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Emerging Voices of Tribal Perspectives in Water Resources

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Journal of Contemporary Water Research & Education

Issue No. 163 **April 2018**

Emerging Voices of Tribal Perspectives in Water Resources

Emerging Voices of Tribal Perspectives in Water Resources
Karletta Chief.....1

Native Water Protection Flows Through Self- Determination: Understanding Tribal Water Quality Standards and "Treatment as a State"
Sibyl Diver.....6

Disparities in Water Quality in Indian Country
Otakuye Conroy-Ben and Rain Richard.....31

Tribal Economies: Water Settlements, Agriculture, and Gaming in the Western U.S.
Suhina Deol and Bonnie Colby.....45

Assessing Tribal College Priorities for Enhancing Climate Adaptation on Reservation Lands
Helen M. Fillmore, Loretta Singletary, and John Phillips.....64

Climate Change in the Lumbee River Watershed and Potential Impacts on the Lumbee Tribe of North Carolina
Ryan E. Emanuel.....79

Perspectives on Water Resources among Anishinaabe and Non-Native Residents of the Great Lakes Region
Andrew T. Kozich, Kathleen E. Halvorsen, and Alex S. Mayer.....94

Navajo Nation, USA, Precipitation Variability from 2002 to 2015
Crystal L. Tulley-Cordova, Courtenay Strong, Irving P. Brady, Jerome Bekis, and Gabriel J. Bowen.....109

Navajo Nation Snowpack Variability from 1985-2014 and Implications for Water Resources Management
Lani M. Tsinnajinnie, David S. Gutzler, and Jason John.....124

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Journal of Contemporary Water Research & Education
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Emerging Voices of Tribal Perspectives in Water Resources

Karletta Chief

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Tribal perspectives in water resources and education are often overlooked. Only recently, the field of hydrologic sciences began to include people in conducting science (Sivapalan et al. 2012) and to value indigenous perspectives with western science (Huntington 2002; Redsteer et al. 2012). The April 2018 issue of *Journal of Contemporary Water Research & Education* (JCWRE) explores emerging voices in tribal communities related to water resources quality and quantity and impacts to tribal water resources such as climate change and water use. This special issue begins with three foundational papers, providing a baseline understanding on water quality regulation, water quality disparities, and tribal economies as they relate to water settlements. The special issue features articles focusing on various water challenges facing tribes and the role of tribal colleges in addressing these challenges. There are less than 0.3% of Native American graduate students and post-doctorates in Science and Engineering and only a handful in hydrologic sciences and related sciences (NCSES 2016). While tribal lands are rich in natural resources and have significant water challenges (Cozetto et al. 2007; Smith and Frehner 2010), it is very unique that 67% of the lead authors are Native American including three Native American faculty, three Native American graduate students, and one Tribal College and University (TCU) Faculty. A deep discussion on water challenges facing tribes and Native American scientists working on these challenges are emerging voices of tribal perspectives in water resources.

This special April 2018 issue rose out of my initial discussions with conference organizers at the 2015 Universities Council on Water Resources Annual Conference in Henderson, NV, increasing the voice and presence of tribal perspectives in water resources. This led to an invitation to me to organize a special session at the 2017 conference in Fort Collins, CO, which I titled "Tribal Perspectives on Water Management Topics and Collaborative Engagement Approaches" (Chief et al. 2017). Two of the speakers from this session, O. Conroy-Ben and R.E. Emanuel, wrote papers based on their presentations that are published in this April 2018 issue. Through these collaborations, I partnered with an all Native American geoscience principal investigator team including O. Conroy-Ben (Arizona State University), R.E. Emanuel (North Carolina State University), R. Torres (University of South Carolina), and S. Pete (Salish Kootenai College). In the fall of 2017, we 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" to be held at a tribal college, Salish Kootenai College, in Pablo, MT in August 2018. The purpose of this symposium is 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. This JCWRE April 2018 issue on "Emerging Voices of Tribal Perspectives in Water Resources" is a building block towards these NSF ICER objectives.

There are 567 federally recognized tribes in the United States and 62 tribes who are state recognized; additionally, there are many tribes who are not state or federally recognized, but may be seeking federal recognition (Koenig 2007; Department of the Interior 2018). Tribes are diverse in their culture, language, land base, and government. Tribes are situated in urban and rural areas, in various geographic and ecological regions, and range from small to large in population (Cozetto et al. 2013). In stark contrast to the 99% of Americans who have access to clean water, 12% of Native Americans in the U.S. do not have access to clean water (Cozetto et al. 2013). On the Navajo Nation, 25-40% of households haul water. Hauling water creates increased susceptibility to waterborne diseases. In addition, tribes have 10% of the U.S. energy reserves and contribute billions of dollars to the national energy economy, but are only 1% of the U.S. population, making them vulnerable to impacts of mining on their people and environment (Smith and Frehner 2010). Furthermore, federally recognized tribes have a nation-to-nation relationship with the U.S. federal government and their sovereign status means tribes have federal reserved water rights, which are often not quantified due to legal and political challenges in defining water rights. Federally recognized tribes are also eligible to determine tribal water quality standards through the Clean Water Act (CWA) under Treatment as a State (TAS) provisions. Their uniqueness guides the way in which water and natural resources are managed and how they view the environment. Their similarities as sovereign nations provide similar legal rights, protections, and challenges.

The first article by Diver provides a foundation for understanding water quality regulation on tribal lands and explains the history and challenges facing tribes in environmental self-determination. Diver examines the way tribes exercise their tribal sovereignty and self-determination to develop their own tribal water quality standards and TAS programs under the CWA Amendments of 1987. Diver delves in deeper to examine the political and legal impacts of tribal water quality standards and begins to examine the environmental and social impacts. This article provides insight as to why so few tribes have tribal water quality standards – only 16% (54) of tribes, out of about 330 eligible tribes, have established TAS status to administer a Section 303 water quality standards program. Recent TAS revisions enable greater tribal water regulation authority over the entire tribal reservation despite landowner status. Working through the federal permitting process, tribes can use their own water quality standards to influence off-reservation water use. Diver asks if tribes can leverage the federal environmental regulatory framework while creating their own regulatory frameworks under tribal law.

A complementary article to Diver is written by Conroy-Ben and Richard who investigate the evident disparities in drinking water quality for tribal communities. These include maximum level contaminant level violations, reporting and monitoring, and public notice. Using public data from the Environmental Protection Agency's Enforcement and Compliance History Online (ECHO) for 2014-2017, violations were compared between tribal and non-tribal areas of the same state. Conroy-Ben and Richard found that tribal facilities had violation points six times the national average, and in certain states, these violations affected a larger percentage of tribal population than non-tribal populations. This article highlights the need to improve infrastructure and water quality regulation in tribal communities.

The third article by Deol and Colby focuses on tribal economies in the western United States and explores patterns in water rights, agriculture, gaming, and economies. The paper summarizes and compares critical information for selected tribal nations which have and have not quantified tribal water rights. Nine variables were examined to investigate patterns across tribal nations, including: 1) Value of Agricultural Products Sold, 2) Unemployment, 3) Income, 4) Education, 5) Population, 6) Proximity to Major City, 7) Casino, 8) Water Rights, and 9) Year. Southwestern tribes have the lowest revenue from agricultural products. Northwestern tribes have higher rates of water quantification followed by Southwestern tribes. Midwestern tribes have the highest casino operations. Deol and Colby find a significant difference between tribes with quantified water rights and tribes without water rights in terms of having higher agriculture revenue, higher

population, a closer proximity to larger cities, lower education, and lower income. Tribal nations in this study that operate casinos had lower rates of water quantification. Development of tribal economies involves diverse types of enterprises, understanding regional differences, and building upon the strengths of each sovereign nation. While settling tribal water rights can contribute to tribal economies, a deeper look at causal relationships between gaming, agriculture, water rights, and tribal economic indicators is warranted. This will require in-depth location-specific research.

Climate change will impact tribal communities and tribal waters in unique ways due to the deep connections between indigenous people and the environment, as well as the strong land-based values and subsistence activities practiced by many indigenous peoples (Cozetto et al. 2013). Tribal College and Universities (TCUs) are centers of higher learning in tribal communities and offer a platform on which climate change adaptation in tribal communities can be addressed through education, research, and outreach. The fourth article, Fillmore et al., surveyed TCUs in 2016 to assess the priorities of TCUs in climate adaptation teaching, research, and outreach. Survey results represent 68% of the TCUs including administrators, outreach educators, staff, faculty instructors, and students. The interviews were grouped according to United States Geological Survey (USGS) Hydrology Unit Code (HUC) and were also grouped based on similar climate and ecological units and aridity units based on precipitation. Top concerns include food-sovereignty programs and climate change impacts on tribal water resources. Although TCUs have great potential to promote and implement climate adaptation, lack of funding limits TCUs from fully exploring these opportunities. Literature gaps exist on topics of climate change impacts and adaptation on tribal lands, particularly when focusing on specific ways in which to enhance tribal capacity for adaptation. Fillmore et al. fill a literature gap, particularly with regards to climate change and TCUs, and provide direction on where TCUs can be supported to improve teaching, research, outreach, and professional development to forward climate adaptation on tribal lands.

Another major contribution to the knowledge base of tribal climate adaptation is the fifth paper by Emanuel. This article outlines climate change issues and impacts on the Lumbee Tribe of North Carolina. Currently, there is a significant literature gap on climate change impacts on tribes along the Atlantic Coastal Plain who are often considered to be in water rich environments. Like many Native American communities, climate change impacts extend into the traditional and cultural livelihoods of the Lumbee Tribe. Emanuel highlights the challenges experienced by a state recognized tribe, as opposed to the experiences of federally recognized tribes that are covered by preceding papers. For the Lumbee Tribe, climate change impacts to wetland and aquatic ecosystems also pose risks to cultural loss. As a state recognized tribe, many of the statutory protections, which Diver, and Deol and Colby discuss in this journal issue, are not applicable to the Lumbee Tribe. However, like many federally recognized tribes, cultural and traditional impacts are real risks for the Lumbee Tribe.

The sixth article by Kozich et al. complements Emanuel and focuses on Anishinaabe perspectives on water resources and conservation in the water-rich region of the Great Lakes. Interviews revealed multiple insights: water was important, water quality was of higher concern than water quality, and Native American perspectives were unique from non-Native perspectives. Similar to the importance of the cultural values of water that Diver and Emanuel discuss, Kozich et al. finds a reoccurring theme of cultural and spiritual values of Anishinaabe interviewees with water. The overall importance of water quality to the Anishinaabe people complements the papers by Diver, and Conroy-Ben and Richard.

The final two papers of this special issue by Tulley-Cordova et al. and Tsinnajinnie et al. focus on quantifying precipitation and snowpack variability on the Navajo Nation. These papers are unique because both papers involved close partnership with the Navajo Nation Department of Water Resources to leverage existing hydrologic data and collect additional samples to answer important research questions. Both papers involved large and comprehensive hydrologic data sets on the Navajo Nation where data had not be scientifically analyzed or interpreted. Tulley-Cordova et al. characterized hydroclimatic changes on the Navajo

Nation using data from 90 sites from 2002 to 2015 to identify regional precipitation patterns using quantitative cluster analysis. They correlated the cluster groups with climatic modes and variables to identify how regional precipitation relates to larger climatic patterns. Tsinnajinnie et al. characterized snowpack data for the period 1985-2014 using nine Navajo Nation snow survey stations and identified snowpack patterns, variability, and trends. This characterization provided a basis to evaluate the efficacy of snowpack data collection efforts to focus on important data points and reduce redundancy to save tribal managers' time and money. Given climate change impacts on water resources on tribal lands, the importance of monitoring and characterizing water resources is critical for the Navajo Nation. These two papers are excellent examples of partnerships with tribal water resources managers who are working to collect data, conduct research, and manage water resources for a tribe where 25-40% of households haul water (NDWR 2003; ITFAS 2008), but where tribal members are deeply connected to water and rely heavily on water for spiritual, cultural, and livelihood purposes.

In conclusion, this JCWRE April 2018 issue on emerging tribal voices in water resources brings together foundational papers with tribal college priorities and tribal case examples from the Great Lakes Region to the Atlantic Coast to the Southwest. The breadth and depth of this issue provides a foundational understanding of water quality governance, water quality disparities, and tribal economies with examples of socio-hydrological, climatic, and hydrologic research. Successful hydrologic research in tribal communities requires respectful engagement that involves an equal partnership with the tribe; oversight by the tribe; research plans that respect indigenous cultural contexts, histories of interactions with settler governments and researchers; and considers socio-economic and political context (Chief et al. 2016). Furthermore, when researchers are from the tribal communities, there is greater understanding of cultural context, a foundation where trust can be built, and commitment to give back to their communities. With a very small percentage of Native Americans in the sciences, much less in the hydrologic sciences, I am pleased that 67% of the lead authors are Native American, three are Native American professors, and three are Native American graduate students working in their tribal communities. This April 2018 issue is also pleased to highlight research priorities for Tribal Colleges and Universities, and to have one author who is a TCU professor, which demonstrates a move toward TCUs engaging in research activities that can be incorporated back into the education of tribal college students. There is still a lot of work needed to fill the literature gap of tribal voices in the hydrologic sciences; with more respectful partnerships with tribes and tribal researchers leading these efforts, this gap will begin to fill.

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science projects. Since 2011, Dr. Chief collaborated in securing $14.4M in grants and $6.8M of that total is directed towards extension programs. Since 2011, she had conducted 86 conference/scholarly presentations including 7 invited national talks and 4 internationally invited talks, and conducted over 114 community presentations. She may be contacted at: University of Arizona Department of Soil, Water and Environmental Science, PO Box 210038, Room 429, Tucson, AZ 85721; or via email at kchief@email.arizona.edu.

