exhibit higher concentrations of sodium, sulfate, and bicarbonate than the coal aquifers. These elevated concentrations are due to the dissolution of minerals and clays in the spoils aquifers. The ion exchange of the calcium and magnesium ions in favor of the sodium ion within the spoils aquifer also increases the TDS. In the spoils aquifer, the predominant anion will be sulfate (Slagle et al. 1985). TDS levels in spoils aquifers may reach 5,000 mg/L as demonstrated in mined areas in southeastern Montana (Davis 1984).

The sample originating from the North Decker Mine site area also demonstrated an elevated SAR level. The water was likely sourced from dewatering of the coal seam aquifer in an attempt to drawdown the groundwater table. The mine site in the area had not yet been reclaimed and would require continuous dewatering as the nearby Tongue River Reservoir would elevate the groundwater table. The outfall fed directly into the Tongue River Reservoir. Several measurements of the Tongue River Reservoir in this area showed an average SAR level of 0.63. Although the water had elevated SAR levels of 2.1 discharged to the reservoir, it was within SAR permit levels and below the CBM contaminant limit for SAR levels permitted by the Montana Department of Environmental Quality.

Land Area to be Impacted by Mine Development

A significant portion of each watershed within the reservation boundary would be impacted by the proposed Big Metal Mine development project. The entire Tanner Creek watershed would be impacted upstream of the reservation boundary. The Youngs Creek watershed would be altered within the Upper Youngs Creek boundary, a few miles upstream of the reservation boundary detailed in Figure 2. Depending on the extent of the disturbance on the ridge between Tanner Creek and Youngs Creek, the watershed along Youngs Creek would be impacted up past the headwater boundary of Tanner Creek. The greatest disturbance to actual surface land would be most apparent in the Tanner Creek watershed. The Tanner Creek watershed consists of 70 percent tribal lands, the most tribal land ownership of all the watersheds.

The drainage from backfilled mine spoils in the headwater areas would alter the stream flow from current dominance of typical surface fed flows of calcium-bicarbonate to elevated TDS levels with increases in sodium, bicarbonate, and sulfate (Davis and Dodge 1986). This change would be exhibited in surface water runoff. Groundwater changes in the altered watersheds would also be affected by the higher TDS and increased cation concentration. The Tanner Creek watershed would be completely altered throughout nearly the entire stream length upstream from the reservation border. If removed during mining and replaced by spoils, the permeability of the reclaimed watersheds would be affected and would take on the characteristics of the spoils aquifer. The runoff volume from surface water would be expected to increase due to less vegetation and decreased infiltration or percolation of the saturated spoils soil. The topology would also have more uniform slopes with decreased impediments to flow than the natural rugged landscape. This would lead to increased volumes of surface water runoff from the reclaimed watersheds in Tanner Creek and Youngs Creek (USDOI BIA 1981). As mine spoil samples were limited, surface water in reclaimed sites should be further studied to determine resulting water quality.

Conclusion

Reclaimed mining sites may have lasting impacts on the nearby surface water quality in the study area. Historical and current samples have demonstrated higher SAR and sodium levels downstream of the Ash Creek Mine in the Little Youngs Creek watershed. A sample from a pond in the former Big Horn Mine reclaimed site contained the highest SAR level of all surface water samples. CBM development impacts may have been transient in the Youngs Creek surface water based on sample results. Historical oil and gas development appears to be impacting surface water quality within the Ash Creek watershed.

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Unregulated and Emerging Contaminants in Tribal Water

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Abstract: Emerging contaminants in Tribal water have been unexplored until implementation of the Unregulated Contaminant Monitoring Rule (UCMR) campaigns, which mandated the analysis of up to 30 new contaminants in drinking water every five years. As additions to the Safe Water Drinking Act (SDWA), the UCMR1 – 3 were created to assess contaminants which have not yet been assigned a maximum contaminant level (MCL) but may be regulated in the future to protect human health. While a handful of Tribes (n = 6) participated in UCMR1, public water systems (PWS) within reservation boundaries were intentionally included in representative nation-wide sampling beginning with UCMR2 after a period of Tribal consultation. Still, less than 3% of Tribal PWS were surveyed. The results from UCMR2 revealed that samples from all surveyed Tribal PWS fell below the method detection limits. Target analytes shifted to metals, perfluorinated chemicals, hormones, volatile organic compounds (VOCs), dioxane, and chlorate under UCMR3. Detectable levels of metals (chromium, hexavalent chromium, strontium, and vanadium), chlorate, and dioxane were observed, and in some cases, at concentrations greater than the U.S. Environmental Protection Agency's (EPA's) recommended health reference limit (HRL). The presence of elevated levels of vanadium, strontium, 1,4-dioxane, perfluorooctanesulfonate (PFOS), and chlorate defines a new set of emerging contaminants that needs to be considered with regards to risk, reporting and monitoring, and water treatment in Tribal drinking water.

Keywords: *Tribal Public Water Systems, Unregulated Contaminant Monitoring Rule, drinking water, emerging contaminants*

Established in 1974, the Safe Drinking Water Act (SDWA) regulates drinking water sources in the United States (EPA 1986, 1999a). The SDWA enables the U.S. Environmental Protection Agency (EPA) to create primary and secondary contaminant standards that are then used by state and Tribal governments to implement water treatment practices. Primary drinking water standards set a maximum concentration level (MCL) for contaminants with regards to human health concerns and are enforceable by law. The SDWA includes National Primary Drinking Water Regulations which require monitoring and reporting results of drinking water systems and public notification in the case of a MCL or Treatment Technology (TT) violation. In addition, the EPA created secondary standards for contaminants that are not considered to be a health risk but can result in unwanted aesthetic and cosmetic effects or become problematic to system equipment. Secondary standards are not enforced by the EPA, but some governments have independently chosen to regulate these contaminants. The SDWA sets these standards for both surface water and groundwater sources.

Tribal water quality within the United States follows the guidelines of the EPA's SDWA, where the sovereign nations must meet the MCL, TT, and subsequent ruled amendments when a water system serves greater than 25 consumers. Results are reported by the EPA, providing information on compliance, violations, and remedial actions taken, where necessary (EPA 2017a). Often, Tribal public water systems (PWS) are small facilities (<3,300 persons served), which may have issues in elevated violations for health-related requirements, monitoring, reporting, and notifications (Rubin 2013; Conroy-Ben and Richard 2018).

The Unregulated Contaminant Monitoring Rule (UCMR) was an amendment to the SDWA, which mandated the monitoring of up to 30 new contaminants every five years. There were four UCMR campaigns (UCMR1 – 4) as of 2019, covering metals, pathogens, and their associated toxins, and other emerging contaminants (Table 1). Each UCMR campaign is comprised of List 1 monitored contaminants and List 2 contaminants which are included in a screening survey. UCMR1 (2001 – 2005) List 1 chemicals were reserved for large facilities and select small facilities, while List 2 was for a subset of List 1 small facilities (EPA 1999b, 2019a). Under UMCR2 (2007 – 2011), all PWS serving greater than 10,000 people were required to participate, in addition to a select number of PWS serving less than 10,000 people (EPA 2007, 2019c). UCMR2 List 1 contained 10 chemicals for which there were established and well-adapted analytical methods. UCMR2 List 2 contaminants required the development of analytical methods. UCMR3 List 1 contaminants (2012 – 2016) were part of assessment monitoring, where samples from all large systems and a select number of facilities serving less than 10,000 people were analyzed for 21 chemicals (EPA 2012a, 2019d). UCMR3 List 2 included seven hormones to be monitored in all PWS greater than 100,000 customers, and select large and small facilities. Pre-screening (List 3) of select PWS was also conducted for two viruses (List 3), enterovirus and norovirus. As of October 2019, the UCMR4 campaign was on-going, where large groundwater systems were to monitor for non-cyanotoxin contaminants; groundwater and groundwater under the influence of surface water sources were to monitor additional contaminants (pesticides, alcohols, semivolatiles, metals, and brominated haloacetic acids) (EPA 2016b, 2019b).

Emerging contaminant monitoring and research in Tribal communities prior to and during the UCMR campaigns have been limited to a few published studies. Here, we discuss the major findings of the unregulated contaminant surveys in Tribal drinking water sources, pointing to the need to promote participation of PWS in Indian Country in UCMR campaigns and to target specific chemicals for future monitoring.

Methods

UCMR1 – 3 data were downloaded in October of 2019 (EPA 2012b, 2017c, 2017d). Data fields reported by the U.S. EPA included the PWS, facility, sampling point, water source (as surface water, groundwater, or groundwater under the influence of surface water), sampling event date, analytes, EPA analytical method, and other sample/facility identifiers. Raw data (concentrations as µg/L) for each sampling point were averaged over the number of sampling events (up to four) during the respective UCMR. Tribal affiliations were assigned by matching the PWS identification number from the UCMR dataset to Tribal names and reservations listed in the EPA's Enforcement Compliance History Online (ECHO) (EPA 2017a). Public water systems and sampling points were de-identified, although these details are publicly available in downloaded data. Finally, surveyed Tribes may have more than one PWS, but only one to two PWS per Tribe were monitored under the UCMR.

Results and Discussion

The EPA selected a number of small (<3,300 customers) to large (>10,000 customers) PWS serving Indian Country under UCMR2 – 3 PWS to be tested for unregulated contaminants. As of October 2019, there were 1018 PWS within Tribal boundaries (EPA 2017a). Of these Tribal PWS, less than 2.9% were surveyed for the UCMR campaign (For UCMR1, n = 6 Tribal PWS or 0.6%; for UCMR2, n = 19 Tribal PWS or 1.9%; and for UCMR3, n = 30 Tribal PWS or 2.9%). The amount of non-Tribal PWS that participated in UCMR3 was 4%, pointing to Tribal under-representation during the UCMR campaign by at least ten systems.