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Native Water Protection Flows Through Self-Determination: Understanding Tribal Water Quality Standards and "Treatment as a State"

Sibyl Diver

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Abstract: For Indigenous communities, protecting traditional lands and waters is of the utmost importance. In the U.S. context, scholars have documented an unfortunate neglect of water quality on tribal lands. Treatment as a State (TAS) provisions, adopted in the 1987 amendments to the Clean Water Act, and tribal Water Quality Standards (WQSs) programs are intended to address such problems. Importantly, tribal WQSs may be more stringent than neighboring state standards, and can be used to influence pollution levels coming from upstream, off-reservation users. Tribes can also develop WQSs that support unique tribal values, including ceremonial and cultural uses of native waters. Yet scholarly debates question whether tribal environmental self-determination strategies can fully succeed within dominant regulatory structures. Based on a synthesis of the published literature, this article examines tribal WQSs as a case of tribal environmental self-determination. The author discusses how U.S. tribes pursue WQSs under TAS, program outcomes, and why so few tribes have established WQSs to date. Because most scholarship was found within the legal literature, the author focuses on the legal and political outcomes that arise from tribal WQSs, and analyzes specific opportunities and constraints for program participants. The author also considers how some tribes use WQSs as a "third space" strategy—simultaneously working inside and outside of dominant government structures to advance tribal sovereignty (Bruyneel 2007). Additional research is needed to understand the diversity of tribal environmental self-determination strategies that occur through federal regulatory frameworks and under tribal law.

Keywords: *water governance, Indigenous environmental politics, Native American tribes, tribal sovereignty, U.S. water policy, Clean Water Act, cooperative federalism, collaborative management (co-management)*

"Mni waconi. Water is life. And life for indigenous peoples is about our right to control our lands and preserve our resources for future generations" (Curley 2016).

For Indigenous communities, protecting the waters on their traditional lands is of the utmost importance. Indigenous-led mobilizations around the Dakota Access Pipeline System (Curley 2016), the Salish Sea coastal region (Norman 2017), and the Gold King Mine Spill (Chief et al. 2016) all exemplify extraordinary efforts to address ongoing threats to native waters. Such Indigenous water protection initiatives are part of a broader cultural survival strategy, which includes working in a contemporary context to preserve and enhance the lands and waters that Indigenous communities continue to depend on (e.g., Marx et al. 1998; Suagee 1998; Diver 2016, 2017). While Indigenous water protection is partly driven by human health concerns and a desire for equal access to clean water (e.g., deLemos et al. 2009), for many communities, it is also part of deeply held Indigenous knowledge regarding the mutual responsibilities or reciprocal relations between Indigenous peoples and the waters that have long sustained them (Lake et al. 2010; McGregor 2014; Arsenault et al. 2018). Given their distinct regulatory authorities, close connections

to the land, and diverse cultures, tribes are well positioned to drive future innovation in water governance (Ranco and Suagee 2007; Warner 2015).

In the U.S. context, scholars and the media have documented an unfortunate neglect of water quality on tribal lands (e.g., EHN 2016; Teodoro et al. 2016; Conroy-Ben and Richard 2018). Although the U.S. federal government generally asserts regulatory authority over reservation environments, tribes have found that federal agencies are often unable or unwilling to provide the desired level of environmental protection due to lack of capacity and other challenges (Grant 2007; Sanders 2010). Recent research has demonstrated that regulatory enforcement is less rigorous for facilities discharging into waterways located on tribal lands, in comparison to non-tribal lands (Teodoro et al. 2016; Conroy-Ben and Richard 2018). In some cases, jurisdictional conflicts within and around reservations have contributed to the lack of enforcement by tribes, states, and the federal government (Rodgers 2004; Lefthand-Begay 2014; Anderson 2015). At the same time, access to safe water supply and/or waste disposal facilities is disproportionately low for many tribal communities (IHS n.d.).

These problems reflect a significant environmental justice issue for water quality: the environment and public health are less effectively protected on Indian reservations than elsewhere (Goldtooth 1995; Sanders 2010). Tribal community advocates have responded with a call for greater tribal environmental self-determination, in part, by developing enforceable environmental standards on tribal lands (Ranco and Suagee 2007; Sproat 2016). In international law, self-determination refers to the right of Indigenous peoples to "freely determine their political status and freely pursue their economic, social and cultural development" (United Nations 1976). Indigenous self-determination may also entail rejecting governance models rooted in European cultural values and reinstituting Indigenous governance traditions (Alfred 2005).

Tribal "Treatment as a State" (TAS) provisions, adopted in 1987 amendments to the U.S. Clean Water Act (CWA), are intended to address these problems. TAS provisions enable the federal government to delegate authority to eligible tribes for selected CWA programs, including Section 303 for Water Quality Standards (WQSs). Evolving out of federal policy on tribal self-determination, tribes meeting certain criteria can propose their own WQSs on tribal trust lands. Once approved by the U.S. Environmental Protection Agency (EPA), tribal WQSs are then implemented in coordination with the federal agency. Importantly, tribal standards may be more stringent than their neighbors' standards, can be driven by cultural or ceremonial uses, and can be used to influence pollution levels coming from upstream, off-reservation users (Grijalva 2006; Anderson 2015). Since 1987, a number of tribes have adopted WQSs under TAS to protect tribal waters across a wide diversity of contexts. These include industrial pollution sources discharging toxins in the Northeast, forestry operations adding sediment to salmon streams in the Pacific Northwest, large scale oil and gas development increasing risks of toxic spills in the Southwest, agricultural areas generating high levels of nutrients in Mountain States, mining operations discharging wastewater around the Great Lakes, and wastewater treatment plants affecting multiple reservations.[1]

There is a gap, however, between the vision and the reality of leveraging TAS provisions to increase tribal environmental self-determination. Out of the approximately 330 federally recognized tribes that meet TAS eligibility requirements,[2] there are 54 tribes that have received TAS status for administering a WQS program under Section 303. Only 44 of these have had their initial WQSs approved by the EPA—or less than 10% of eligible tribes (USEPA n.d.(a)) (see Figure 1).

1 For a current list of tribes with WQSs and additional case context see https://www.epa.gov/wqs-tech/epa-approvals-tribal-water-quality-standards-and-contacts, and https://www.epa.gov/wqs-tech/case-studies-video-and-publications-tribal-water-quality-standards.

2 To be eligible for TAS status under the CWA Section 518, tribes must be federally recognized and have a reservation, a term that is interpreted broadly by the EPA to include all tribal trust lands. (See the EPA's most recent discussion of this in its May 2016 revision to its CWA TAS regulations 81 CFR 30183, May 16, 2016). Because only one of Alaska's tribes has a formal reservation and other forms of trust land are uncommon in the state, most Alaska tribes are not eligible. Tribes that are unrecognized by the federal government are also not eligible.

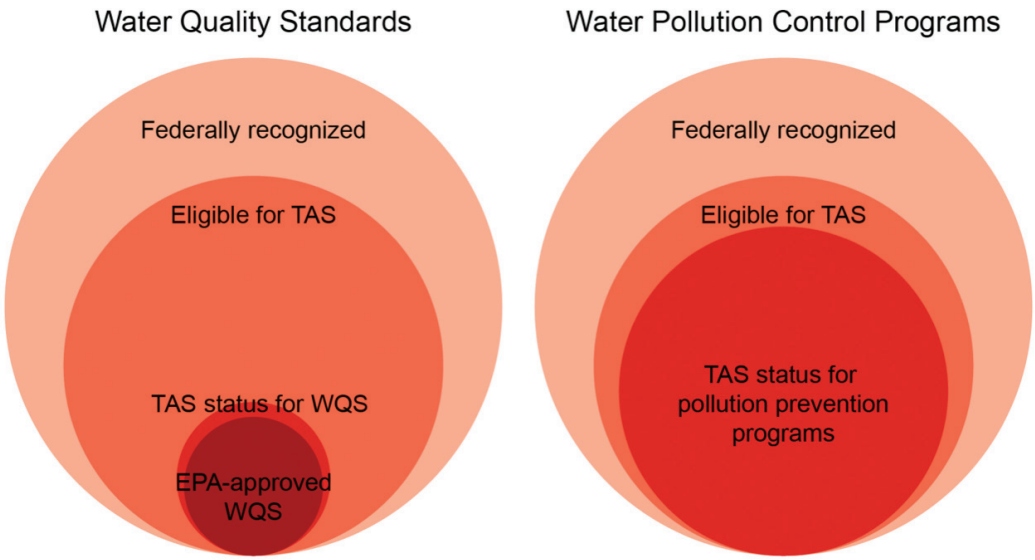

Figure 1. Proportion of eligible tribes gaining TAS status for Water Quality Standards (WQSs) Programs (Section 303) vs. tribes gaining TAS status for Water Pollution Control Programs (Section 106). Figure by Kelly Hopping.

This observation is not intended to overgeneralize, or suggest that TAS provisions are not helpful to tribes. For example, under Section 106, a different CWA program that provides federal grants for water pollution control programs, a much larger number of tribes have gained TAS status—about 75% of those eligible.[3] However, as a funding and monitoring program, Section 106 grants do not provide tribes with the same regulatory authority over native waters that they gain through Section 303 for WQSs. Nor do TAS applications for Section 106 funding programs require the same level of detail or scrutiny that are required for TAS approval of Section 303 standards.[4]

To better understand tribal environmental self-determination, this article synthesizes the published literature to discuss how U.S. tribes pursue tribal WQSs under TAS, program outcomes, and why so few tribes have established WQSs to date. The bulk of scholarship is in the legal literature, examining the environmental regulatory process, sources of tribal authority, and legal or political outcomes (e.g., Grijalva 2006; Anderson 2015), and there are few in-depth empirical studies evaluating the environmental and social impacts of tribal WQSs. Based on these existing studies, the author analyzes the legal and political outcomes that arise from tribal WQSs. To interpret these findings, the author turns to current scholarly debates questioning whether tribal environmental self-determination strategies can fully succeed within dominant regulatory structures. Key questions include, how and to what extent are federal environmental regulatory framework regulations helpful for tribes, and when do tribes need to create their own policies, laws, and regulations? Given that federal environmental regulations were initially constructed without the participation of tribal governments (Marx et al. 1998), the author considers how tribal WQSs under TAS can inform efforts to create new environmental governance institutions that authentically support tribal environmental self-determination.

Methods

For the literature review, the author conducted a search on Web of Science, Google Scholar, and HeinOnline for tribal water quality standards and Treatment as a State and selected relevant

3 For more information on tribal participation in Section 106 programs, see https://www.epa.gov/water-pollution-control-section-106-grants/tribal-grants-under-section-106-clean-water-act.

4 See the general requirements for TAS, which are set forth in CWA Section 518 and for the 106 program at 40 CFR 130.6(d) and 40 CFR 35.583.

Table 1. Selected historical events shaping Treatment as a State provisions, and tribal Water Quality Standards Programs.

1948 Federal Water Pollution Control Act (FWPCA) is passed.
1962 Rachel Carson's Silent Spring is published.
1964 Office of Economic Opportunity sets the precedent of directly funding tribal governments as part of their "War on Poverty" programs.
1970 Nixon signs the National Environmental Policy Act (NEPA) into law, the Clean Air Act is enacted by Congress, the first Earth Day is observed.
1970 U.S. Environmental Protection Agency is started.
1970 President Nixon issues a message to Congress emphasizing Indian self-determination by delegating federal program implementation responsibilities to interested tribes.
1972 FWPCA is amended, known as the Clean Water Act (CWA).
1973 FWPCA rule adds Indian facilities to the list of dischargers excluded from state regulation.
1974 The Boldt Decision, *U.S. v. Washington,* affirms treaty fishing rights, allocating 50% of fish returning to usual and accustomed areas to treaty tribes, inciting a violent backlash from non-tribal fishermen and states against tribes.
1974 EPA rule on prevention of significant deterioration (PSD) under the Clean Air Act enables "Indian Governing Bodies" to administer the PSD program on Indian reservations.
1975 Indian Self-Determination and Educational Assistance Act is passed by Congress.
1975 EPA Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) authorizes tribal programs for certifying commercial pesticide applicators on Indian reservations, enabling tribal programs to govern non-Indians on reservations.
1976 EPA approves the Northern Cheyenne's proposal to create a more protective status of their reservation's airshed in response to the planned expansion of a nearby coal-fired power plant (a "redesignation" under the PSD program).
1977 Clean Air Act amendments adopt the treatment of tribes as states, and the EPA PSD program.
1978 Congress amends FIFRA to codify the EPA 1975 FIFRA Rule, and authorizes tribes as being eligible for cooperative agreements and grants for pesticide management.
1978 Supreme Court case *Oliphant v. Suquamish Indian Tribe* limits tribal criminal jurisdiction over non-Indians within reservation borders.
1979 Council for Environmental Quality promulgates regulations implementing NEPA environmental analysis requirements for federal agencies to invite Indian tribes to participate in the scoping process.
1980 EPA Indian Policy is adopted as the agency's first cross-program Indian policy, becoming the first federal agency to establish an official Indian policy.
1981 Supreme Court case *United States v. Montana* limits tribal civil jurisdiction on reservations with exceptions that confirm the EPA's approach to tribal water quality issues.
1982 EPA rejects the State of Washington's request for RCRA interim hazardous waste responsibility throughout the State including Indian reservations.
1983 President Reagan issues his Indian Policy Statement supporting tribal self-government, and continuing the federal-tribal relationship.
1984 Acting on President Reagan's initiative, the EPA Indian Policy is signed by Administrator Ruckelshaus and includes implementation guidance.
1986 Congress adds treatment as a state (TAS) provisions to the Safe Drinking Water Act, Sec 1451.
1987 Congress adopts TAS provisions of the Clean Water Act, Section 518(e).

Table 1 Continued.

1989 Supreme Court case *Brendale v. Confederated Tribes and Bands of the Yakima Indian Nation* limits tribal civil regulatory authority over non-Indian fee lands.
1990 Congress passes TAS provisions of the Clean Air Act, Section 301(d).
1991 EPA issues its final rule for reservation water quality standards.
1994 EPA establishes its American Indian Environmental Office.
1994 President Clinton directs federal agencies to ensure meaningful consultations with tribes on regulatory policies and actions significantly affecting them.
1996 *City of Albuquerque v. Browner* is the first case challenging WQSs set by a tribe under TAS provisions, and confirms the ability of tribes to set more stringent standards than federal minimums.
1998 In *Montana v. EPA* 1998, the State of Montana challenged the EPA's grant of TAS status to the Confederated Salish and Kootenai Tribes. The court upheld the EPA's approval of the confederated tribes' TAS status based on substantial threats to tribal health and welfare from non-member activities (*Montana* test).
2000 When the Penobscot and Passamaquoddy Tribes request stricter permits for pulp mills impacting tribal waters, state opponents file a Freedom of Information Act (FOIA) lawsuit to gain all documentation related to tribal authority over water resources and other internal matters.
2001 In *Wisconsin v. EPA,* the court holds that EPA's grant of TAS status was consistent with CWA purposes, despite disputes over submerged lands within the Mole Lake Reservation.
2001 In *Nevada v. Hicks,* the U.S. Supreme Court further limits tribal regulation on reservation lands.
2004 The Pawnee Nation of Oklahoma gains TAS status and WQS approval, and the state responds by filing a lawsuit to challenge the EPA's decision. In addition, a Republican Senator adds a legislative amendment buried within a transportation bill, which has limited tribal sovereignty over their reservation environment.
2014 EPA's 1984 Indian Policy is reaffirmed by EPA Administrator Gina McCarthy.
2016 The EPA reinterprets TAS provisions enabling tribal WQSs, section 518(e)(2) of the CWA, to be based on Congressionally delegated authority to tribes for the purposes of the CWA.

articles. The author pursued additional citations from within these articles, as well as publications from established scholars in this field. The review included selected overview materials on TAS provisions and tribal WQSs available at Stanford University libraries.

Based on existing scholarship in legal journals, this synthesis provides insight into issues around tribal jurisdiction, historical origins, and self-determination arising from TAS provisions for tribal WQSs. These findings illuminate the legal and political outcomes for tribes that have developed EPA-approved WQSs, as an example of tribal environmental self-determination. Given the lack of published non-legal case studies, the author has included several EPA cases and white papers in the synthesis as a starting point for discussing the environmental and social outcomes of tribal WQSs.

Historical and Legal Origins: Treatment as a State

Complexities of Tribal Sovereignty

The following section outlines the historical and legal context for the EPA's TAS programs and tribal WQSs, which were first developed in the early 1970s (see Table 1). In U.S. federal policy, Native American tribes are widely recognized as having authority over their members and territories (Grijalva 2006). As legal scholar Charles Wilkinson explains, "Tribal sovereignty predated the formation of the United States and continued after it" (Wilkinson 1987, p. 103). This principle was affirmed in Chief Justice Marshall's Supreme Court decision in *Worcester v. Georgia* (1832), which rejected state authority over tribal nations based on the "preexisting power of the

nation to govern itself" (Anderson 2015, p. 199). As Wilkins and Lomawaima (2001, p. 5) write, tribal sovereignty is "inherent, pre- or extra constitutional, and is explicitly recognized in the constitution." Definitions of tribal sovereignty also reflect international law, where sovereignty "emanates from the unique identity and culture of peoples and is therefore an inherent and inalienable right of peoples to the qualities customarily associated with nations" (Barker 2005, p. 3). The political status of U.S. tribes positions them as a third sovereign (i.e., tribes, states, and the federal government). It is because of their unique political status that "Indian tribes enjoy a special relationship with the federal government," a status that is separate from and higher than the states (Kickingbird et al. 1983, p. 5).

At the same time, the U.S. government continues to assume jurisdictional authority over Indian territory, and under U.S. law, tribes are often viewed as "domestic dependent nations." A guiding principle for tribal land management is the "trust relationship" between U.S. tribes and the federal government, defined as "the unique and moral duty of the United States to assist Indians in the protection of their property and rights" (Kickingbird et al. 1983, p. 6). As Wilkins and Lomawaima (2001, p. 13) explain, "trust is the notion of federal responsibility to protect or enhance tribal assets." This means that the federal government holds a fiduciary obligation to protect tribal trust lands, or lands that are held by the federal government "in trust" for Native American tribes or tribal members. A key source of federal authority is the doctrine of Congressional plenary power, by which Congress assumes the ultimate "power to change and redefine the scope of the relationship" (Kickingbird et al. 1983, p. 6).

The legal doctrines that support U.S. federal Indian policy are not unproblematic. Different audiences have interpreted these doctrines in vastly different ways at different times. For example, the trust relationship is unfortunately associated with a history of paternalistic federal Indian programs (Grijalva 2006). U.S. federal Indian policy has been highly inconsistent, as evidenced by wide pendulum swings of policy orientations, e.g., from treaty-making to the removal of tribes onto reservations, or from assimilation to self-determination (Deloria and Lytle 1984). In addition, scholars strongly refute "plenary power" concepts suggesting that Congress could hold unlimited or absolute power over tribes, as being irreconcilable with tribal sovereignty, inconsistent with the U.S. Constitution, and contradictory to democratic governance (e.g., Wilkins and Lomawaima 2001). The term sovereignty is problematic in itself, with the origins of this word coming from European colonial law and Christian ideologies (Barker 2005).

Tribes today emphasize that "the relationship between American Indian tribes and the U.S. federal government is an ongoing contest over sovereignty" (Wilkins and Lomawaima 2001, p. 5). Tribes argue for inherent sovereignty, "powers that could only be surrendered on the initiative of the tribe or changed, but not abolished, by the Congress." This is in contrast to delegated sovereignty, since the idea of Congress delegating powers that might be radically changed or cancelled by a future legislature is highly problematic (Deloria and Lytle 1984, p. 159). Indigenous scholars also critique uneven political negotiations that limit tribal self-determination. In particular, scholars note the contradictions involved with recognizing the sovereignty of Indigenous peoples through colonial legal systems, which include Supreme Court decisions setting the terms of tribal sovereignty in the U.S. context (Barker 2005).

Given these concerns, many Indigenous peoples have long questioned the viability of working within dominant governance models that "recognized indigenous sovereignty yet always subsumed it to that of the state" (Alfred 2005, p. 35). As Deloria and Lytle (1984, p. 19) write, self-determination cannot exist at the "whim of the controlling federal government." Some Indigenous communities are now exploring opportunities for recovering longstanding Indigenous political traditions in a contemporary context, which Alfred (2005, p. 40) describes as an "uneven process of reinstituting systems that promote the goals and reinforce the values of indigenous cultures, against the constant efforts of the Canadian and United States governments to maintain the systems of dominance imposed on indigenous communities during the last century."

Thus, the backdrop for tribal environmental self-determination strategies is the ongoing tensions between "realism and idealism." Such tensions arise when elected tribal officials are working within existing political structures at the same time that traditional tribal leaders are working outside the dominant system to reinvent tribal governance (Deloria and Lytle 1984, p. 242). While both groups want self-determination, conflict often ensues. Elected officials may be criticized as being overly pragmatic and without moral principles, and traditionalists may be seen as being unrealistic and overly romantic. To balance the tensions that run through diverse tribal communities, some scholars explore possibilities for a middle ground, a tribal governance strategy, that is neither replicating dominant state structures nor creating tribal enclaves (e.g., Deloria and Lytle 1984). Bruyneel's (2007) "third space of sovereignty" concept provides an example of strategies that simultaneously engage with territorial and non-territorial struggles over tribal sovereignty. The third space analytic suggests a "politics-on-the-boundaries" approach, where Indigenous struggles exist "neither simply inside nor outside the American political system" (Bruyneel 2007, xvii p. 20). This approach includes identifying productive policy negotiation spaces that engage overlapping interests among multiple sovereigns, spaces where communities can both assert Indigenous sovereignty goals and push back on dominant state policies.

Conflicts Over Tribal Lands

Such complexities around federal Indian law doctrine and tribal sovereignty set the stage for U.S. EPA TAS policies to emerge in the early 70s. Galloway (1995) has characterized two main drivers for the policy shifts that enabled TAS provisions and greater regulatory control by tribes over tribal lands. These are 1) a long history of Indian and non-Indian conflict, and 2) the onset of the self-determination era in federal Indian policy, discussed below.

Ongoing conflict between Indians and non-Indians has led to increased competition over regulatory authority on tribal lands, and necessitated TAS provisions. In the U.S. context, many Native American tribes were removed from their traditional homelands to reservations, areas where the federal government holds title to the land in trust on behalf of the tribe.[5] Many contemporary jurisdictional conflicts over tribal lands stem from the 1887 Dawes Act (or General Allotment Act), which drastically changed the property regime of Indian reservations. By transferring communally held tribal lands to individual tribal members and transferring so-called "surplus" lands to the federal government, the Act created the "checkerboard" patterns of landownership that continue to deter adequate regulation on Indian reservations today. Whereas there were 138 million acres of tribal lands in 1887, only 48 million acres of land were held by tribes and their members when the allotment policy was ended in 1934, less than 50 years later (Corntassel and Witmer 2008, p. 11). Much of this loss was due to land speculation and fraud. Following the Dawes Act, Indian-owned allotments within a reservation could be transferred to non-Indians to become what is now referred to as "non-Indian fee lands" (Anderson 2015). When Congress passed the Indian Reorganization Act (IRA) in 1934, this established the current framework of tribal governments—a framework that has been sharply criticized for its departure from traditional Indigenous values of self-government (e.g., Deloria and Lytle 1984).

Following allotment and the resulting shift in reservation property regimes, Supreme Court rulings affecting tribal jurisdiction over Indian and non-Indian fee lands have led to the "checkerboarding of regulatory authority" on Indian reservations, and within Indian Country more broadly. For example, *Oliphant v. Suquamish Indian Tribe* (1978) determined that tribal courts do not have criminal jurisdiction over non-Indians (Galloway 1995). This was followed by *Montana v. United States* (1981), which limited tribes' civil jurisdiction over non-Indians on non-Indian fee lands within Indian Country (Anderson

5 The creation of reservations has also affected tribal water rights and ongoing disputes over water quantity. Although it is not the focus of this article, the Supreme Court decision *Winters v. United States* (1908) held that the right to use waters flowing through a reservation was reserved for the tribe by the legal agreement establishing the reservation. In some cases, water quality issues may be affected by a tribe's reserved rights for water quantity, including salt water intrusion problems (Marx et. al 1998).

2015).[6] Importantly, *Montana* established two exceptions enabling tribal civil jurisdiction within the reservation, regardless of land status or tribal membership. These are 1) a "consent" exception, when nonmembers enter into consensual arrangements (e.g., contracts, leases, etc.), and 2) a "health and welfare" exception that applies to activities that "threaten to have a direct effect on the political integrity, the economic security, or the health or welfare of the tribe" (Mazurek et al. 1998; Getches et al. 2005). In other words, when that conduct has a serious and substantial effect on the health and welfare of the tribe, tribes may exercise civil authority over non-Indian conduct on fee lands within the reservation (Rey-Bear 1995; Leisy 1999). By applying the so-called "*Montana* test" and recognizing the close connection between water quality and tribal health and wellbeing, the EPA effectively confirmed tribes' inherent authority over their reservations for the purpose of setting tribal WQSs, including tribal authority over non-Indians on fee lands (Moser 2004; Grijalva 2006). Importantly, following legal definitions of Indian Country established through Supreme Court case law, the EPA's definition of "reservation" encompasses both formal reservations and "informal" reservations (i.e., other forms of trust lands set aside for Indian people) (USEPA 2011, p. 3).[7] Courts have generally precluded state authority over tribal lands unless there is express Congressional delegation of authority to states under applicable statutes, and have also upheld EPA policies treating reservations as "single administrative units" (Mazurek et al. 1998; Anderson 2015).

U.S. Tribal Self-Determination Era

Following a confluence of events, including the Native American rights movement of the 1960s, a dramatic increase in court rulings on tribal issues, new federal legislation, and increased tribal government capacity, the 1970s ushered in a new era in federal Indian law of tribal self-determination (Wilkinson and AILTP 2004; Wilkinson 2005). Rejecting the extreme federal Indian policy positions of paternalism, termination, and assimilation held by previous administrations, President Nixon's 1970 Congressional Address called for delegating federal program implementation responsibility (as well as adequate federal financial support) to interested tribes, and moving away from direct federal operation of Indian programs (Nixon 1970). A few years later, the Indian Self-Determination and Education Assistance Act of 1975 encouraged tribes to "assume administrative responsibility for federally funded programs that were designed for their benefit" (Wilkinson and AILP 2004, p. 17). In 1983, President Reagan affirmed Nixon's policy approach in his Indian Policy Statement supporting tribal self-governance and the federal-tribal relationship (Reagan 1983).

The policy shift of delegating program administrative authority to tribes fit with the cooperative federalism governance models underpinning the 1972 Clean Water Act (Sanders 2010). Cooperative federalism envisions a "structured federal-state partnership acknowledging both the national interest in environmental management as well as states'

6 Indian Country is a technical legal term, defined at 18 U.S.C. Section 1151 to include a) all land within the limits of any Indian reservation under the jurisdiction of the United States Government, notwithstanding the issuance of any patent, and, including rights-of-way running through the reservation; b) all dependent Indian communities within the borders of the United States whether within the original or subsequently acquired territory thereof, and whether within or without the limits of a state; and c) all Indian allotments, the Indian titles to which have not been extinguished, including rights-of-way running through the same.