Tribal PWS Size and Participation in UCMR1–3

Of the ~1000 Tribal PWS within Tribal boundaries, 26 were designated as large facilities

Table 1. Contaminants monitored under each Unregulated Contaminant Monitoring Rule (UCMR) campaigns 1 through 3. Lists under each UCMR specify contaminants targeted for select facility sizes. "Contaminants" refers to both chemicals and pathogens; UCMR1 and UCMR2 list chemicals only, while UCMR3 lists chemicals and viruses.

Rule	Class	Chemicals
UCMR1		
List 1:	Herbicides	acetochlor, EPTC, molinate, terbacil; degradates: DCPA mono- and di-acid
	Insecticide degradate	4,4'-DDE
	Octane enhancer	MTBE
	Organic precursors	2,4-dinitrotoluene, 2,6-dinitrotoluene
	Oxygen additive	perchlorate
List 2:	Combustion product	2,4,6-trichlorophenol, 2-methylphenol
	Herbicide	diuron, linuron, prometon; by-product: 2,4-dichlorophenol
	Insecticide	diazinon, disulfoton, fonofos, terbufos,
	Organic precursor	1,2-diphenylhydrazine, nitrobenzene (List 1 & 2)
	Industrial product	2,4-dinitrophenol
UCMR2		
List 1:	Explosives	1,3-dinitrobenzene, 2,4,6-TNT, RDX
	Flame retardants	2,2',4,4',5,5'-hexabromobiphenyl (HBB), 2,2',4,4',5,5'-hexabromodiphenyl ether (BDE-153), 2,2',4,4',5-pentabromodiphenyl ether (BDE-99), 2,2',4,4',6-pentabromodiphenyl ether (BDE-100), 2,2',4,4'-tetrabromodiphenyl ether (BDE-47)
	Insecticides	dimethoate, terbufos sulfone
List 2:	Acetanilides	acetochlor, alachlor, metolachlor; degradates: acetochlor ethane sulfonic acid, acetochlor oxanilic acid, alachlor ethane sulfonic acid, alachlor oxanilic acid, metolachlor ethane sulfonic acid, metolachlor oxanilic acid
	Nitrosamines	N-nitroso-diethylamine (NDEA), N-nitroso-dimethylamine (NDMA), N-nitroso-di-n-butylamine (NDBA), N-nitroso-di-n-propylamine (NDPA), N-nitroso-methylethylamine (NMEA), N-nitroso-pyrrolidine (NPYR)
UCMR3		
List 1:	Metals	Co, Cr, Cr6+, Mb, Sr, V
	Oxyhalide anion	chlorate
	PFCs	perfluorobutanesulfonic acid (PFBS), perfluoroheptanoic acid (PFHpA), perfluorohexanesulfonic acid (PFHxS), perfluorononanoic acid (PFNA), perfluorooctanesulfonic acid (PFOS), perfluorooctanoic acid (PFOA)
	Synthetic organic	1,4-dioxane
	VOCs	1,1-dichloroethane, 1,2,3-trichloropropane, 1,3-butadiene, bromochloromethane (halon 1011), methyl bromide, chlorodifluoromethane (HCFC-22), chloromethane
List 2:	Hormones	androstenedione, equilin, estradiol, estriol, estrone, ethynylestradiol, testosterone
List 3:	Viruses	enteroviruses, noroviruses

(>10,000 individuals served), whereas the other 97.3% were small and medium facilities (Table 2). This information served two roles: first, each of the UCMRs listed and prioritized chemicals according to facility size and water source; second, large facilities were responsible for their own analyses, whereas the EPA covered the cost of analysis for small facilities, ranging from \$50 to \$470 per sample. Complimentary analyses can be beneficial for Tribes that are resource limited, but still wish to explore unregulated contaminants. Under UCMR1, only very small (25 – 500) to small (501 – 3,300) facilities were sampled (n = 6). For UCMR2, 5 out of 26 large Tribal PWS participated, with an additional three medium-sized (3,301 – 10,000) and 11 designated as small or very small PWS. Under UCMR3, 15 out of the 26 large facilities in Indian Country participated, with an additional 16 small Tribal PWS surveyed.

Frequency of Analysis and Detection of UCMR1–3 Contaminants

The objective of the UCMR Survey was to evaluate the frequency and levels of unregulated contaminants in PWS across the United States. With respect to Tribal drinking water, participation varied in each UCMR (Table 2), and surveyed contaminants were not analyzed in all participating PWS (Figure 1). A number of Tribal PWS were analyzed across two or more UCMRs: Gila River Indian Community, Manshantucket Pequot, Morongo Band of Cahuilla Mission Indians, Navajo Nation, Pechanga Band of Luiseño Mission Indians, Shakopee Mdewakanton Sioux Community, Turtle Mountain Band of Chippewa, and White Mountain Apache; Mescalero Apache participated in UCMR1 – 3. Results from the campaign highlighted insignificant and problematic unregulated contaminants in Tribal PWS.

Under UCMR1, six Tribal PWS were evaluated for List 1 contaminants. One facility was also evaluated for List 2 analyses. Results showed that all sampling point concentrations fell below the method detection limits for each analyte. With UCMR2, 39 Tribal drinking water facilities and/or sources from 19 different Tribal PWS were analyzed for List 1 and 2 contaminants (explosives, herbicides and herbicide degradates, insecticides, nitrosamines, and brominated flame retardants; see Table 1). Nearly 75% of samples were analyzed for List 1 contaminants, reflective of readily available analytical methods, with the remaining samples analyzed under List 2. As with UCMR1, all sample concentrations fell below the method detection limits.

Under UCMR3, samples from 76 Tribal drinking water treatment plants (85 sampling points) from 30 different Tribal PWS were analyzed for chlorate, metals, volatile organic compounds (VOCs), synthetic organics, and hormones. VOCs, metals, perfluorinated chemicals (PFCs), chlorate, and 1,4-dioxane were analyzed most frequently (80% of PWS, Figure 1) while the least frequently analyzed contaminants were the hormones (23% of Tribal PWS). Hormones were not detected in any Tribal samples, as concentrations fell below the method detection limit. The VOC Halon 1011 and PFCs (PFHpA, PfHxS, and PFOS) were each detected in separate samples, whereas the other VOCs and PFCs were not detected. With the exception of cobalt, metals were detected in 57 – 80% of Tribal PWS, chlorate in 67% of PWS, and 1,4-dioxane in 13% of PWS.

As unregulated contaminants, MCLs had not yet been established and there were no enforceable actions imposed during this monitoring campaign. However, HRL or health reference levels provide guidance on the suggested maxima that should be present in drinking water due to potential adverse health or environmental effects. When comparing UCRM3 measured quantities to HRL, five contaminants were found in excess of HRL in Tribal drinking water (Figures 1 and 2): 1,4-dioxane, a probable human carcinogen, (health advisory concentration of 0.35 – 35 µg/L, (EPA 2017b)) in 1 out of 30 Tribal PWS; PFOS, a probable endocrine disruptor, in 1 out of 30 Tribal PWS (health advisory concentration = 0.07 µg/L, (EPA 2016a)); chlorate, a disinfection by-product, (HLR = 210 µg/L, (EPA 2016c)) in 12 out of 30 Tribal PWS; strontium (HRL = 1,500 µg/L, (EPA 2017b)) in 1 out of 30 Tribal PWS; and vanadium (HRL = 21 µg/L; (EPA 2016c)) in 4 out of 30 Tribal PWS.

The drinking water source provided insight into the prevalence of contaminant type. All vanadium and strontium HRL exceedances arose from groundwater sources alone, though

Table 2. List of Tribal Public Water Systems (PWS) participating in Unregulated Contaminant Monitoring Rule Campaign, UCMR1 – 3, by Tribal PWS size and drinking water source. GU = groundwater under the influence of surface water. Beginning with UCMR3, Tribal PWS were identified as only small or large facilities. Small = < 3,300; medium = 3,310 – 10,000; and large = > 10,000 customers.

UCMR	Size	No.	Groundwater source	No.	Surface water source
UCMR1	Small	1	Blackfeet Tribe	5	Three Affiliated Tribes
		2	Fort McDowell Yavapai Nation	6	Kickapoo Tribe (Kansas)
		3	Mescalero Apache Tribe		
		4	Stockbridge Munsee Community		
UCMR2	Small	7	Mescalero Apache Tribe	23	Grindstone Indian Rancheria
		8	Minnesota Chippewa Tribe	24	Hoopa Valley Tribe
		9	Navajo Nation	25	Southern Ute Indian Tribe
		10	Paiute-Shoshone Indians of the Bishop Community		
		11	Rincon Band of Luiseno Mission Indians		
		12	San Carlos Apache Tribe		
		13	Sault Ste. Marie Tribe of Chippewa		
		14	Zia Pueblo		
	Medium	15	Gila River Indian Community		
		16	Little River Band of Ottawa Indians		
		17	Morongo Band of Cahuilla Mission Indians		
	Large	18	Mashantucket Pequot Tribe (GU)		
		19	Pechanga Band of Luiseño Mission Indians		
		20	Shakopee Mdewakanton Sioux Community		
		21	Turtle Mountain Band of Chippewa Indians		
		22	White Mountain Apache Tribe		
UCMR3	Small	26	Gila River Indian Community	51	Cow Creek Band of Umpqua Indians
		27	Navajo Nation	27	Navajo Nation
		28	Lac Courte Oreilles Band (Lake Superior Chippewa)	52	Oglala Sioux Tribe
		29	Lac du Flambeau Band (Lake Superior Chippewa)	53	Tulalip Tribes
		30	Muckleshoot Indian Tribe		
		31	Kaibab Band of Paiute Indians		
		32	Pueblo of Jemez		
		33	Pueblo of Laguna		
		34	Pueblo of San Ildefonso		
		35	Reno-Sparks		
		36	Soboba Band of Luiseño Indians		
		37	Tohono O'odham Nation		
	Large	38	Mashantucket Pequot Tribe (GU)	54	Mohegan Indian Tribe
		39	White Mountain Apache Tribe	39	White Mountain Apache Tribe
		40	Morongo Band of Cahuilla Mission Indians		
		41	Pala Band of Luiseño Mission Indians		
		42	Pechanga Band of Luiseño Mission Indians		
		43	Pueblo of Sandia		
		44	Rumsey Indian Rancheria of Wintun Indians		
		45	Saginaw Chippewa Indian Tribe		
		46	Salt River Pima-Maricopa Indian Community		
		47	Shakopee Mdewakanton Sioux Community		
		48	Stockbridge-Munsee Band of Mohicans		
		49	Turtle Mountain Band of Chippewa		
		50	Mescalero Apache Tribe		

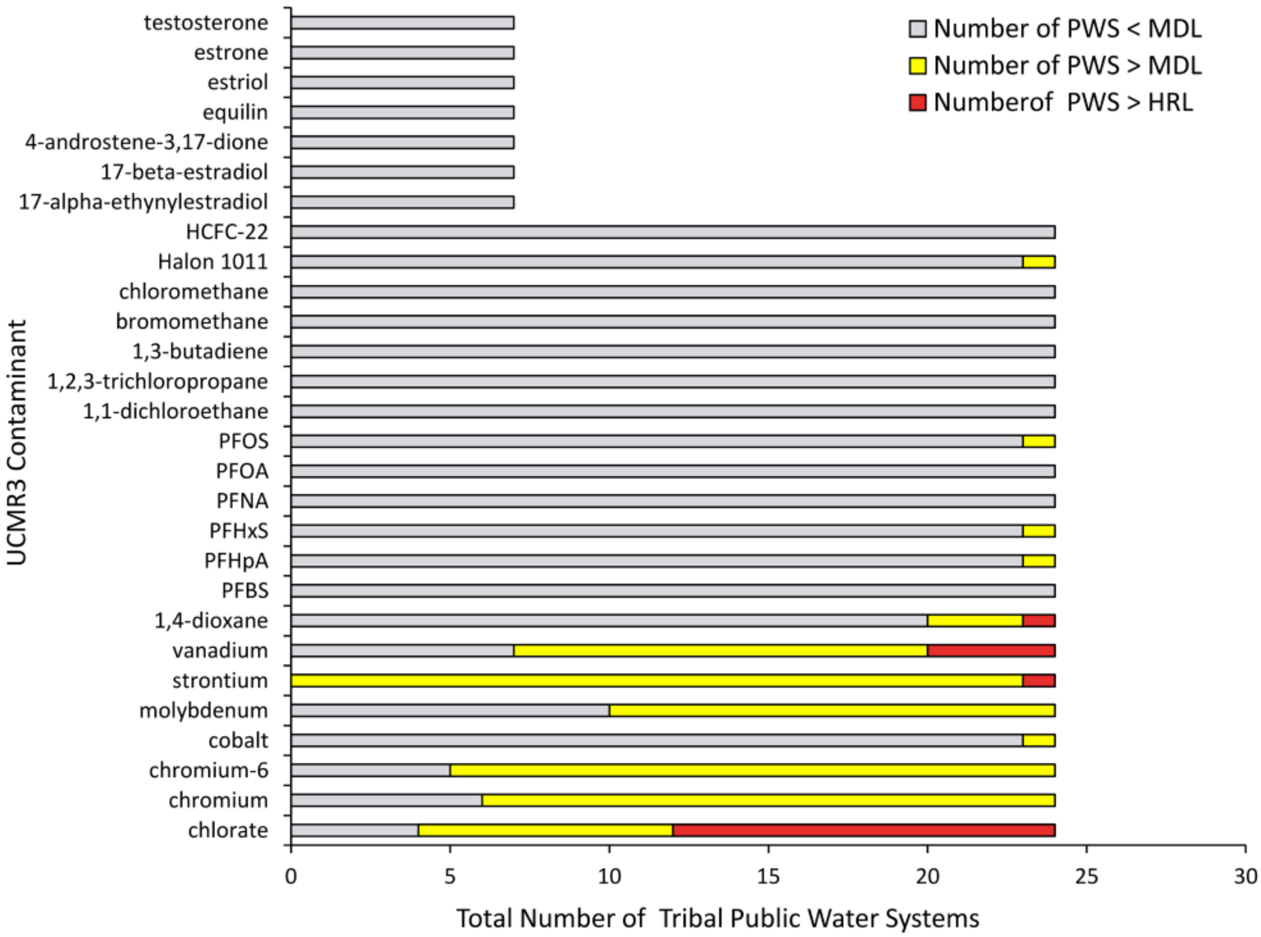

Figure 1. Thirty Tribal public water systems (PWS) sampled for Unregulated Contaminant Monitoring Rule Campaign 3 (UCMR3) contaminants are shown in bars. Number of Tribal PWS with non-detects is shown in gray. Number of Tribal PWS exceeding the method detection limit (MDL) is shown in yellow. Number of Tribal PWS exceeding the health reference limit (HRL) is shown in red. Hormones were analyzed in seven Tribal PWS; all were non-detects; the remaining contaminants were analyzed in 23 Tribal PWS.

metals (vanadium, strontium, and chromium/hexavalent chromium) in general were detected in both surface and groundwater sources. Molybdenum was detected only in groundwater sources. Chlorate, a disinfection by-product, and dioxane were from both groundwater and surface water sources. The single perfluorinated sample (containing PFOS, PFHxS, and PFHpA) detected came from a groundwater source located near a major metropolitan area. Additional water parameters, including water treatment processes and disinfectant type, were not available in the UCMR dataset, nor in the ECHO.

Without this information, it is difficult to predict what actions will be needed to correct exceedances of the HRL in Tribal PWSs, should these contaminants become regulated. Five (out of 30) of the Tribal PWS exceeded the HRLs of two contaminants (1 – chlorate and 2 – dioxane, PFOS, strontium, or vanadium), the highest of the group surveyed. Nine additional Tribal PWS exceeded one HRL (chlorate or vanadium). Ten PWS will not require remedial actions, as UCMR contaminants were detected, but were measured less than all HRLs, while the other six PWS had no contaminants detected. The implications of the UCMR campaign on Tribal facilities are unknown, as the objective of the survey is to evaluate the prevalence of contaminants in drinking water, which are not yet regulated.

Tribal-specific analyses of emerging contaminants in environmental water samples

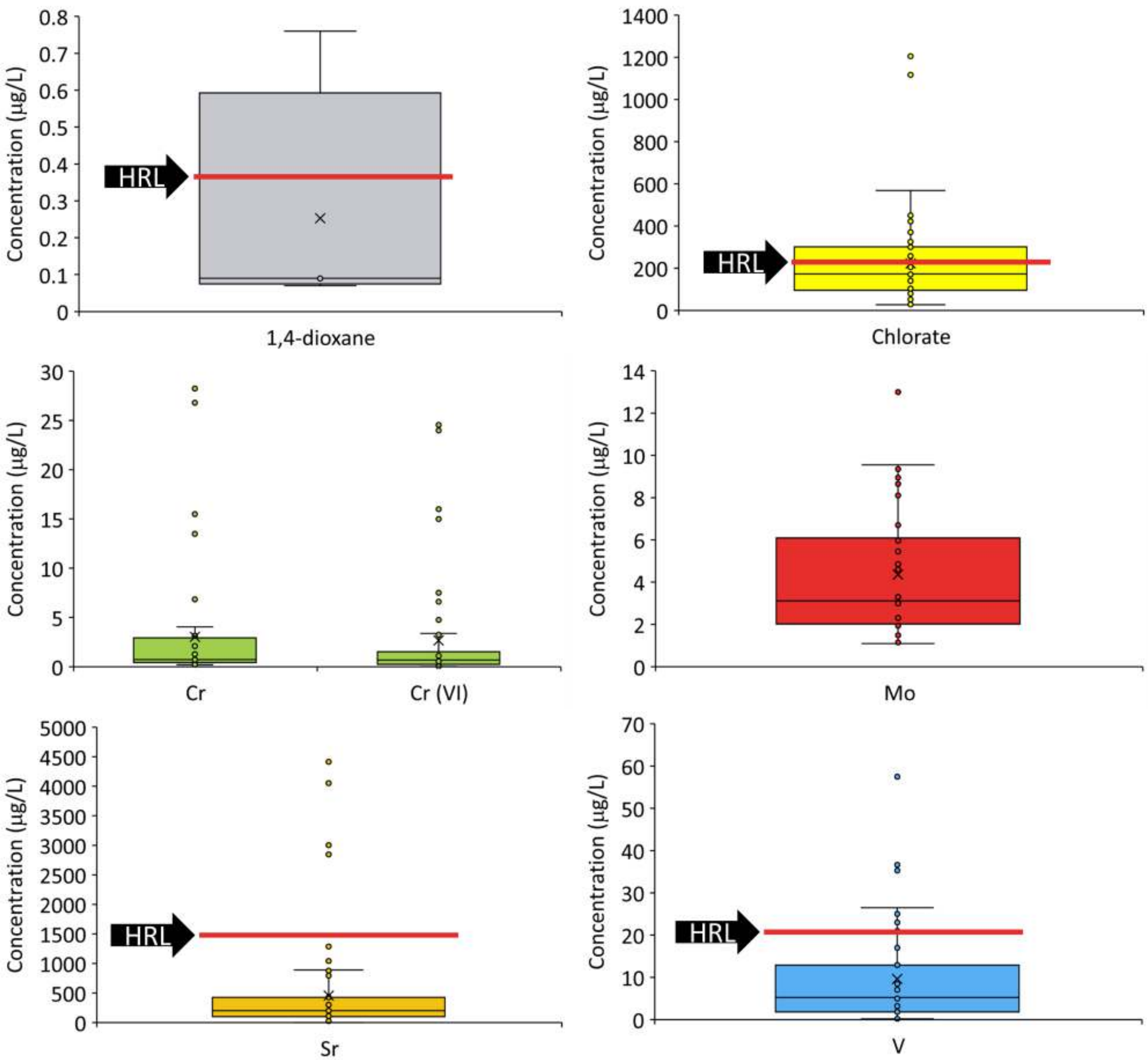

Figure 2. Concentration range in µg/L of Unregulated Contaminant Monitoring Rule Campaign 3 (UCMR3) contaminants in Tribal Public Water Systems (PWS). The health reference limit (HRL) is shown in black arrow indicating the HRL value for the contaminant. Tribal PWS exceed the HRL for the contaminants 1,4-dioxane, chlorate, strontium, and vanadium.