7 The EPA's definition of "reservation" encompasses both formal reservations and "informal" reservations, i.e., trust lands set aside for Indian tribes. The EPA considers on a case-by-case basis whether other types of lands may be considered "reservations" under federal Indian law even though they may not be formally designated as such. Following legal definitions of Indian Country, the Agency recognizes two categories of lands: Pueblos and tribal trust lands (which can be owned by individuals or a tribe). In defining Indian Country, the EPA has had to interpret the law in light of Supreme Court case law. See for example, *Oklahoma Tax Comm'n v. Sac and Fox Nation*, 508 U.S. 114, 123 (1993); 56 Fed. Reg. 64876, 64881 (1991); or 63 Fed. Reg. 7254, 7258 (1998). See the EPA's May 16, 2016 revised reinterpretation of the CWA Tribal Provision at 81 CFR 30183. Available at: https://www.gpo.gov/fdsys/granule/FR-2016-05-16/2016-11511. Also see EPA Office of Science and Technology. TAS for the Water Quality Standards Program. Frequently Asked Questions (FAQ). September 2017. EPA-820-F-17-020. Available at: https://www.epa.gov/sites/production/files/2017-07/documents/tas-wqs-faq.pdf.

historic responsibility over public health and welfare" (Grijalva 2006, p. 198). Using the cooperative federalism approach, the EPA establishes certain federal environmental quality standards as a floor or baseline. A state then has the option of assuming regulation authority over relevant government programs by submitting a plan with standards that meet or exceed federal minimums. Once a state program is approved, the state assumes primary enforcement authority, or "primacy," and implements its own program in lieu of the federal agency implementing federal standards (Mazurek et al. 1998). To ensure compliance, the EPA retains "preemptory federal enforcement power" (Grijalva 2006, p. 200).

For the EPA, applying a cooperative federalism model to tribal environmental management in Indian Country was "born simply of practical necessity" (Grijalva 2006, p. 292). Because states lacked regulatory authority in Indian Country, the EPA was faced with a regulatory void for water quality. If state WQSs did not apply to tribal lands, what was the appropriate standard? This became an issue for the EPA, in part due to increased federal liability associated with the potential mismanagement of tribal trust lands (Grijalva 2006). The EPA's alternative solution was to substitute tribes for states as its cooperative partner. The agency's new approach amounted to recognizing tribes (like states) as "'local governments' with site-specific knowledge of their territories, and governmental responsibility for protecting legitimate local interests" (Grijalva 2006, p. 228).

Prior to Congress adopting TAS provisions, the EPA began to carve out a state-like role for tribes within some of its regulatory processes in the early 1970s (see Table 1, Timeline). This was, in part, stimulated by U.S. federal policy on tribal self-determination. Despite a backlash from states rejecting the increased recognition of tribal governments and their jurisdictional authority, the EPA proceeded with its efforts with delegating environmental regulatory responsibility to tribes (Hanna et al. 2012). In 1980, the EPA became the first U.S. federal agency to establish a formal Indian policy (Baker 1996). The 1980 EPA Indian Policy was centered on tribal implementation of federal environmental programs on Indian reservations (Grijalva 2006). When initial policy implementation proved lacking, agency leadership approved the EPA's 1984 Indian Policy that introduced implementation guidelines, funding commitments, and a plan for applying the agency's new Indian Policy across EPA programs. These initial EPA policies viewed inherent tribal sovereignty as the basis of tribal regulatory authority, and no statutory amendments were deemed necessary for policy implementation. By incorporating tribal provisions and TAS guidelines into its 1987 CWA amendments, Congress later confirmed the EPA's approach under Section 518.

As a caveat to the EPA's stated goals of supporting tribal self-determination, tribes harbor significant concerns regarding federalist governance models that transfer federal powers to state governments. In multiple cases, the shift towards federalist models has forced tribes out of exclusive federal-tribal government relationships based on treaties, etc. and into more direct political and legal relationships with state governments, which have historically challenged the nationhood status of tribes (Corntassel and Witmer 2008). In the 1970s, for example, states began to apply for delegated authority over environmental programs, including the CWA. It was at this time that states such as Oklahoma, New Mexico, and Washington attempted to assert state environmental permitting authority in Indian Country, despite lacking the legal authority to do so. These events forced the EPA to engage with the jurisdictional implications of delegating environmental regulatory authority in the context of Federal Indian law (Chandler 1994; Goldtooth 1995; Grijalva 2006). By transferring the same federal regulatory powers to tribes that had been provided to the states, TAS provisions in the CWA represent an effort to maintain equal footing among sovereigns within the cooperative federalist framework. Because the strong power imbalances that characterize state-tribal relations are still an issue, TAS provisions and associated EPA regulations on water quality have emphasized the direct government-to-government relationship between federal agencies and tribes. However, the challenges to tribal sovereignty that arise from federalist governance models are still a concern (Corntassel and Witmer 2008).

Program Functions for TAS (Section 518) and WQSs (Section 303) under the CWA

Originating from amendments to the Federal Water Pollution Control Act of 1948, the 1972 Clean Water Act aims to restore and maintain the integrity of U.S. waters, primarily by eliminating or controlling the discharge of pollutants into surface waters. The CWA's pollution control strategy is based on three main components. First, the approach applies technology-based standards for point source pollution, which are regulated through National Pollutant Discharge Elimination System (NPDES) permits. Second, the CWA requires states and tribes to create WQSs as a backup or safety net to the technology-based limitations on pollution discharges. Third, the Act establishes an anti-degradation policy, which requires protection of existing water quality. With this "always cleaner, never dirtier" approach, federal law does not permit the degradation of "high quality waters" without sufficient justification, thereby encouraging the "ratcheting up" of water quality over time. Additionally, Section 319 was added through 1987 CWA amendments to require the implementation of "non-point source management programs" (Salzman and Thompson 2014).

When Congress adopted TAS provisions as Section 518 of the 1987 CWA amendments, it authorized the EPA to treat eligible Indian tribes in a manner similar to states (TAS) for the purpose of administering CWA regulatory programs and receiving related federal grants. To be eligible for TAS status, tribes must meet several criteria. These criteria include being federally recognized, having a governing body carrying out substantial governmental duties and powers, having appropriate jurisdictional authority over desired regulatory areas, and being capable of carrying out program functions—a set of criteria that excludes many tribal communities (see note 2). TAS provisions, where Indian tribes play essentially the same regulatory role for Indian Country that states do for state lands, apply to the Clean Air Act, Clean Water Act, and Safe Drinking Water Act programs (USEPA n.d.). While statutory law legitimizes the TAS approach, the EPA's regulatory framework has played an even greater role in guiding tribal water governance (Berry 2016).

Once the EPA has approved a tribe's TAS status at a basic level, tribes submit separate TAS applications for the different programs to become eligible for delegation (see Table 2) (USEPA 1993). This "tiered" approach allows tribes to "ramp up" their capacity, and take on greater regulatory authority over time (Sanders 2010). The format for tribal applications varies. Depending on available time and resources, as well as preexisting jurisdictional conflicts with neighboring states, tribes can choose to 1) negotiate a cooperative agreement with an adjoining state to apply state standards, 2) adopt an adjoining state's standards with or without revision (thereby directly exercising tribal regulatory authority), or 3) adopt independent standards "from scratch" in order to account for unique site-specific conditions and designated uses (Galloway 1995). Mirroring the application process for states, TAS tribes must submit a formal application, seek out public comment, and work through EPA decision-making processes (Mazurek et al. 1998). Alternately, tribes may ask the EPA to promulgate standards for water on tribal lands—an approach that only one tribe, the Confederated Tribe of the Colville Reservation, has followed to date (Sanders 2010; USEPA n.d.(a)).

Regardless of their chosen approach, tribes must meet or exceed federal minimum requirements for WQSs under the CWA (Sanders 2010). WQSs consist of **designated uses** (e.g., fish and wildlife protection, recreation, cultural use) and **water quality criteria** (numeric or descriptive) that are based on those designated uses. To address CWA anti-degradation provisions, standards may include separate **classifications** for high-quality waters of recreational or ecological significance (Galloway 1995). For example, tribes or states may upgrade the classification of specific water bodies from lower class (good quality) to higher quality (excellent or extraordinary quality) to ensure greater levels of protection. EPA staff are tasked with providing technical assistance through the application process. Tribes are also eligible to apply for EPA program funding to support program development, including the development of tribal WQSs (Mazurek et al. 1998).

Table 2. Selected EPA Programs Available to Tribes, under the Clean Water Act (USEPA 1993).

Section 104(b)(3) – Special Projects (wetlands, non-point source, point source)
Section 104(g)(1) – Onsite Assistance for Waste Water Treatment
Section 106 – Water Pollution Control Funds
Section 303 – Water Quality Standards
Section 314 – Clean Lakes
Section 319(h) – Non-point Source Pollution Control
Section 401 – Certification for Point Source Discharge Permits
Section 402 – National Pollutant Discharge Elimination System
Section 404 – Wetlands Protection
Section 518 – Treatment as a State (TAS)
Title II Grants for Construction of Waste Water Treatment Facilities
Title VI State Water Pollution Control Revolving Funds
Other Programs: Ground Water, Mining Waste, Environmental Assessment

As discussed above, tribal WQSs can apply to all individuals within the entirety of a tribe's reservation boundaries, without distinguishing different categories of on-reservation land. Thus, for the purposes of water quality, a tribe's inherent authority over reservation waters is not necessarily determined by who owns the title to the land (Kannler 2002). This approach is intended to discourage "checkerboarded" environmental regulation in Indian Country. EPA regulations have confirmed the civil jurisdiction of tribes over non-Indians (and non-members) across the reservation, including jurisdiction over activities occurring on non-Indian fee lands (Anderson 2015, p. 244). As mentioned earlier, the EPA interprets the term "reservation" broadly to include formal reservations, and "informal" reservations (i.e., trust lands such as individual or tribal allotments, and Pueblos)—an approach that is consistent with Supreme Court rulings and legal definitions of Indian Country in federal statutes (Anderson et al. 2010). EPA policies on tribal jurisdiction are applied on a case-by-case basis, however. Until recently, tribes with checkerboarded reservations still needed to demonstrate their jurisdictional authority over fee lands under the *Montana* test. And tribes with more complex land ownership regimes might obtain TAS for only a subset of water resources within its reservation borders (Marx et al. 1998) or not at all.

Program requirements for demonstrating tribal jurisdictional authority have recently changed, however. To provide greater access to tribes for TAS programs, the EPA issued a new rule on May 16, 2016 with a revised reinterpretation of the CWA Tribal Provision (81 CFR 30183). Following the May 2016 reinterpretation, the EPA now recognizes tribal authority to administer CWA programs as an express delegation of authority by Congress. This effectively eliminates the need for tribes with non-Indian fee lands within their reservations to demonstrate inherent authority under the *Montana* test. Rather, as with the current TAS application process under the Clean Air Act, tribes will simply indicate the exterior boundaries of their reservation (see note 8). This new approach significantly streamlines the application process for TAS status and WQSs (Anderson 2015; USEPA n.d.(b)).

Tribal WQSs are typically enforced through NPDES permits in coordination with the EPA, as well as through non-point source control programs (USEPA 1990). In order to address differences across multiple jurisdictions, the same EPA regulations that apply to interstate water quality disputes can apply to tribes. For example, through the permitting process, the EPA has the authority to

require an upstream NPDES discharger to comply with downstream state or tribal WQSs (Anderson et al. 2010). Congress has designated the EPA as the final arbiter of inconsistent tribal and state water regulations. Tribes or states, but not others, may raise cross-jurisdictional conflicts through an established EPA dispute mechanism (Anderson 2015, p. 243).

As discussed earlier, these are opt-in programs that follow principles of self-determination, and not all tribes have elected to pursue TAS status or tribal WQSs. It is important to recognize that TAS is not the only regulatory framework available to tribes. Tribes often adopt their own laws and water codes, which primarily apply to tribal members on tribal lands. In some cases, tribal law may continue informal practices of culturally specific decision-making (Vesely 2014; Berry 2016). Tribes may also pursue regulation through partnership agreements with neighboring sovereigns, including strategies that facilitate the cross-deputizing of enforcement agents to enable regulation across tribe-state borders (Hanna et al. 2012). Non-TAS tribes can still participate in environmental programs (regulatory or non-regulatory), e.g., through cooperative agreements, grants, and other programs based on tribal law (USEPA 2008; Grijalva 2010; Warner 2015).

In instances where tribes have not formally asserted regulatory authority over water quality, however, the EPA retains regulatory authority to enforce federal environmental laws within Indian Country, as the appropriate federal agency tasked with implementing federal trust responsibility (Getches et al. 2005; Anderson 2015). Thus far, the EPA has declined to impose federal WQSs on Indian reservations (Getches et al. 2005), although the agency has recently considered issuing baseline WQSs in Indian Country (Sanders 2010; USEPA n.d.(c)).

Discussion: TAS Implications for Protecting Native Waters and Tribal Sovereignty

Opportunities

The literature on tribal WQS programs documents a wide range of opportunities for tribes. This section unpacks these opportunities, their broader significance, and TAS program mechanisms that provide for them.

Compared to laws set by tribal governments that may apply only to tribal members on tribal lands, EPA-approved WQSs offer a significant **increase in tribal authority** over reservation waters, particularly for point source pollution discharges. One of the primary advantages of the EPA's tribal WQS program is that it can provide a consistent regulatory policy covering the entire Indian reservation, regardless of land ownership status—especially following the May 2016 reinterpretation of CWA tribal provisions. This is highly significant given Supreme Court decisions that have limited tribal jurisdiction over non-Indians within reservation boundaries, especially on non-Indian fee lands (Anderson 2015). By partnering with the EPA, tribes can influence off-reservation water users, a strategy that is especially relevant when tribes set WQSs that are more stringent than neighboring state standards (Galloway 1995). Even for tribes that place a high priority on tribal self-determination, working within EPA structures to resolve complex environmental regulation issues can be advantageous because of the substantial deference that the U.S. legal system offers to the EPA's interpretation of environmental statutes (Rey-Bear 1995; Leisy 1999; Grijalva 2003; Maccabee 2015). EPA determinations in respect to tribal authority to regulate under the CWA have consistently been upheld in court (Anderson 2015).