have been previously reported, but in the context of monitoring of wastewater discharge to surface water. The U.S. Geological Survey (USGS) conducted an analysis of emerging contaminants with the collaboration of two Tribes, the Standing Rock Sioux and the Stillaguamish Tribe (Damschen and Lundgren 2009; Wagner et al. 2014). A screening of over 200 contaminants of water and riverbed sediment along the Missouri River on the Standing Rock Indian Reservation showed the antibiotic sulfamethoxazole above method detection limits. The USGS also coordinated with the Stillaguamish Tribe on an ongoing study of the Stillaguamish River basin that included samples from the main river and its tributaries. For several years following initial sampling, samples were taken from three wastewater treatment plants. The USGS plans to continue to monitor the sites. To date, this analysis has primarily detected pharmaceuticals, which have previously not been considered in any UMCR. Hormonal contaminants, listed in the UMCR, were also detected. Though the foci of emerging contaminant monitoring by the USGS and EPA differ, these studies show the potential for detection in Tribal water.

Conclusions

This is the first published review of unregulated contaminants in Tribal PWS providing drinking water to communities. Although better sampling efforts can be made to include additional Tribes, this snapshot revealed important priorities for the monitoring of emerging contaminants, risk assessment, and drinking water treatment. Metals continue to be a priority, and while the inclusion of strontium and vanadium in a regulated list would require drinking water treatment plant upgrades, the public would be protected against adverse health risks. Chlorate, a disinfection by-product, was detected most frequently as exceeding the HRL, in 12 out of 30 Tribal PWS analyzed. Single-point exceedances of 1,4-dioxane and PFOS suggest these emerging contaminants should continue to be monitored. Finally, the survey suggests that emerging contaminants, including hormones, nitrosamines, flame retardants, herbicides, and pesticides, among others, are not presently of concern in drinking water, but should not be neglected in future surveys.

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Walleye Ogaawag Spearing in the Portage Waterway, Michigan: Integrating Mixed Methodology for Insight on an Important Tribal Fishery

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Abstract: The Portage Waterway in Michigan's Upper Peninsula supports traditional Anishnaabe walleye (or *ogaawag* in the Anishnaabe language) spear-harvesting for the Keweenaw Bay Indian Community (KBIC). Through reserved Indian treaty fishing rights, KBIC is highly involved in the waterway's stewardship and annual community spear-harvest. Tribal leadership and fisheries personnel have long documented that annual harvests are far below sustainable quotas. The objectives of this research were to 1) understand the values and concerns of KBIC tribal members on Anishnaabe walleye (*ogaawag*) spear-harvesting, 2) examine water temperature patterns during the spring 2018 harvest to seek insight on how harvests may be optimized, and 3) integrate *Anishinaabe gikendaasowin* or traditional knowledge with science and education. We conducted an online survey in February 2018, containing 27 questions, to gain preliminary insight on KBIC's perspectives of the annual walleye (*ogaawag*) spear-harvest. Nearly all respondents highly value the spear-harvest tradition personally and on behalf of the community. Similarly, nearly all agreed that it is important for the KBIC to manage its own fishery resources, and that the Tribe's Natural Resources Department effectively does so. Respondents also expressed concerns about factors that could impact their harvests, including environmental changes and confrontations with non-Native residents. From May 1 to May 19, 2018, we deployed 13 Onset HOBO Pro V2 temperature dataloggers across the Portage Waterway to measure spring warming patterns in locations popular for spear-fishing. This period encompassed the entire KBIC spear-harvest season, with dataloggers recording water temperature every two hours. Temperature data show that management of the harvest season may need revision, as embayments and sloughs where spear-fishing largely occurs warmed significantly earlier than other parts of the waterway. As the presence of walleye (*ogaawag*) in shallow waters depends on temperature, some parts of the waterway should be opened for harvesting earlier. Our findings will be prepared in a formal recommendation for KBIC leadership in efforts to increase harvests for the Tribal community that rely on walleye (*ogaawag*) as a sacred and traditional food source.

Keywords: *walleye, ogaawag, Anishinaabe, spear-harvest, Keweenaw Bay Indian Community*

The Keweenaw Bay Indian Community (KBIC) is part of a larger Native American group known as the Anishinaabe, meaning "original person" (Benton-Benai 1988). They are one of the largest Indigenous groups in North America with nearly 150 different bands living throughout their homeland in present-day United States and Canada. Currently, Anishinaabe are known by various names: Chippewa, Ojibway, Ojibwe, or Ojibwa, as well as Ottawa or Odawa and Potawatomi or Bodewadomi. All of these peoples are bound within the Anishinaabe people, the larger group who migrated from the Atlantic shores of North America and began settling in the Great Lakes Region before 1000 AD.

The KBIC of the historic Lake Superior Band of Chippewa Indians (Anishnaabe), is a federally recognized Native American Tribe in the

United States and is dedicated to the long-term protection of natural resources and preservation of Anishnaabe culture. This dedication has contributed to the peoples' survival and resiliency for many generations. KBIC is located on L'Anse Indian Reservation approximately 65 miles west of Marquette, Michigan in the L'Anse/Baraga Michigan area. KBIC has dual land bases on both sides of the Keweenaw Bay Peninsula in the Upper Peninsula in Michigan which is connected to the Great Lakes. As a sovereign tribal nation, KBIC actively maintains scientifically-sound planning and management of water resources in partnership with many of the region's governance and educational entities. In doing so, KBIC relies on community members to ensure their efforts integrate *Anishinaabe-gikendaasowin,* an Anishnaabe phrase that is translated to mean "knowledge, information, and synthesis of Anishinaabe teachings" into community governance (Geniusz 2009). It is critical that tribes depend on local Indigenous knowledge holders – the fishers, hunters, and gatherers – to guide and inform scientific research, management regimes, and the education of future generations. Through an integration of knowledge systems, tribes and their many governance partners can learn to better understand and interact with water ecosystems. Great Lakes Indigenous communities have an important role in protecting and restoring Basin ecosystems, particularly because their knowledge and practices have been sustained in the region for millennia.

Through a series of 18th- and 19th-century Indian treaties, Great Lakes Indigenous groups retained the basis of their knowledge: the land in which they originally lived and the waters in which they traditionally fished (Doherty 1990). KBIC is signatory to two treaties with the United States. In the 1842 Treaty with the Chippewa, Lake Superior Chippewa reserved existing rights of hunting, fishing, and gathering within more than 10 million acres of ceded land and water territory for their people (Treaty with the Chippewa 1842). The 1854 Treaty with the Chippewa addresses these rights and established the L'Anse Indian Reservation, approximately 59,000 acres of land in Michigan's Upper Peninsula (Treaty with the Chippewa 1854). The region is comprised of large areas of forested land, diverse aquatic and terrestrial plants and wildlife, and vast lake and river systems with more than 160 tributaries and 70 miles of southern Lake Superior shoreline (Sweat and Rheaume 1998). In 1936 the KBIC achieved status as a federal recognized Tribe upon adoption of their Constitution and By-laws, making the KBIC both the oldest and largest federally-recognized Indian Tribe in Michigan (U.S. Department of the Interior 1937; BIA 2020). It was at this time that KBIC was established as a legal and political entity, organized in accordance with the provisions of the Indian Reorganization Act of 1934.

Since the treaty-making era, Great Lakes Tribes including KBIC have encountered dire consequences due to federal assimilation policies, state regulatory control over harvesting, and environmental degradation and contamination due to extractive industries (e.g., furs, fish, forests, and minerals) (Wilkinson 2005). Much of this history intended to thwart Indigenous knowledge and practices. For decades, treaty harvesting rights were criminalized. For KBIC, 1842 treaty rights were not reaffirmed until the *1971 People v. Jondreau* decision ruled in favor of KBIC (Supreme Court of Michigan 1971). Since that time, KBIC self-governance has grown to include Great Lakes Indian Fish and Wildlife Commission (GLIFWC) membership, operating a fish hatchery facility, and establishing a natural resources department and management regime. It is imperative to understand this history in order to understand the magnitude of both *Anishinaabe-gikendaasowin* loss and revitalization of tribes in the region, including KBIC.

Community survival and resiliency are rooted in *Anishinaabe-gikendaasowi* and are guided by the seventh-generation worldview. The seventh-generation worldview is that today's decisions should be made considering the well-being of seven generations into the future. KBIC faces many current challenges, including changes in seasonal weather patterns, increases in extreme weather events, habitat degradation, pollution, toxic contamination, and loss of native plant, fish, and animal relatives (species). These challenges are exacerbated by the KBIC's limited capacity (e.g., funds, staff, and expertise) and the influence of non-Indigenous residents on the lives of Indigenous people in our region. Tribal communities must address ongoing threats while simultaneously revitalizing Indigenous obligations to land and life and recovering and sharing the knowledge needed to do so. These challenges yield negative social, cultural, and economic consequences, particularly due to the loss of subsistence and commercial harvesting opportunities which also impedes transmission of knowledge to future generations.

The importance of traditional ecological knowledge has been increasingly recognized for promoting resilient ecosystems and the health and safety of those who depend on them (Finn et al. 2017; Deloria et al. 2018; Seltenrich 2018). Traditional ecological knowledge encompasses generations of knowledge and worldviews of Indigenous peoples gained by direct interactions with the natural world over millennia. Its practice calls for a broad accounting of and respect for relationships that compose a holistic understanding of the world; in this view, all things are interrelated and interdependent (Kimmerer 2015; Whyte 2017; Zidny et al. 2020). For Indigenous communities, health is deeply embedded in relations to place and comprised of community, cultural, and spiritual relationships (Adelson 2000; Geniusz 2009; Gagnon 2016). Based on these understandings, governance, research, and resource management are evolving to integrate science and Indigenous knowledge aimed towards improving environmental and human health (Donatuto et al. 2011, 2014, 2016). Traditional ecological knowledge can guide, complement, and supplement biological science and management of natural resources (Menzies and Butler 2014; Zidny et al. 2020). Integrating knowledge systems has also been shown to enhance cross-cultural and cross-scale efforts to better understand social-ecological systems (Berkes 2004) and to increase the relevance of research (Berkes 2012). The health and safety of KBIC requires the ability to use and share its knowledge, *Anishinaabe-gikendaasowi,* across Tribal departments, so that traditional knowledge and science can be integrated to strengthen community and ecosystem resilience for current and future generations. Like many tribes, however, the KBIC is aware of past instances of abuses or disregard of its knowledge by outside researchers, and now requires approval by Tribal leadership to ensure that proper protocols are in place, including ownership of data (Chief et al. 2016; Maldonado et el. 2016).

KBIC is acutely aware of harmful environmental trends and increased potential for extreme events that negatively impact Tribal treaty and trust resources, economic well-being, local infrastructure, and the health and safety of KBIC (KBIC 2002; Gagnon et al. 2013; Nankervis and Hindelang 2014; Kozich 2016; TAM Team 2019). The protection and restoration of Treaty resources are a KBIC priority because Tribal members depend on healthy ecosystems for subsistence, commercial, and cultural purposes. Traditional foods and medicines such as fish, wild game, wild rice (*manoomin*), berries, trees, and plants are gathered within water and terrestrial landscapes in both the local and wider region (GLIFWC 2014). Thus, many stories and observations from KBIC Tribal members and descendants inform management practices and implementation of KBIC strategic plans; their insights are also critical for KBIC governance and planning into the future. Harvesting practices are a means of community identity and well-being (Gagnon 2016; Kozich 2016, 2018), and harvesting is also a vast source of traditional knowledge and community resiliency (Wilson 2001; Whyte 2018). Further, sharing knowledge strengthens cultural identity, fostering resilience (Unger 2011; Wexler 2014). Community fishers, hunters, and gatherers have shared their experiences and knowledge about concerning trends in the area such as the disruption of seasonal phenology, the loss of hunting and gathering grounds, shifts in fish, wildlife, and plants' species, and changes in seasonal temperature trends, including ice cover and access to ice fishing. Clearly, the integration of local knowledge is a priority in water research and education in Keweenaw Bay.

In this study we examined current walleye (*ogaawag*) spear-fishing practices, which follow traditional methods, and integrated continuous water temperature data in walleye (*ogaawag*) habitat to assess the effectiveness of management strategies related to the annual spear-harvest tradition. Spear-harvesting occurs after dark, typically from boats cruising through shallow waters that the walleye (*ogaawag*) enter to spawn at night. Headlamps are worn by fishers, illuminating the eyes of the fish to therefore detect their location. The harvest season occurs in spring during a period of rapid water temperature changes, and the success of the harvest relies on an intimate understanding of walleye (*ogaawag*) behaviors that are linked to specific habitat conditions such as water temperature.

Study Area

The Portage Waterway consists of North and South Entry (connected to Lake Superior), Portage Canal, Portage Lake, Torch Lake, and several smaller bays and connecting waters (Figure 1). The two most popular sites for KBIC spear-fishers are Pike Bay and Dollar Bay, which are small, shallow bays on the south and north sides of Portage Lake, respectively. The total surface area of Portage Waterway is approximately 53 km^2 (Breck 2004). The moderately-developed shoreline totals 145 km, and the 900 km^2 watershed is mostly forested (Hanchin 2016). The waterway bisects the Keweenaw Peninsula that juts into Lake Superior as the northernmost point of mainland Michigan. The peninsula is characterized by billion-year-old geological formations containing among the purest copper in the United States, with peaks exceeding 500 meters in elevation. The peninsula's largest population centers originated as mining settlements in the 1800s. The largest cities, Houghton and Hancock, have a combined population of around 12,000 and are situated on the shores of the Portage Waterway.

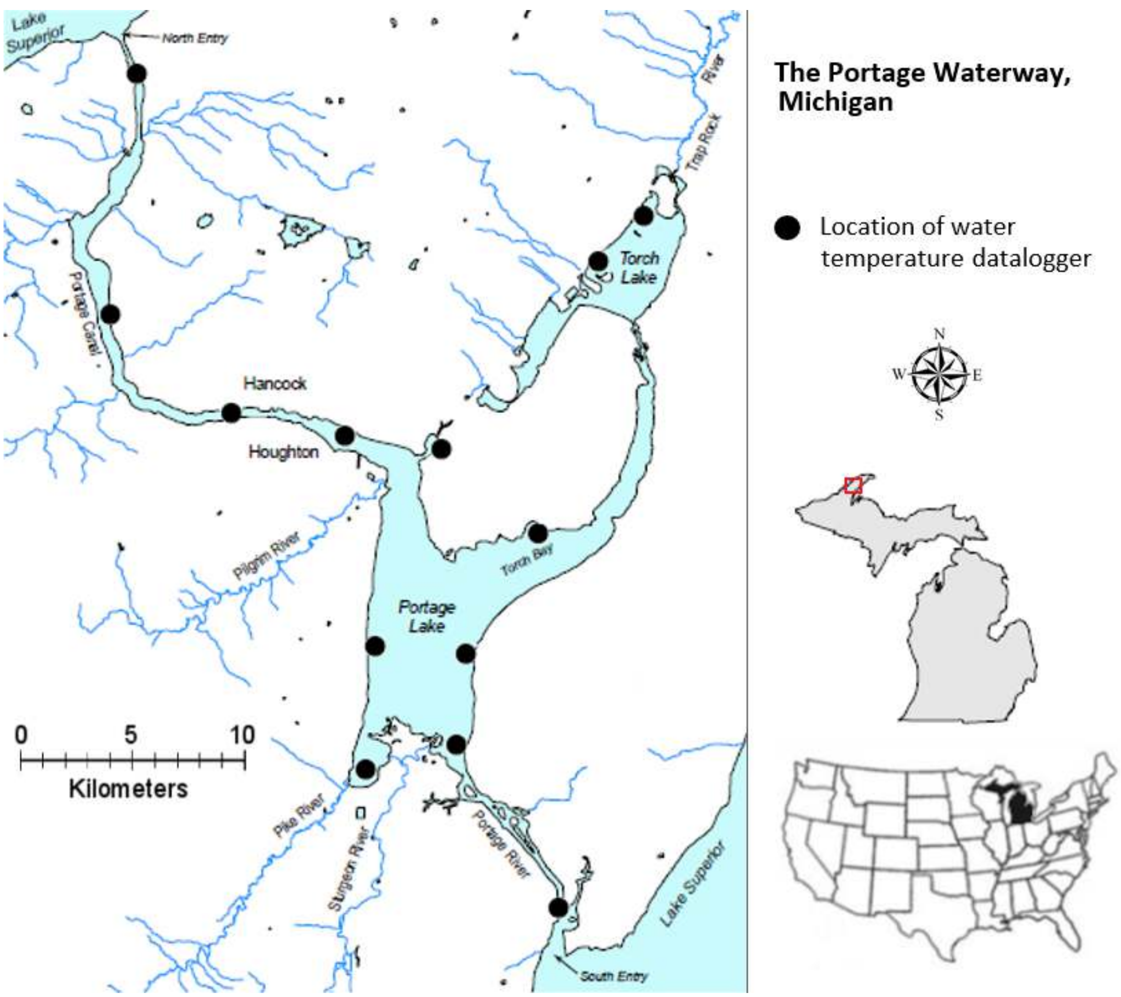

Figure 1. The Portage Waterway system, with dots representing temperature datalogger locations (Image modified from Hanchin 2016).

The waterway is vast and diverse and supports a robust fish community, despite being subjected to a wide range of human-caused disturbances such as shoreline development, dredging and channelization, and industrial contamination (Hanchin 2016). The waterway is located outside the L'Anse Indian Reservation but is within the ancestral homeland of the KBIC. Thus, KBIC members reserve fishing rights to it through the 1842 Treaty with the Chippewa (Treaty with the Chippewa 1842). Walleye (*ogaawag*) are the primary fisheries management species for the KBIC at this site.

The annual Portage Lake walleye (*ogaawag*) harvest is a carefully overseen event. Each fisher is typically allowed to harvest five fish daily. Harvesting is limited to enrolled KBIC members who are required to be in possession of their Tribal identification card. Each fisher's catch is tracked by KBIC Natural Resources Department (KBIC-NRD) personnel stationed at harvest sites. KBIC leadership sets guidelines for the annual harvest in collaboration with the U.S. Fish and Wildlife Service (USFWS), GLIFWC, and Michigan Department of Natural Resources (MDNR). The MDNR plays and important role in this partnership by stocking over one million walleye (*ogaawag*) fry and fingerlings annually. A Total Allowable Catch (TAC) concept is utilized on the waterway, and KBIC is allowed a harvest quota of 2000 adult walleye (*ogaawag*) on an annual basis. This TAC quota has never been reached. A recorded harvest of 1450 walleye (*ogaawag*) occurred in 2010, and since then harvests have typically ranged from 300 to 1000, well short of the TAC. Clearly, KBIC could sustainably harvest many more walleye (*ogaawag*) from the waterway.