TAS status for water quality can help tribes by **facilitating both off-reservation and on-reservation enforcement**. The standards themselves do not impose any direct enforceable requirements, but they become actionable when they are incorporated into a permit or used as a basis for some other regulatory decision. When drafting a permit, the EPA seeks certification from the state or from a tribe that the proposed permit will not violate existing WQSs (Chandler 1994). Thus, EPA protocols for certifying federal discharge permits require the agency to notify any downstream tribes with approved WQSs of potential discharges affecting the tribe's water quality. Under section 401 of the CWA, a tribe with federally approved WQSs can challenge and sometimes veto the issuance of federal discharge permits. If the tribe

denies certification, the federal agency may not issue the permit. In some cases, tribes can impose terms or conditions on a discharge permit to ensure compliance with tribal standards, enforceable by federal law (Grijalva 1995; Sanders 2010). As an example of on-reservation enforcement, the Coeur d'Alene Tribe and the Shoshone Bannock Tribe have denied certification for a NPDES permit that would allow small suction dredges for Idaho mines. Tribes have also used section 401 to limit multi-sector general permits that allow stormwater discharge from industrial activities, such as mining, manufacturing, and oil and gas extraction (Maccabee 2015). No tribe has used section 401 to object to federal permits regarding discharges originating off-reservation thus far, however (Maccabee 2015).

Extending beyond discharge permits, new or revised state-issued WQSs must comply with tribal standards. If this is not the case, the EPA may reject the proposed state program and promulgate federal standards. In addition, U.S. Superfund laws (CERCLA) regulating hazardous waste site clean-up require the EPA to comply with all applicable pollution standards, including tribal WQSs (Anderson 2015). TAS tribes can use their EPA-approved WQSs to develop their own total maximum daily load (TMDL) determinations for impaired waters under section 303(d) of the CWA (Grijalva 2003).[8] Finally, the EPA has established a voluntary **dispute resolution process**, which can only be initiated by states or tribes. Although litigation is always an option, the time and expense involved in lawsuits may make dispute resolution an attractive alternative for resource-strapped tribes (Galloway 1995).

In addition, EPA regulations flowing from EPA Indian policy on tribal self-determination offer tribes substantial **flexibility with how they choose to engage** with CWA programs under TAS. Tribes may select the CWA programs that they wish to assume at a given time (see Table 2). Once they qualify for TAS under the CWA for one program, they can apply this status to future applications for other CWA program and simply submit additional, program-specific information. Tribes can also submit their application for TAS application and tribal WQSs at the same time, for simultaneous consideration. In addition, tribes have substantial flexibility in developing their own independent standards, or basing their standards on the WQSs of neighboring states. As mentioned earlier, tribal WQSs must meet minimum federal standards, but tribes can also access the same policy tools that are available to states for balancing environmental and economic interests. These include policy tools for developing variances, mixing zones, and low-flow exemptions for certain discharges (USEPA 1990). This level of flexibility is highly significant for tribes because, as Grijalva (2006, p. 293) points out, "once [tribal WQSs are] approved by EPA, tribal value judgments balancing environmental quality and economic development become federally enforceable."

Rodgers (2004, p. 820) describes the "creative touch that is open to tribes under the TAS provisions." In developing independent WQSs, tribes set their own designated uses based on **their own values and goals,** which then inform the tribe's water quality criteria. Designated uses may include cultural or ceremonial uses, a regulatory approach that the courts have endorsed as not involving any "excessive entanglement" between government and religion (Galloway 1995). Establishing ceremony as a beneficial use illustrates the deference to tribal values that is permitted within the regulatory framework (Dussias 1999). As Reinhard (2009, p. 559) points out, "EPA decides to approve or reject a use by evaluating whether it is attainable and consistent with the CWA's objective, not by evaluating the principles behind the use." As an additional source of flexibility, pollution criteria can be expressed in multiple ways: through numerical values (e.g., parts per billion), bioassay results (e.g., LC50 value, or a concentration of a pollutant that will kill one half of a given number of test organisms), or narrative criteria (e.g., aspirational statements, like free from odor or toxins). Tribes may add their own classification systems for protecting high quality waters (Galloway 1995). There is significant latitude for creating **more stringent standards**, as long as they meet the federal baseline (Reinhard 2009). In the case of the Pueblo of Isleta, for

8 See EPA regulations on tribal TMDLs, finalized in 2016. Available at: https://www.epa.gov/tmdl/whats-new-impaired-waters-and-tmdls.

example, the Pueblo's water quality standard for arsenic was 1,000 times more stringent than the State of New Mexico standards. In a decision that was backed by the courts, EPA regulators affirmed the Pueblo's standard (Bilut 1994).

Tribal managers in one case study reported **protecting public health** to be one of the top two reasons why tribes pursue their own WQSs (Lefthand-Begay 2014). Although it is often difficult to quantify direct policy impacts on human health (e.g., Sabatier et al. 2005), there are multiple cases documenting tribal WQSs that have contributed to water pollution reductions from off-reservation sources. For example, in New Mexico in 1996, the Pueblo of Isleta successfully leveraged its WQSs through EPA permitting processes to improve the water quality of City of Albuquerque water treatment facility discharges, as an upstream, off-reservation point source affecting reservation waters (Galloway 1995).

Tribal water quality programs have helped the Confederated Salish and Kootenai Tribes (SKT) of the Flathead Reservation in Montana **with reducing pollution** from non-point sources, particularly high nutrient levels from agricultural wastes (USEPA 2006a). Similarly, the Seminole Tribe of Florida has used its WQSs to address high nutrient inputs from large-scale, off-reservation agriculture, which was followed by a measurable decrease in nutrient levels entering reservation waters (USEPA 2003a). For the Hualapai Tribe in Arizona, WQSs have provided an enforceable mechanism for modifying grazing and wildlife management off-reservation, which has improved the quality of culturally important spring waters (USEPA 2006b). By applying the water body classification of Outstanding National Resource Waters (ONRW) to all reservation waters, the Sokaogon Chippewa Community in Wisconsin used their WQSs to help prevent off-reservation resource extraction producing mining wastewater discharges (USEPA 2006c).

Other tribes have leveraged their water quality programs to generate more **effective monitoring and regulation** of tribal waters. For instance, the Fort Peck Tribes (Assiniboine and Sioux Tribes) have used their water quality programs to prioritize degraded waters requiring restoration treatment through biological assessments, particularly to prevent grazing impacts (USEPA 2003b). The Hoopa Valley Tribe is measuring temperature and turbidity, among other criteria, as important indicators of forestry practices that affect soil runoff in order to avoid negative impacts on culturally important salmon (USEPA 2006d).

Expanding access to clean water for tribal members is another important opportunity. In the case of the Navajo Nation, the EPA's limited staff experienced difficulties with administering the public water systems supervision program for Navajo lands, a large area that extends across three southwestern states. Given public health concerns about radium-226, natural uranium, arsenic, and potential drinking water problems, the Navajo Nation decided to administer its own program, and substantially increased the Nation's institutional capacity for regulating water quality (Grant 2007). Similarly, after the Lummi Nation in western Washington experienced ongoing water quality problems from water services administered by the Bureau of Indian Affairs (BIA), the tribe created the Lummi Tribal Sewer and Water District to self-administer services, and provide water and sewer infrastructure for all reservation residents (Sanders 2010).

Tribal managers have also identified **funding opportunities** as a key benefit from TAS program participation (Lefthand-Begay 2014). While only 54 tribes have TAS status for WQS programs under Section 303, a much larger number of tribes have TAS status for other CWA programs that provide significant financial assistance for **capacity building** (Ranco and Suagee 2007). For example, tribes may apply for prevention and reduction grants (Section 104), develop pollution prevention and reduction programs (Section 106), or develop management programs for non-point source pollution (Section 319) (Grijalva 2003). Federal grants have helped TAS tribes improve and grow their natural resource programs. Tribes often use federal grant funds to create additional **job opportunities** for tribal members, which is especially important for tribes in rural areas with high unemployment. For tribes with established natural resource programs, like the Confederated SKT of the Flathead Reservation who recently employed about 135 staff members, sustaining operational program funding is a key priority

(USEPA 2006a). TAS funding can also provide resources for tribes to create new programs, including tribal water monitoring. Some Navajo Nation staff view TAS programs as being more effective than non-TAS programs (Grant 2007), specifically because TAS funding has facilitated greater tribal implementation and enforcement of Navajo Nation environmental policies.

Finally, by working more closely with federal agencies on water quality, TAS tribes are strengthening federal and tribal government-to-government relationships to **increase tribes' political access** to federal policy-makers, i.e., additional time and opportunity for tribes to educate agency officials about their interests (Sanders 2010). Tribal WQSs are part of a broader set of issues that are being negotiated among multiple governmental bodies at any given time. In addition, formal tribal water quality programs can help raise the profile of environmental concerns within tribal governments. This can help ensure that tribal governments remain committed to protecting water quality, by providing the internal funding and political support needed to do so.

Constraints

As with any complex water management policy, multiple challenges arise from implementing tribal WQSs, and participating in TAS programs. In the section below, the author explains some of the primary challenges with tribal WQSs discussed in the literature.

While the purpose of tribal WQSs includes closing a key regulatory gap for tribal lands to ensure equal access to clean water, the program is **not accessible to all tribes.** This is due to the narrow criteria for program eligibility. Only federally recognized tribes with trust lands (formal or informal reservations) can apply, which excludes all unrecognized tribes, some recognized tribes with limited jurisdictional authority over relevant water bodies, and almost all Alaska Natives (Sanders 2010). The land status of tribes based in Oklahoma has created particular problems for tribes that want to access TAS programs (Williams 1993; Chandler 1994). As an additional concern, a tribe must have the financial and technical capacity to deal with the EPA's application process, and potentially with litigation.

A study of two geographically distinct tribes with EPA-approved WQSs found the **highly technical requirements** for the application process to be among the top concerns reported (Lefthand-Begay 2014). Until the EPA's May 2016 reinterpretation, applications required substantial technical support with generating documentation that ranged from a tribal government's source of authority, to maps of tribal jurisdictional areas, to locations of surface waters targeted for WQSs (Grijalva 1995). Tribes often need to hire attorneys or other specialists to complete their applications (Lefthand-Begay 2014). While there do not appear to be any court decisions rejecting a tribal application for TAS for failure to meet the *Montana* test, the need to demonstrate tribal jurisdictional authority has historically placed a significant administrative burden on tribes applying for WQSs (Grijalva 2003; Anderson 2015). In addition, tribes must enumerate the qualifications of their technical and administrative staff, and include a funding plan for how they will provide technical training (Sanders 2010; Lefthand-Begay 2014). While tribes with TAS status can apply for funding to support program application costs, funding access is limited and competitive (Ranco and Suagee 2007). Tribes may face challenges with hiring staff with advanced degrees, which can jeopardize program approval (e.g., Grant 2007). In addition, problems with the EPA review process can occur when individual EPA staff lack an adequate understanding of treaties, federal trust responsibilities, and tribal law (Lefthand-Begay 2014).

Financial limitations were another key problem (Lefthand-Begay 2014), as tribes may consider WQS programs too expensive to implement (Porter 2007). Lack of independent funding has long been a problem for tribal environmental programs, even on energy rich reservations (Ambler 1990; Ludvig 2013). In terms of federal funds, tribes may unfortunately be "late to the party." While tribes only began applying for tribal WQSs in the early 90s, states were developing their WQS programs and associated water treatment infrastructure in the 70s and 80s—at a time when more federal funding opportunities were available for institution-building and program implementation (Grijalva 2006). Thus, the federal financial support that once helped non-tribal facilities gain compliance with

environmental laws and assume environmental regulatory authority is no longer available to tribal governments (Teodoro et al. 2016). The EPA has attempted to address this challenge through instituting a low matching funds requirement for tribes (much lower than for states), and in some cases waiving the matching funds requirement (Dussias 1999). In some cases, tribes pursue creative strategies for overcoming cost barriers. For example, Marx et al. (1998) describe how one tribe joined a tribal consortium with common interests in order to share application costs. Still, limited resources present a significant structural barrier for tribes that wish to forward self-determination and environmental protection through TAS and WQS programs.

As an additional constraint, recent U.S. Supreme Court decisions that have limited tribal jurisdiction may lead tribes to avoid TAS programs, as a potential source of **increased risk of conflict,** particularly with non-Indians (Fort 1995). Several TAS tribes have been met by strong resistance from states and business interests, as discussed below. The ongoing threat of lawsuits from entities that are hostile to tribal sovereignty, e.g., states, political groups, or individuals, especially non-Indians located within reservations, is a primary driver for the EPA's intensive application process, and the agency's conservative interpretations of tribal jurisdiction (Galloway 1995; Rey-Bear 1995). To preempt potential legal challenges, the EPA has conducted a careful case-by-case review of tribal jurisdictional authority for each application to date (Grant 2007). To put concerns regarding lawsuits in perspective, however, there have been only three legal challenges to tribal WQSs in over twenty-four years, and these have generally upheld the validity of the EPA's approach (Anderson 2015).

A common reason for tribes to forego TAS programs, or to proceed cautiously, is a tribe's concern about potential state challenges to tribal sovereignty (Grijalva 2003). In some cases, tribes addressing WQSs within a hostile political environment have experienced serious problems. For example, when the Penobscot and Passamaquoddy Tribes requested stricter levels for dioxin discharges by paper and pulp mills in 2000, state opponents filed a lawsuit, which leveraged the Maine Freedom of Access Act to gain all materials on tribal authority (Rodgers 2004). As a second example, after the Pawnee Nation of Oklahoma gained EPA-approved WQSs in 2004, the State of Oklahoma filed a lawsuit. Opponents also inserted a legislative amendment in an unrelated bill, which has since limited the ability of tribes in Oklahoma to obtain EPA approval for TAS status (Grant 2007; Sanders 2010). In other cases, jurisdictional tensions between tribal natural resource managers and non-native businesses located on trust lands have led to some businesses evading tribal enforcement, thereby increasing health risks to the tribal community (Lefthand-Begay 2014).