As part of the management strategy for Portage Waterway, there is a declaration of spearing season commencement, and closure, by the KBIC President on an annual basis. The harvest season occurs shortly after ice melt as water temperature warms in the nearshore. This is when walleye (*ogaawag*) move into shallow waters for spawning and are therefore susceptible to spearing. Spawning behaviors begin when water reaches 34°F and peaks as temperature increases to 42-44°F (Rawson 1956; Scott and Crossman 1973; Auer 1982; Becker 1983). As temperature continues warming and approaches 50°F, spawning diminishes and walleye (*ogaawag*) move out to deeper waters. The spear-harvest season ends at this time.

Based on annual harvests falling well below sustainable levels, we hypothesized that the designated timing of the harvest season may not accurately correlate with the peak abundance of walleye (*ogaawag*) in key harvest locations. Tribal management traditionally declares uniform open and close dates for harvesting across the entire Portage Waterway based on singular, daily temperature readings in the main waterway without accounting for system-wide temperature variations (and the corresponding behaviors of walleye, *ogaawag*). The objectives of this research were to 1) understand the values and concerns of KBIC Tribal members on Anishnaabe walleye (*ogaawag*) spear-harvesting, 2) examine detailed water temperature patterns during the spring 2018 harvest to seek insight on how harvests may be optimized, and 3) integrate *Anishinaabe gikendaasowin* or traditional knowledge with science and education in the community.

In 2015 the KBIC-NRD began collaborating with the Keweenaw Bay Ojibwa Community College (KBOCC) Environmental Science Department to better understand relationships between local water temperature trends and populations of culturally-significant fish species. We began by examining on-reservation streams that provide critical habitat for the brook trout, *Salvelinus fontinalis*, or in Anishnaabe *Mookijiwanibi-namegos*. In 2016 efforts expanded to include the Portage Waterway at areas of KBIC member spear-harvesting. This ongoing collaboration combines resources of both KBIC-NRD and KBOCC, including fisheries biologists, college faculty, and numerous student assistants who gain hands-on training and opportunities for independent research. The goal of these ongoing efforts is ultimately to inform KBIC leadership of potential revisions to its fisheries management in light of potential environmental changes and the substantial resources that KBIC invests in its fisheries. The KBIC-NRD actively assesses Portage Waterway walleye (*ogaawag*) populations through regular sampling, and documents in great detail the walleye (*ogaawag*) harvested by Tribal members during the annual spear season.

Methods

Tribal Approved Research

This research was designed and informed by KBIC. It is reflective of KBIC priorities, desires, and values, and its research approaches, results, and applications are intended to support Indigenous sovereignty and promote Indigenous nation-building. It is true that research with Indigenous communities is fraught with historical abuses and ongoing inequitable power dynamics (Geniusz 2009; Smith 2013; Gagnon et al. 2017). However, this study is rooted in a long-term research engagement between established partners with the goal of strengthening partnerships for community benefit. Because we have conducted respectful and equitable research in partnership previously, and have done so relying on community engagement, we employed best practices in community engagement and fostering partnership with the KBIC. Ultimately, the KBIC oversees and approves research conducted on KBIC. Therefore, all proposals and research protocols used in this study were approved by the KBIC Tribal Council and the KBOCC Institutional Review Board.

Survey

An online survey was administered for two weeks in February 2018, using Survey Monkey, to gain preliminary insight on KBIC's perspectives of the annual walleye (*ogaawag*) spear-harvest. Participants were recruited through various community social media outlets, including the KBOCC and KBIC Facebook pages. The inclusion criteria were adults of age of 18 or older and an enrolled member of KBIC. As with much research based on self-reporting, however, we did not include measures to ensure that participants met these criteria. Anonymity was protected by recording only IP addresses of participants. The survey instrument contained 27 questions covering topics of walleye (*ogaawag*) spear-harvest participation, views of KBIC management of walleye (*ogaawag*) fishery, importance of the walleye (*ogaawag*) spear-harvest tradition, and other related concerns (Appendix 1). Aside from demographic questions, most items in the survey instrument were structured using 4- or 5-point Likert scales. Questions were developed collaboratively by KBOCC researchers, KBIC member student assistants, and KBIC-NRD personnel. All protocols, including survey questions, were reviewed and approved by the KBOCC Institutional Review Board that is majority-composed of enrolled KBIC members. Participant were informed of the objectives of our research. Details of our project were clearly described, including our intent to share summary findings in a student Capstone project, with KBIC leadership, and across the broader scientific community through media such as conferences and publications. Participants had the choice of clicking to indicate their agreement and continue to the survey, or clicking to exit the survey. Participants were not compensated for completing the survey.

Water Temperature

In late April 2018, 13 temperature dataloggers (Onset HOBO Pro V2) were deployed across 13 target locations in nearshore areas of the Portage Waterway to measure the water temperature in degrees Fahrenheit (Figure 1). As soon as ice-out occurred, dataloggers were installed at sites, preceding the spear-harvest season by five days (Figure 1). The 13 target locations were selected for study based on known or suspected walleye (*ogaawag*) spawning activity. We hypothesized many of these sites to exhibit early spring warming patterns compared to the larger open-water areas of the waterway. The deployment was led by KBIC-NRD fisheries personnel assisted by KBOCC student interns. Dataloggers were attached to weights and secured to the substrate at GPS-recorded locations at a depth of approximately one meter, corresponding to walleye (*ogaawag*) spawning behaviors and suitable depths for spearing. Temperatures were recorded every two hours from May 1, 2018 to May 19, 2018. This period corresponds to five days before the harvest season, eight days of the harvest season, and five days after the season closed.

After retrieval, dataloggers were returned to the KBOCC science lab for data upload and analysis. Dataloggers were removed from their protective housing and linked to a computer using proprietary HOBO hardware and software. Outliers removed included temperature readings recorded between the time dataloggers were activated in the lab and when they were deployed in the water. Analysis occurred after individual data files were converted from the HOBO software to spreadsheet format using Windows Excel.

Comprehensive harvest data were collected nightly at harvest sites following established annual protocols approved by KBIC leadership. KBIC-NRD personnel, assisted by technicians and KBOCC student interns, recorded the number of fish harvested as well as the size, weight, and sex of each. As in all annual harvests, findings were integrated into an annual report prepared for KBIC leadership and agency partners and were shared with us as part of this collaboration.

Survey Results

The survey recruitment yielded 53 participants over a two-week period in February 2018. Some respondents did not answer all survey questions; consequently, the details that follow reflect responses ranging from 49 to 53 depending on the question. Results provide valuable insight on the importance of walleye (*ogaawag*) spear-fishing to KBIC. For instance, 33 respondents (63%) stated that they regularly participate in the Portage Waterway walleye (*ogaawag*) spear-harvest, with a plurality stating that they fish five or more nights per season. Forty-six (92%) agreed that walleye (*ogaawag*) spear-fishing in the waterway is important to them personally, while 49 (98%) agreed that it is important to the KBIC in general. Forty respondents (82%) stated that they would sign up for a free walleye (*ogaawag*) spear-fishing mentorship program if one was offered. Table 1 summarizes the reasons for participation in the walleye (*ogaawag*) spear-harvest.

The survey contained two questions related to sovereignty and treaty rights. When asked about the importance of the KBIC managing its own walleye (*ogaawag*) fishery at the Portage Waterway, all 50 respondents agreed that it is important (86% strongly agreed; 14% somewhat agreed). Similarly, all but two respondents (96%) agreed that KBIC-NRD manages the fishery effectively.

Respondents expressed many concerns about the walleye (*ogaawag*) spear-fishing tradition in the waterway. Forty-three (86%) agreed that they are concerned about the safety of eating walleye (*ogaawag*) due to mercury or other contaminants. Most respondents also agreed that their harvests have already been impacted by other environmental stressors. For instance (after removing responses of "I don't know"), 37 of 38 (97%) believe their walleye (*ogaawag*) harvests have been impacted by climate change, 36 of 37 (97%) by aquatic invasive species, and 39 of 41 (95%) by lakeshore urban development. As for future scenarios, 48 of 50 (96%) agreed that they are concerned about the potential for uncharacteristic conditions involving warming water, intense weather events, and changes to ice patterns.

As has been documented in recent decades (e.g., the "walleye war"), confrontations with non-Native residents over Tribal fishing rights appear to remain an issue in the area (Nesper 2002). Thirteen of 50 respondents (26%) agreed that their treaty-protected right to spear walleye (*ogaawag*) is respected by the surrounding non-Native community. Only eight of 50 respondents (16%) agreed that they feel safe from discrimination when spearing walleye (*ogaawag*) at the Portage Waterway. In an optional question for write-in

Table 1. Top five reasons for walleye (*ogaawag*) spear-fishing as reported by KBIC Tribal members. Respondents were allowed to select multiple answers.

Reason	Number of respondents	Percent of respondents
Exercising treaty rights	29	56
Sustenance/food source	27	52
Quality time with family	26	50
Cultural tradition	24	46
Connecting with community	12	23

comments, some respondents reported instances of verbal abuse and threats. Others described examples of non-Native lakeshore property-owners purposely startling walleye (*ogaawag*) fish by throwing rocks or shining excessive light at the water. Similar accounts were reported to KBIC-NRD personnel at fishing sites throughout the duration of the harvest season. These accounts were logged for use in official documentation submitted in a final harvest report to KBIC leadership.

Water Temperature Results

Each datalogger recorded 216 temperature readings during the deployment period. As hypothesized, different parts of the waterway exhibited different warming patterns. We found the nearshore waters of Pike Bay and Dollar Bay to have warmed the fastest of all study sites, exceeding optimal walleye (*ogaawag*) spawning temperatures before the harvest commenced (Figure 2). The rapid warming at these locations was likely a result of relatively shallow depth (4-5 m) and because they are fed by runoff from significant nearby streams. Conversely, the main Portage Lake contains the deepest water (16 m) and greatest surface area of the system and was the slowest to warm. It was the only part of the entire waterway to be mostly near ideal spawning temperatures throughout the harvest season. After the closure of the harvest on May 14, 2018, based on temperatures in the main Portage Lake, the warming pattern in all study sites appeared to stabilize during the five days of additional datalogger deployment (Figure 2).

The comparison of Pike and Dollar Bays to the main Portage Lake shown in Figure 2 is particularly useful to KBIC leadership, based on the popularity of walleye (*ogaawag*) spearing in the bays as determined by harvest data. Temperature data from the six loggers across these sites were grouped (two bay loggers and four Portage loggers), and an unpaired t-test confirmed that the differences in daily mean temperatures between the groups were statistically significant on all days of the harvest season. Data collected from the remaining seven loggers throughout the waterway showed that other sites warmed at rates between those of Pike and Dollar Bays and the main Portage Lake. Findings from these sites are incorporated in our management recommendation, illustrated in Figure 3.

The annual harvest report prepared for KBIC leadership and natural resource partners revealed that the 2018 walleye (*ogaawag*) harvest for the waterway was far below the TAC of 2000 fish. The total catch was 331 fish, representing 16.5% of what KBIC-NRD biologists established as a sustainable harvest. The harvest was impacted by a shorter than usual walleye (*ogaawag*) spearing season due to persistent ice coverage in many parts of the waterway, followed by rapid warming that resulted in turbid runoff from streams impairing visibility of walleye (*ogaawag*) in some harvest locations (as anecdotally reported on-site by KBIC fishers). These details were noted in daily records of KBIC-NRD fisheries personnel who were present at the waterway throughout the harvest.

Discussion

Respondents of our community survey clearly demonstrated that treaty fishing rights in the Portage Waterway and the annual walleye (*ogaawag*) spear-fishing tradition are highly valued. Previous interview-based research in the KBIC revealed the same conclusions but questions did not focus specifically on a singular water body or fish species (Kozich 2016, 2018). It is noteworthy that 37% of survey respondents did not report personally participating in walleye (*ogaawag*) spear-fishing, yet nearly all respondents agreed that the tradition is personally important to them. This finding could perhaps be explained by the common (and traditional) practice of harvest-sharing across the community, as well as respondents' satisfaction in knowing that important cultural traditions continue. Clarity on this question would enrich follow-up studies.

Those who do participate in walleye (*ogaawag*) spear-fishing appear to do so enthusiastically, with the majority of those participating stating that they typically fish five nights or more per season (the 2018 season lasted eight days). Furthermore, the high interest in a community walleye (*ogaawag*) spear-fishing mentorship program could be an important finding for KBIC leaders striving to develop community programs intended to restore traditional Anishinaabe culture,

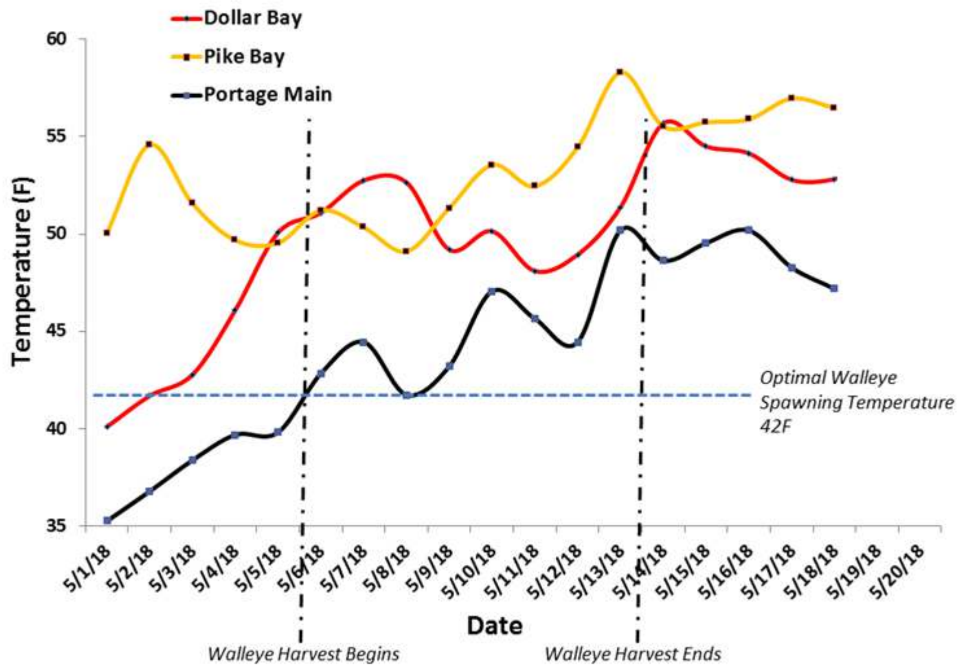

Figure 2. Comparison of water temperatures at 1 m depth in Pike Bay, Dollar Bay, and the main Portage Lake, Michigan.

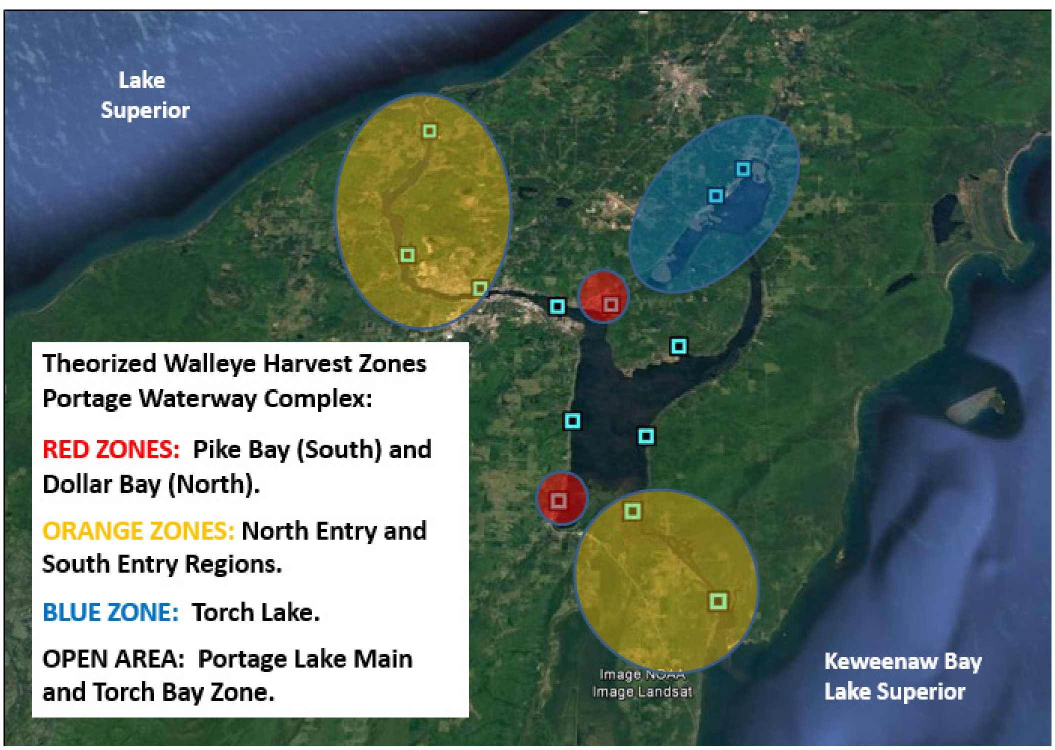

Figure 3. Recommended zoned management of the Portage Waterway system for a potentially increased spring spear-harvest season. Red zones reached optimal temperatures fastest and should be opened for spear-fishing first. Yellow zones were the next to reach optimal spawning temperature and should be opened second. The Blue zone (Torch Lake) would be opened next, ultimately followed by the Main Portage Lake and Torch Bay.

following generations of assimilation and lost knowledge. Recent community programs have successfully re-introduced KBIC members to traditional gardening, maple sugar harvesting, and wild ricing. The sharing of traditional ecological knowledge can have wide-ranging positive outcomes, not only for community members but also for natural systems (Finn et al. 2017; Deloria et al. 2018; Seltenrich 2018). In this instance, participants would not simply learn how to fish but could also develop respectful and reciprocal relationships with Mother Earth, in keeping with long-standing cultural values (Kimmerer 2015; Whyte 2017). Traditional ecological knowledge is already integrated in the biological management of the Portage Waterway, but a mentorship program led by active spear-fishers could appeal to a new generation of participants who do not have to feel ashamed of their culture in the ways that their recent ancestors did (Berkes 2004, 2012; Menzies and Butler 2014; Whyte 2017, 2018).

Unfortunately, KBIC fishers have long been subjected to harassment or intimidation (or worse) from non-Native residents (Nesper 2002), and similar incidents were again documented in the 2018 harvest report. Details of treaty fishing rights have historically been misunderstood by many non-Natives in the area. Examples of typical behaviors, as included in the 2018 harvest report, include the hurling of objects at walleye (*ogaawag*) spear-fishers from shore, distraction by the shining of bright lights, accusations of depleted walleye (*ogaawag*) populations, and the questioning about why KBIC members are not required to purchase state-issued fishing licenses. These intimidation behaviors likely explain why only 26% of survey respondents agreed that their treaty-protected rights to spear walleye (*ogaawag*) are respected by the surrounding community, and only 16% feel safe from discrimination when walleye (*ogaawag*) spear-fishing at the Portage Waterway.