This political reality suggests that tribes may need to balance "the reality of opposition" with the "certainty of benefits" (Sanders 2010, p. 21). Depending on their ability to engage with legal uncertainty and potential jurisdictional challenges from non-Indian governments, some tribes may choose to prioritize conflict avoidance and forego applying for WQSs (Galloway 1995; Sanders 2010). Others may avoid asserting tribal water protection standards in controversial areas of their reservation with competing jurisdictional claims. In some cases, tribes like the Navajo Nation have purposefully taken a more conservative approach in order to prevent major delays in EPA approval processes (Grant 2007). Unfortunately, limiting tribal WQSs to only parts of a reservation increases the **likelihood of "checkerboard" environmental regulation** and limited protection for tribal waters, an outcome that frustrates one of the main drivers for the EPA's TAS policy under the CWA.

Given that the CWA was not designed to meet the specific needs of tribes, TAS programs include a number of **contradictory messages for tribal self-determination**. One fundamental challenge is reflected in the program title "Treatment as a State." For many tribes, the idea of being treated as a state is an affront to tribal sovereignty, and overlooks the government-to-government relationship that tribes have with federal agencies (Porter 2007). In response to complaints from tribes, in 1994, the EPA shifted its language to "treatment in a manner that is similar to states" (Marx et al. 1998), but the original TAS language is still widely used. As discussed above, tribal self-determination advocates are deeply concerned that using U.S. legal frameworks as the primary

basis for tribal governance will only further embed tribes within ongoing colonial systems (Fleder and Ranco 2004; Alfred 2005). Alternately, scholars argue that when tribes are more fully empowered (politically and financially) to develop their own governance structures based on tribal law and traditional knowledge, tribes stand a better chance to push past colonial legacies and develop policies that fit their culture and local conditions (Borrows 1997; Craft 2013; McGregor 2014).

TAS programs can also force tribes into a problematic legal debate over sources of tribal authority (e.g., Kannler 2002). When the EPA issued its May 2016 reinterpretation of CWA tribal provisions as a Congressionally "delegated authority," tribal water quality programs were no longer entirely dependent on inherent authority for their legitimacy. From an administrative perspective, this shift conveyed a substantial advantage to tribes applying for TAS because delegated authority is not subject to the *Montana* test (Anderson et al. 2010). However, delegated authority suggests that Congress has used its plenary power to return, or reinvest, the original regulatory powers to an individual tribe, which raises concerns for tribes with a strong sense of their inherent rights and responsibilities (Tweedy 2005). This goes back to the Supreme Court's understanding of Congress maintaining "plenary power" over tribes. Regardless of EPA policy, tribes emphasize their "inherent authority," or the authority tribal governments have retained over their people and land base throughout history, which continues to exist alongside any Congressional delegations or authority. However, inherent authority has proven to be more amorphous and difficult for courts to interpret (Tweedy 2005).

As a related challenge, tribes that gain regulatory authority through TAS programs are still working within the context of environmental federalism and are subject to the **EPA's final decision-making authority**. This includes the TAS application process, where the EPA was granted substantial control to interpret the scope of a tribe's inherent authority. And it is still the EPA that makes the permitting decisions for discharges affecting tribal waters. This becomes a concern when there are strong **differences in values between federal agencies and tribes**. Grijalva (2006, p. 278) shares a more pessimistic view on the possibility of alignment between tribal and federal governments. He anticipates that the EPA has retained responsibility and final authority for decisions affecting human health and the environment and would therefore "disregard tribal interests and objections perceived in conflict with human health and/or environmental interests." There is an additional concern that affirming agency control over the reservation environment during a hostile administration could pose great risk for tribes (Fleder and Ranco 2004). And because the federal government's greater national interests may conflict with tribal interests, some tribes may simply choose to adopt and enforce their own tribal water code (Vesely 2014).

Tribes electing to participate in TAS and WQS programs must operate within the constraints of federal laws that are intended to prevent and address conflict between multiple sovereigns (Sanders 2010). For example, when designating uses of a water body and the appropriate criteria for those uses, a tribe must ensure its WQSs for reservation waters do not interfere with WQSs for downstream waters. Tribes must follow requirements for reviewing standards every three years, and maintain public records of the decision-making process and public involvement (USEPA 1990; USEPA 2016). These are important elements of due process that are at the heart of state-tribe jurisdictional conflicts and have been addressed through the Indian Civil Rights Act (Monette 1996; Marx et al. 1998). Some tribes may view this as a reasonable limitation, since a highly mobile resource like water requires a common legal framework for regulating across jurisdictions. At the same time, operating within standard policy used for states can cause unique problems for tribes. For instance, public comment periods required through the review process for tribal WQSs can open up complex legal questions of tribal jurisdiction over reservation lands for broad public debate within communities that have limited understanding of federal Indian policy (Galloway 1995). Thus, as Sanders (2010, p. 545) writes, "tribal governments applying for TAS status may be exposed to challenges that risk their sovereign ability to protect their lands and natural resources as well as their relationship with the federal government."

To be clear, TAS offers only a **partial delegation of authority** (Whyte 2011). This speaks to some of the structural problems with U.S. federal Indian law and self-determination. At the same time, the policy does empower tribes with a similar level of authority as states (Leisy 1999), and it is a rare case of a clear and consistent federal policy on tribal jurisdiction over non-Indians (Marx et al. 1998). Partial delegation is a significant step up from other alternatives available to tribes. For example, when TAS status is not offered, as in the regulation of solid waste through the Resource Conservation and Recovery Act (RCRA), tribes are treated more like municipalities. As a result, there is a notable difference in the ability of tribes to influence environmental outcomes of solid waste on their reservation (Goldtooth 1995).

The practical reality is that sovereignty is always limited, but the extent of these limitations, their outcomes, and the manner in which these limitations came to be is highly important. For this reason, some tribes may take a pragmatic approach and evaluate the power sharing that occurs through the EPA's TAS programs through a critical collaborative management framework. This approach considers the degree of tribal participation at different levels of decision-making authority (e.g., Schlager and Ostrom 1992; Diver 2012, 2016). At the operational level (e.g., day to day management decisions), for example, tribes gain extensive authority and capacity to create and implement tribal WQSs. At a policy level (e.g., rule-making on rights/responsibilities), EPA regulations provide tribes with the flexibility to set standards that reflect an individual tribe's values. At the constitutional level of authority (e.g., rules for rule-making), it is the EPA and Congress that set the rules of engagement, with some consultation with tribes. This line of analysis suggests tribal WQSs provide significant gains at the operational and policy levels. It also points out the limitations on power sharing at the constitutional level.

For those tribes that attain TAS status for WQSs, there is a question of whether the existing program framework can fit their needs. For example, in terms of reaching desired environmental outcomes, the CWA has been criticized for being **less effective for non-point source pollution** than for point source discharges (Salzman and Thompson 2014; Warner 2015). There is also a question of a **lack of "cultural match"** between the application of EPA policy frameworks to tribal WQSs and the diversity of U.S. tribes that they are intended to serve. Cultural match refers to "the match between governing institutions and the prevailing ideas in the community about how authority should be organized and exercised" (Cornell and Kalt 1998, p 201). Despite the concept of tribes having the flexibility to develop their own policies, studies report that the EPA generally recommends for tribes to adopt the standards from adjacent states when first setting tribal WQSs (Ranco 2009). In some cases tribal managers report EPA staff resisting proposals to incorporate traditional knowledge into tribal WQSs (Lefthand-Begay 2014). This may be based on a presumption that tribal programs resembling federal or state WQSs are more likely to survive litigation. Some tribes have reported that mimicking existing federal programs has significantly sped up EPA approvals, and has facilitated agreements with non-Indian owned facilities on the reservation (Grant 2007). These findings suggest that the stated goal of recognizing the distinct cultural values of tribes is not fully met in practice.

Policies that limit tribes to a single approach disregard the purpose of TAS as a self-determination strategy. At its core, TAS provisions are intended to enable tribes to develop WQSs that are "protective of their unique lifestyles, which generally would not be possible under most state or current federal water quality regulations" (Lefthand-Begay 2014, p. 73). Tribes may require more protective regulatory standards to address their individual needs. This may include tribal standards developed to protect ceremonial practices that involve bathing or ingesting water, as exemplified by the Pueblo of Isleta's WQSs. In addition, economic realities on the reservation may require an individualized approach to working with reservation businesses, e.g., a more collaborative regulatory approach that does not lead with a threat of closure (Lefthand-Begay 2014). The issue at hand is the increased risk of substituting state or federal values for the values of an individual tribe, and losing the opportunity for tribal environmental programs to act as "laboratories for creativity," which can draw from multiple knowledge systems to create new innovations for water governance (Ranco and Suagee 2007, p. 702).

Another concern for tribes is the **political risk regarding the longevity of EPA programs** enabling tribal WQSs. As Sanders (2010, p. 564) describes, tribes opting to enact their own WQSs are often "confronted with vague EPA support, non-Indian jurisdictional challenges, and the ongoing threat of changing federal law and policy." Funding to sustain tribal environmental programs, including administrative requirements, is a primary concern. Just like states, EPA-approved tribes must develop all of the laws and regulations within their own governments to authorize tribal environmental activities. They must also meet WQS program requirements under federal law (Grant 2007). As one tribal manager reported in a case study interview "With TAS there comes more authority and the responsibility to be in compliance with regulations. This costs money and tribes often don't have the funding sources that states have" (Lefthand-Begay 2014, p. 46). If tribes are to devote time and resources to gaining EPA-approved WQSs, it is reasonable to question whether these programs can survive to benefit future generations.

Developing tribal WQSs also involves accepting some level of political risk and uncertainty about future court decisions. To date, there has not been a Supreme Court case on tribal authority for WQSs, so there is always the risk of litigation if non-members find the tribal regime unfair (Anderson 2015). Litigation over tribal authority, particularly further limitations on tribal civil jurisdiction over non-Indians on non-Indian fee lands, could place both tribal WQSs and broader tribal jurisdictional concerns at risk (Sanders 2010). As an additional concern, Anderson (2015) discusses the risk of the EPA shifting its position if the agency were to determine that it is too time consuming and expensive to administer the programs. It is unclear how funding cuts under the current Pruitt EPA administration may impact TAS programs in the near future. Indicating a more positive trajectory, EPA officials have just announced the approval of two new tribal WQSs in California.[9]

9 On April 5, 2018 at the 2018 California Tribal Water Summit, agency officials announced that the EPA had just approved (as of April 3, 2018) TAS for WQSs for two new tribes in California. The standards are not yet available on the EPA website. These approvals will increase the total number of tribes with TAS for WQSs from 54 to 56.

Conclusion

Tribal water quality standards under TAS provisions enhance tribal self-governance of native waters through the comprehensive statutory framework of the Clean Water Act. Given the highly mobile nature of water resources, CWA tribal provisions address water pollution across multiple jurisdictions, yet the legal framework also allows for (and anticipates) differences among sovereigns. Some tribes are successfully assuming program implementation authority under the CWA and developing their own WQSs to protect and improve water quality across the entire reservation. Such improvements in environmental quality can benefit fish and wildlife, and tribal and non-tribal people—both on and off the reservation. Thus, tribes are using their WQSs to further tribal self-determination and additional benefits (see Table 3). As a strong caveat, however, the program is not a good fit or a priority for all tribal governments. There have also been significant challenges for tribes seeking to establish and enforce tribal environmental jurisdiction over reservation lands.

Overall, EPA-approved WQSs have resulted in important legal and political outcomes for tribes. This is a case of Congress and the EPA attempting to work with tribes to "uncheckerboard" environmental regulation on Indian reservations. When adopted, tribal WQSs facilitate greater tribal environmental self-determination over their territories in the form of increased tribal jurisdiction over reservation waters. Tribal WQSs also enable tribes to work in partnership with the EPA to influence off-reservation areas, where upstream discharges may be originating. In response to concerns over cooperative federalism models eroding tribal self-determination, tribal WQS programs still facilitate substantive government-to-government relationships between tribes and federal agencies. In addition, tribal standards are distinct from those of neighboring states, and are often motivated by tribal community values, including ceremonial uses. In this way, TAS programs offer some insight into how federal regulatory institutions can better support culturally appropriate water governance, which embraces Indigenous knowledge and self-determination. Thus, by working through CWA legal structures,

Table 3. Summary of key opportunities and constraints arising from Treatment as a State (TAS) provisions and tribal Water Quality Standard (WQS) programs.

Opportunities	Constraints
• increases tribal authority • facilitates tribal enforcement (on-reservation and off-reservation) • provides a dispute resolution process • offers flexibility of engagement • recognizes tribal values • allows more stringent standards • protects public health • enables pollution reduction • supports monitoring and regulation • expands access to clean water • program funding, capacity building, and jobs • increases political access	• not accessible to all tribes • highly technical application process • financial limitations • increased risk of conflict • persistence of "checkerboard" regulation • contradictions for self-determination • federal agency is the final decision-maker • differences in values • partial delegation of authority (operational and policy levels) • less effective for non-point source pollution • lack of cultural match • political risk to program longevity

tribes leverage a highly developed federal legal framework to actualize their values for protecting reservation water quality.

From a pragmatic viewpoint, increased access to technical assistance and federal funds has significantly helped tribes to grow their own tribal governance institutions, and improve water treatment infrastructure that benefits tribal members. Through the process of creating and implementing tribal WQSs, TAS tribes also gain increased access to federal level decision-makers. Evaluating the EPA's TAS programs through a critical collaborative management framework suggests that tribal WQSs provide significant gains for tribal self-determination at the operational and policy levels.