Survey respondents expressed many concerns about possible negative impacts to the Portage Waterway walleye (*ogaawag*) fishery. Several KBIC departments and partners, including GLIFWC, are dutiful in their efforts to increase community awareness of local environmental issues such as aquatic invasive species and mercury exposure from fish consumption. Survey respondents appear to be quite aware of these and other similar threats, as noted previously (Kozich 2016). Researchers in the community are also aware, however, that potential negative impacts from harmful environmental trends can extend to the viability of treaty and trust resources on which the community depends (Gagnon et al. 2013; Nankervis and Hindelang 2014; TAM Team 2019). Ongoing community insight, revealed through interviews, surveys, and other media, is an essential component of community governance, identity, and resiliency.

Bountiful spring walleye (*ogaawag*) harvests could potentially reinvigorate cultural traditions and alleviate concerns about the well-being of the Portage Waterway fishery, but KBIC walleye (*ogaawag*) harvest quotas have never been approached. Only 331 walleye (*ogaawag*) were harvested during the 2018 spear season, representing 16.5% of the waterway's quota. While this total reflects a decrease from the 2017 harvest, it is not beyond recent norms. Walleye (*ogaawag*) are an important source of sustenance for community members, and the harvest tradition is an important exercise of off-reservation fishing rights guaranteed by the 1842 Treaty with the Chippewa (GLIFWC 2014; Gagnon 2016; Kozich 2016, 2018), yet the fishery resource continues to be under-utilized.

Based on findings from our water temperature data from across the waterway in May 2018 across 13 sites, we believe walleye (*ogaawag*) harvests could be maximized through a revised management plan. We believe our mixed-methods research contained a key link in this regard – survey respondents cited sustenance as an important reason for their participation in the annual spear-harvest, yet the TAC has never been reached. In other words, participants like to eat walleye (*ogaawag*) and there are many more that can sustainably be harvested from the waterway.

We found substantial differences in spring warming patterns across different zones of the waterway where walleye (*ogaawag*) spear-fishing occurs. Shallower bays and inlets warmed much more rapidly than the larger, open zones of the system. While this is not a surprise, the extent of the diverse temperature trends was not fully understood, previously. Rapid warming resulted in popular spear-fishing locations being too warm for walleye (*ogaawag*) spawning before the spearing season opened. Harvests could likely be increased by opening the season earlier in these sites, instead of having the same opening date for the entire system.

Our pending best-management recommendation is illustrated in Figure 3. Based on our 2018 findings, the red zones in the image represent the fastest-warming areas within the waterway, and the locations to be opened first for harvesting. These embayments were shown to exceed optimal temperature for walleye (*ogaawag*) spawning before the harvest opened in 2018 (see Figure 2). In other words, the majority of walleye (*ogaawag*) had likely departed these sites for deeper waters before anyone arrived attempting to catch them. The yellow zones in Figure 3, North Entry and South Entry of the waterway, were the next to reach optimal spawning temperature and would ideally be opened secondly for harvest. These zones would then be followed by the blue zone (Torch Lake), and ultimately followed by the Main Portage Lake and Torch Bay. Implementing this type of zoned management strategy would require additional day-to-day monitoring of warming trends for maximum effectiveness regarding the timing of the season commencement. However, doing so could potentially result in a maximized walleye (*ogaawag*) harvest while keeping within sustainable limits.

We speculate that the likelihood of increased walleye (*ogaawag*) harvests from spear-fishing could lead to greater community engagement in a tradition that survey respondents identified as important. Respondents were clear in their agreement that walleye (*ogaawag*) are a key source of sustenance and that spear-fishing is a valued cultural and family tradition. For instance, the fastest-warming zones in our study (Dollar Bay and Pike Bay) have been identified as very popular spear-fishing sites for many community members. A better coordination of the harvest season timing with the presence of walleye (*ogaawag*) could not only provide more meals, but potentially introduce new participants to traditional fishing methods, locations, and values, assisted by scientific knowledge from management partners (i.e., KBIC-NRD and KBOCC). This outcome would speak to the concept of community *gikendaasowin* introduced earlier in this paper.

In service to the community and by incorporating Indigenous research methods, we achieved our objective of gaining preliminary insight on water temperature, harvest records, and community sentiment relevant to spring walleye (*ogaawag*) fishing in the Portage Waterway, Michigan. Despite the importance of walleye (*ogaawag*) fishing to the community, recent harvests are very low, relative to management limits. Water temperature data suggest a mismatch between harvest dates and walleye (*ogaawag*) fish spawning and migration, especially for the shallower water bodies that include the community's most popular harvest sites. We are prepared to offer recommendations to KBIC leaders for improving walleye (*ogaawag*) harvests in this valued fishery.

Our findings introduce many intriguing opportunities for potential expansion. Water temperature and walleye (*ogaawag*) harvest data were again collected in 2019, and will likewise be analyzed to see if similar trends occurred as in 2018. Ideas for future project expansion include increased emphasis on walleye (*ogaawag*) population studies, focusing on the spawning phase, as we continue learning about water temperature trends. If local spring weather patterns indicate the likelihood for long-term rapid warming trends (and correspondingly altered snowmelt rates), it could also contribute to better understanding of how runoff intensity and temperature influence the shallow embayments of the waterway. Lastly, semi-structured interviews with KBIC members could provide qualitative enrichment of key findings from our survey. We gained abundant conversational insight during our interactions with community members at fishing sites, but did not incorporate procedures suitable for their inclusion in this paper.

Conclusion

This case study represents an integration of *Anishinaabe gikendaasowin*, science and education, to explore water temperature trends in Lake Superior's Portage Waterway, Michigan, and to use those findings to inform the governance of KBIC fisheries. Our interdisciplinary research incorporates water temperature and fish harvest data as well as findings from a survey conducted among KBIC Tribal members who fish in the waterway. In further recognition of Indigenous research methods, we also participated in daily harvests, interacting with and documenting shared knowledge from community spear-fishers to learn about relationships between humans, water, and fish (Wilson 2001; Hart 2010). In this article we share the cultural significance of the important fishery and management recommendations that could result in a more productive yet sustainable harvest for community members. The research team is composed of Tribal College faculty, a Tribal fisheries biologist, and KBIC-member Tribal College students.

Our work speaks to many organizational missions, as a collaborative effort to combine multiple ways of knowing to enhance community well-being. Research is an iterative process that extends beyond the life of a study project. Indeed, the term "re-search" conveys Indigenous ways of searching, seeking, and gathering knowledge from an Indigenous perspective. In *Kaandossiwin: How We Come to Know* (2012), Anishinaabe scholar Kathleen Absolon describes re-search as "journeys of learning, being, and doing," in which the researcher, inquiry, and approach undergo transformation throughout, and as a result of, the journey of searching. Thus, research is dependent on the positions of the partners engaged in the process. It is place-based and people-based inquiry, and the discovery process is expected to be as transformative as the resultant set of (re)solutions. In light of community values and anticipated environmental changes, our discovery process will continue.

Appendix 1

Questions included in the 2018 community survey, "Exploring perspectives on walleye (*ogaawag*) spear-fishing in the Keweenaw Bay Indian Community." Questions 6-17 and 26 used a 5-point Likert scale, ranging from "strongly agree" to "strongly disagree."

1. What is your age?
2. Are you an enrolled member of the KBIC?
3. What is your gender?
4. Have you ever participated in spring walleye (*ogaawag*) spear-fishing?
5. Please select the reasons you participate in walleye (*ogaawag*) spear-fishing (check all that apply).
6. It is important for the KBIC to manage its own walleye (*ogaawag*) fishery at the Portage Waterway.
7. The KBIC effectively manages the Portage Waterway walleye (*ogaawag*) fishery.
8. I am concerned about the safety of eating walleye (*ogaawag*) from the Portage Waterway.
9. I am concerned about environmental changes that could impact walleye (*ogaawag*) habitat in the Portage Waterway.
10. Spear-fishing in the Portage Waterway is important to me.
11. Spear-fishing in the Portage Waterway is important to the Tribal community.
12. I believe my spear-harvest has been affected by climate change.
13. I believe my spear-harvest has been affected by aquatic invasive species.
14. I believe my spear-harvest has been affected by pollution.
15. I believe my spear-harvest has been affected by urban development.
16. I believe my treaty-protected right to spear walleye (*ogaawag*) is respected by the surrounding community.
17. I believe I am safe from discrimination when I spear walleye (*ogaawag*) at the Portage Waterway.
18. What does walleye (*ogaawag*) spear-fishing mean to you?
19. How many children do you have?
20. In an average spring walleye (*ogaawag*) spear-harvesting season, how many nights do you participate in the harvest?
21. In an average spring walleye (*ogaawag*) spear-harvesting season, how many nights do your children participate in the harvest?
22. At what age did you learn how to spear-fish for spring walleye?

23. Who taught you how to spear walleye (*ogaawag*)? (Check all that apply)
24. Who taught your children to spear walleye (*ogaawag*)? (Check all that apply)
25. If your children haven't participated in spear-fishing, what has kept them from participating? (Check all that apply)
26. If there was a free mentorship program to teach myself and/or my children how to spear-harvest, I would sign up.
27. Is there anything else you would like to share?

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Sophia Michels is a 2020 graduate of the Environmental Science program at Keweenaw Bay Ojibwa Community College. Her contributions to this work reflect the Capstone research project she successfully defended for her graduation. She also delivered presentations of this work at three national conferences, winning a first-place award among student presenters in March 2019.

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We are closely monitoring the situation related to COVID-19 alongside government and health agencies. We are working with the Graduate Hotel to potentially postpone the conference but new dates have not been determined. We will stay abreast of the evolving situation and ultimately act in the most effective way to safeguard our employees, partners and attendees from potential health threats. Registration links will be sent out once dates have been agreed upon. We hope we're able to see all of you soon.

#ucowr2020

For more info, visit www.ucowr.org.
General questions about the conference can be directed to Karl Williard (williard@siu.edu), Executive Director of UCOWR.

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