At the same time, scholarly critiques demonstrate how TAS provisions offer a highly contingent form of tribal self-determination. Since pre-existing regulatory frameworks were not developed with or for Native American tribes, it is not surprising that TAS provisions place significant restrictions on what tribal water governance looks like. The EPA retains ultimate decision-making power through agency approval processes that determine everything from tribal eligibility, to WQS frameworks, to the public review process. To be fair, EPA regulations do leave significant flexibility for tribes to self-determine the goals and content of their WQSs (Bilut 1994). But the EPA remains central to the regulatory processes governing tribal waters.

Structural limitations prevent many tribes from meeting eligibility requirements for TAS programs, including almost all Alaska tribes. For those tribes that are eligible, lack of resources, technical barriers, and jurisdictional requirements have prevented many tribes from accessing WQSs under Section 303. In contrast, tribes have been more successful accessing CWA funding programs through Section 106. Although the May 2016 reinterpretation of TAS authority may address some of the WQS application barriers, the TAS approval process remains slow and political, depending on the political will of federal agencies. In this way, tribal WQSs may be viewed as shoring up the problematic political framework of "nations within" (e.g., Alfred 2005).

Yet, Indigenous-led institutions are always operating within imposed political constraints. As

part of exercising Indigenous self-determination, scholars assert that Indigenous peoples are choosing for themselves how and when to operate within these constraints (Bruyneel 2007; Cornell 2013). As a case in point, TAS programs may be providing tribes with a useful "pivot point," i.e., an existing government policy that provides a starting point for Indigenous communities to negotiate meaningful policy change (Diver 2016, 2017). In contrast to conflicts over water quantity, water quality may function as a productive "third space" for negotiating tribal environmental self-determination. This is in part, because water quality is not necessarily a zero-sum game: one group's gain in water quality may provide benefits to their neighbors, representing an area where multiple sovereigns can negotiate more effectively based on overlapping interests. In one sense, developing tribal WQSs is a territorial strategy, where tribes are working within existing regulations to reestablish jurisdictional authority over their entire reservation, regardless of colonial legacies that have led to the "checkerboarding" of Indian Country. In this way, tribal WQSs offer tribes an opportunity to push back on property regimes that have limited tribes' ability to regulate their reservation environments. But WQSs are also an extra-territorial strategy, where tribes are affecting water quality governance off-reservation and throughout a broader watershed area. By applying tribal WQSs upstream, the TAS approach reflects a more holistic approach to environmental governance, where we may better recognize how the health and welfare of fish, wildlife, tribal, and non-tribal peoples are all interconnected through our shared waterways and across multiple jurisdictions.

Importantly, the legal and policy analysis of tribal WQSs impacts provides only a partial view of tribal self-determination strategies. Developing EPA-approved regulatory standards is only one approach that tribes are taking to protect reservation waters—an approach that may be paired with more tribally-centered strategies, such as tribes using customary law to create their own tribal water codes (Reinhard 2009; Warner 2015), engaging in direct action protests around water quality impacts, or teaching tribal youth about longstanding Indigenous water relations. Additional research is needed to understand the diversity of tribal strategies for environmental self-determination. Of particular interest is how some tribes may use tribal WQSs as a "third space" strategy—simultaneously working inside and outside of government structures (Bruyneel 2007)—and how such strategies may contribute to an individual tribe's ability to realize its full range of aspirations for self-determination.

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Disparities in Water Quality in Indian Country

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Abstract: Tribal Nations in the United States are afflicted by a number of disparities including health, socioeconomics, education, and contaminant exposure to name a few. To understand drinking water quality disparities, we analyzed Safe Drinking Water Act violations in Indian Country found in the Environmental Protection Agency's (EPA's) Enforcement and Compliance History Online (ECHO) and compared them to violations in non-tribal areas of the same state for the time period 2014 – 2017. The violations assessed were total point accumulations per year per 1,000 customers, health-based maximum contaminant limit (MCL), reporting and monitoring, and public notice for each state reporting tribal data. Violation point disparities were evident, as tribal facilities acquired nearly six times the points of the national average. In some states, health-based tribal water quality was better than in non-tribal communities, however Arizona, Iowa, Idaho, Montana, Utah, and Wyoming had MCL violations affecting a greater percentage of tribal populations than non-tribal. Nation-wide, monitoring and reporting violations affected tribal communities at nearly twice the rate of non-tribal customers. Public notice reporting was high and comparable for both tribal and non-tribal facilities. Finally, a comparison of small drinking water facilities, under which ~97% of the surveyed tribal drinking water falls, confirmed state-wide disparities. Solutions for the apparent disparities in Indian Country and on non-tribal lands may be as simple as rectifying monitoring and reporting violations, though this correction will not shift the overall water quality difference. Addressing MCL and treatment violations is the next step to reduce the disparity.

Keywords: *drinking water quality, tribal water quality, EPA ECHO, disparity*

There are 567 federally recognized American Indian and Alaska Native Tribal nations throughout the United States (Department of the Interior 2016). Based on the U.S. Constitution, each tribal nation has a sovereign status, resulting in a unique government-to-government relationship. Several federal agencies work directly with tribal nations (e.g., Bureau of Indian Affairs, Bureau of Indian Education, Indian Health Service, Office of Tribal Justice), while other agencies house tribal divisions within their agency (Department of Interior, Environmental Protection Agency (EPA), Department of Energy). Federal laws apply to sovereign nations, and such is the case regarding environmental regulations through the U.S. EPA. Tribes may, however, adapt stricter or additional regulations to protect their people, land, air, and water.

Established under the 1986 Safe Drinking Water Act (SDWA) Amendments, tribes may develop their own water quality standards (Public Law 99-339 1986). This "primacy" allows tribes to establish and enforce their own standards through an application process, but they must meet the minimum EPA health-based criteria of established standards under the SDWA and follow treatment standards for groundwater and surface water (Diver 2018). The EPA's regional offices are responsible for monitoring, enforcement, and compliance for those tribes that do not have primacy. As of November 2017, the only tribe to receive primacy is the Navajo Nation (EPA 2017c). In Alaska, water facilities that serve Native villages fall under state primacy.

The SDWA applies to public water systems (Calabrese 1989). The EPA's definition of a

public system is one that provides water to at least 25 people or has 15 service connections for a minimum of 60 days per year. The SDWA regulates health-based contaminants that are known or are likely to occur in drinking water, including organic pollutants, inorganics, pathogen indicators, radionuclides, and disinfectants and disinfection by-products. Maximum Contaminant Level Goals (MCLGs) are goals the EPA would like to attain, but they are not enforceable. There are also federally enforceable limits set for these contaminants known as maximum contaminant levels (MCLs). These levels are set near or at the MCLG based on technological and cost feasibility (EPA 2017b).

The original SDWA monitored the 28 chemicals listed in the Public Health Drinking Water Standards and introduced other organic and inorganic chemicals that required monitoring (EPA 1999). Total coliform bacterial levels also required monitoring. As time passed more standards were set, such as monitoring for trihalomethanes and radionuclides. The Act has had two major amendments, one in 1986 and the other in 1996. Currently, the SDWA includes chemical monitoring, pathogen monitoring, and surface water treatment requirements through risk-based assessments. Furthermore, the SDWA believes in the "right to know" as a way to promote public involvement and awareness, thereby improving accountability for the local governments and water treatment plants.

The Interim Enhanced Surface Water Treatment Rule (IESWTR) went into effect December 1998 (EPA 1998). The rule applies to public water systems serving 10,000 or more customers that use surface waters or groundwater under direct influence of surface water as source water for drinking. The rule addresses standards and treatment techniques for *Cryptosporidium*. The MCLG for *Cryptosporidium* has been set to zero by the rule. Public systems that use filtration as part of their treatment train must meet 2-log removal requirements for *Cryptosporidium*. For public systems that do not use filtration, they must set forth a watershed protection program to address *Cryptosporidium*. Other key elements of this rule define requirements for covers on newly completed water reservoirs, mandate state-led sanitary inspections, and require data collection of microbial inactivation levels to determine risk of disinfection byproducts.

The Surface Water Treatment Rule (SWTR) went into effect June 1989 (EPA 1989). The rule requires that surface water and groundwater under direct influence of surface water be filtered and disinfected. The SWTR set MCLs for viruses, bacteria, and *Giardia lamblia* and established treatment techniques for filtered and unfiltered water systems to decrease exposure of microbial pathogens.

Additional regulations that were implemented under the SDWA deal with the water source, and include the groundwater rule and variations of the surface water treatment rule. The Groundwater Rule went into effect November 2006 (EPA 2006), and imparts protection from microbial pathogens in source groundwater used by public systems. The rule is a risk-based approach with four main parts: 1) routine sanitary inspections of specific criteria and identification of major deficiencies; 2) source water monitoring when triggers are violated for total coliform or other state implemented criteria; 3) corrective action for systems with source fecal contamination or other significant shortcomings; 4) compliance monitoring of the water treatment system to confirm 4-log removal or inactivation (99.99%) of viruses has been achieved.

The Long Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR; EPA 2002) specifies treatment of microbial polluted water, focusing on small facilities (customers < 10,000). The Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) went into effect January 2006 (EPA 2007). The rule focuses on microbial protection measures required by higher risk public water systems using surface water as source, mainly addressing *Cryptosporidium*. If systems cannot provide the maximum level of treatment for *Cryptosporidium*, then monitoring of source water is needed to establish proper treatment requirements. The treatment requirements for *Cryptosporidium* depend on whether or not the public system uses filtration in their treatment train. Furthermore, the rule creates treatment techniques for uncovered water reservoirs and endorses the Stage 2 Disinfection Byproduct Rule, which enforces monitoring of haloacetic acids (HAAs) and trihalomethanes (THMs), when a public system

wants to make corrections to their disinfection practice.

The EPA provides public notices regarding actions such as regulation and permitting. The public notice process serves as communication between the public and the EPA. The EPA allows participation from the public during the public notice period in the form of comments or public meetings. At other times the EPA uses the process to inform the public of a final report.

Environmental rules also apply to tribal lands, which may be under the jurisdiction of a tribe or a regional EPA office. Utilities, whether operated privately, by tribes, or by the federal government, are responsible for quarterly testing, reporting, addressing violations, and notifying the public of violations. In this report, we compared SDWA violations in "Indian Country" (tribal lands) and non-tribal lands to gain a better understanding of recent water quality disparities. Important parameters assessed were: violation points accrued; drinking water source; population served; and violations involving public notice, monitoring and reporting, and health (MCL and treatment technology (TT)). Tribal and non-tribal data were aggregated by state to protect identity and to pool numbers from systems serving small tribes.

Methodology

Water quality reports were downloaded from the EPA's ECHO in October 2017, representing data from July 1, 2014 through June 30, 2017 (EPA 2017a). Search criteria entered included drinking water source type, location (Indian Country or not in Indian Country; by state), health-based violations, public notice violations (MCL violations), and monitoring/reporting violations. Individual compliance reports were accessed to differentiate between violations that were health-based versus those not reported or monitored. Non-Indian Country data for the same states were accessed using the same search criteria. In total, 30 states were part of this analysis; the remaining 20 states did not have tribal drinking water facilities within their boundaries.

To protect individual tribal and facility identities, data are presented by state and as total population affected, rather than by number of facilities out of compliance. This is because tribal and non-tribal facilities represent customer numbers spanning orders of magnitude ($n = 25 – 8 \times 10^6$ customers). In addition, the data are not differentiated by tribe, but rather by state.

Results and Discussion

Drinking Water Sources in Indian Country

There are 1001 drinking water utilities in "Indian Country" (all within 30 states) that report water quality data to the EPA. The source water report of each facility includes surface water, groundwater, and groundwater under the influence of surface water (included in groundwater data), some of which is purchased (not shown). Other than Alaska and North Dakota, a majority of tribal water facilities use groundwater as their drinking water source (Figure 1). However, when service population is included, tribal communities in Colorado, Kansas, Montana, North Carolina, New York, Oregon, Texas, and Wyoming shift to predominantly surface water sources (Figure 2). Non-tribal drinking water facilities obtain a majority of their source water from groundwater in all 30 states (Figure 3). The total customer water intake shifts to surface water, with the exception of Florida, Iowa, Idaho, Minnesota, Mississippi, Montana, Nebraska, New Mexico, South Dakota, and Wisconsin, whose water sources are primarily groundwater (Figure 4).

We then determined if tribal populations receive the same water source type as non-tribal customers within their state. To evaluate this, the surface water to groundwater population ratio was determined (data not shown). States that had greater percentage of the population serviced by surface water sources for both tribal and non-tribal communities included Colorado, Kansas, North Carolina, New York, Oregon, Texas, and Wyoming. However, in Alabama, Arizona, California, Massachusetts, Michigan, North Dakota, Nevada, Oklahoma, Rhode Island, Utah, and Washington, the non-tribal water source was primarily surface water, whereas the tribal water source was groundwater, based on customers served. This is an important distinction because certain contaminants are associated with groundwater and others with surface water sources, as discussed later.

Drinking Water Violation Points Accrued

To determine the overall disparity of drinking water violations in Indian Country, we evaluated the violation points accumulated by tribal and non-tribal facilities by state. The EPA tracks total violations (over five years) through a point system where 1 point is assigned for violations of public notice, violations of monitoring/reporting, and for each year a violation is not addressed; 5 points for each MCL or treatment technology violation that is not coliform or nitrate, monitoring/reporting violations of nitrate, and repeat monitoring violations of coliform; and 10 points for acute MCL violations of coliform or nitrate. This weighted point system puts emphasis on MCL violations and less on reporting/monitoring and public notice violations.

Because this is a three-year study and the point system is assessed for the previous five years, we divided the total points by 5 to obtain annual points accrued. Results show that the six worst offending states in Indian Country are AZ > WA > NM > CA > NV > UT on a per year basis (data

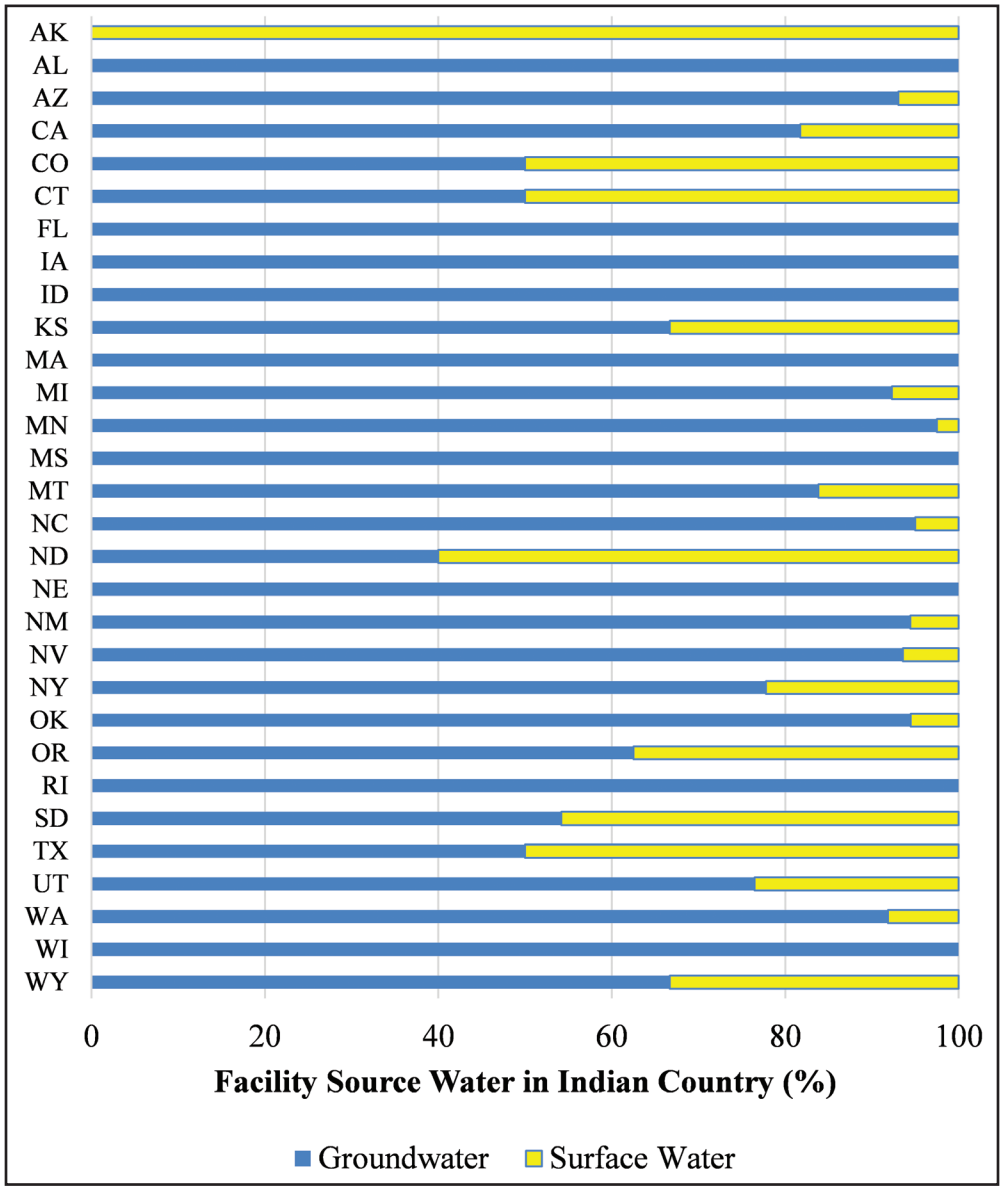

Figure 1. Facility source water percentage in Indian Country, by state.

not shown). The average points over a five-year period for each state do not account for the number of facilities out of compliance, or the number of customers per facility. This may explain why Arizona, Washington, New Mexico, and California have higher accumulated points, as there are more facilities and tribes.

To correct this, we normalized the data on a per 1,000 customer basis by state (Table 1). The data were aggregated (Figure 5), showing a statistical difference between non-tribal and tribal customers with respect to drinking water violation points. The average points accumulated per 1,000 customers per year was 0.86 for non-tribal water, and 5.13 for tribal water. The point disparity is statistically significant ($p < 0.05$), and serves as the basis for this study.

SDWA Compliance

SDWA compliance and violations are reported quarterly by individual water facilities. Those that fail to conduct or report values are out of compliance under monitoring and reporting requirements. If reported values exceed MCLs or

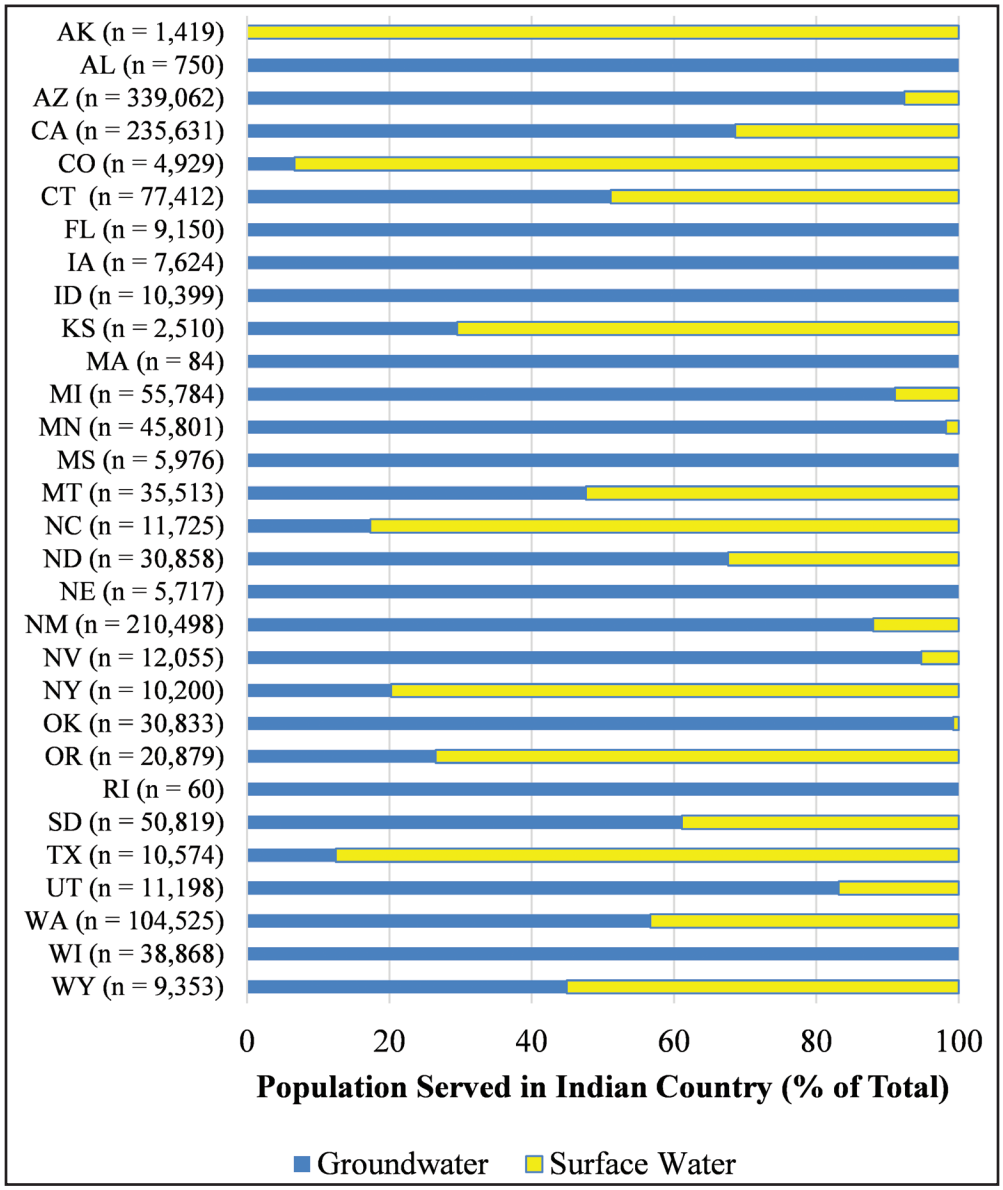

Figure 2. Customer source water in Indian Country, by state.

do not meet TT standards, a health-based violation is noted. For this analysis, we report the state tribal population (as percent) affected by a health-based violation during any quarter of the three-year time period (Figure 6).

Contaminant MCL and TT exceedances varied from state to state in tribal communities. There were no health-based SDWA violations in Alabama, Colorado, Connecticut, Florida, Kansas, Massachusetts, Michigan, Mississippi, North Carolina, North Dakota, Nebraska, Rhode Island, South Dakota, Texas, and Wisconsin during the time period of interest. All other states had MCL violations for at least one quarter of the three-year period. In these states, the most common contaminant-based violations were the coliform and revised coliform rule and arsenic, followed by total HAA and total THM. Less commonly, violations of total radium, nitrate, total carbon, diethyl hexyl phthalate (DEHP), and the lead and copper rule were also reported. Treatment-based violations included the groundwater rule

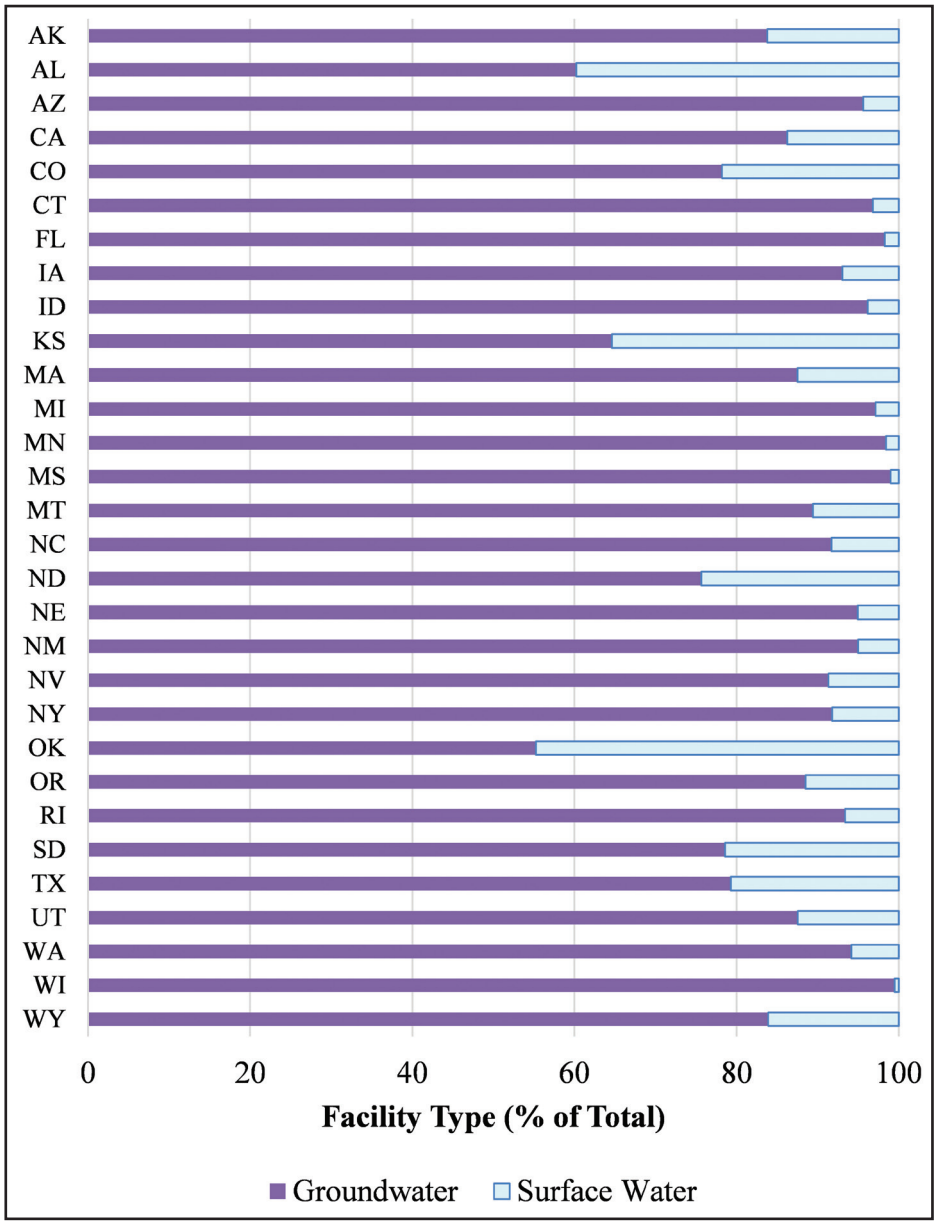

Figure 3. Non-tribal facility source water, by state.

and the SWTR. Analyzing the distribution within individual states, arsenic pollution affected tribal populations in New Mexico, Utah, and Washington to the greatest extent. Violations of the groundwater rule impacted tribes in Iowa, Oklahoma, and Wyoming. Coliform/revised coliform violations were prevalent in tribal communities in Arizona, Iowa, Idaho, Nevada, New York, and Oregon. The water source played a role in contaminant type, with surface water contributing to the elevated incidence of total HAA, total THM, and total carbon (C), indicators of elevated organic carbon in the source water (Figure 7). All other contaminants were primarily found in drinking water arising from groundwater sources, including coliform.

Comparisons between tribal and non-tribal facilities reveal that tribal customers in certain states are disproportionately affected by poor water quality, as measured by health-based MCL or TT violations, while those in other states fare better than non-tribal facilities (Table 2). MCL violations affected tribal customers in Alaska,

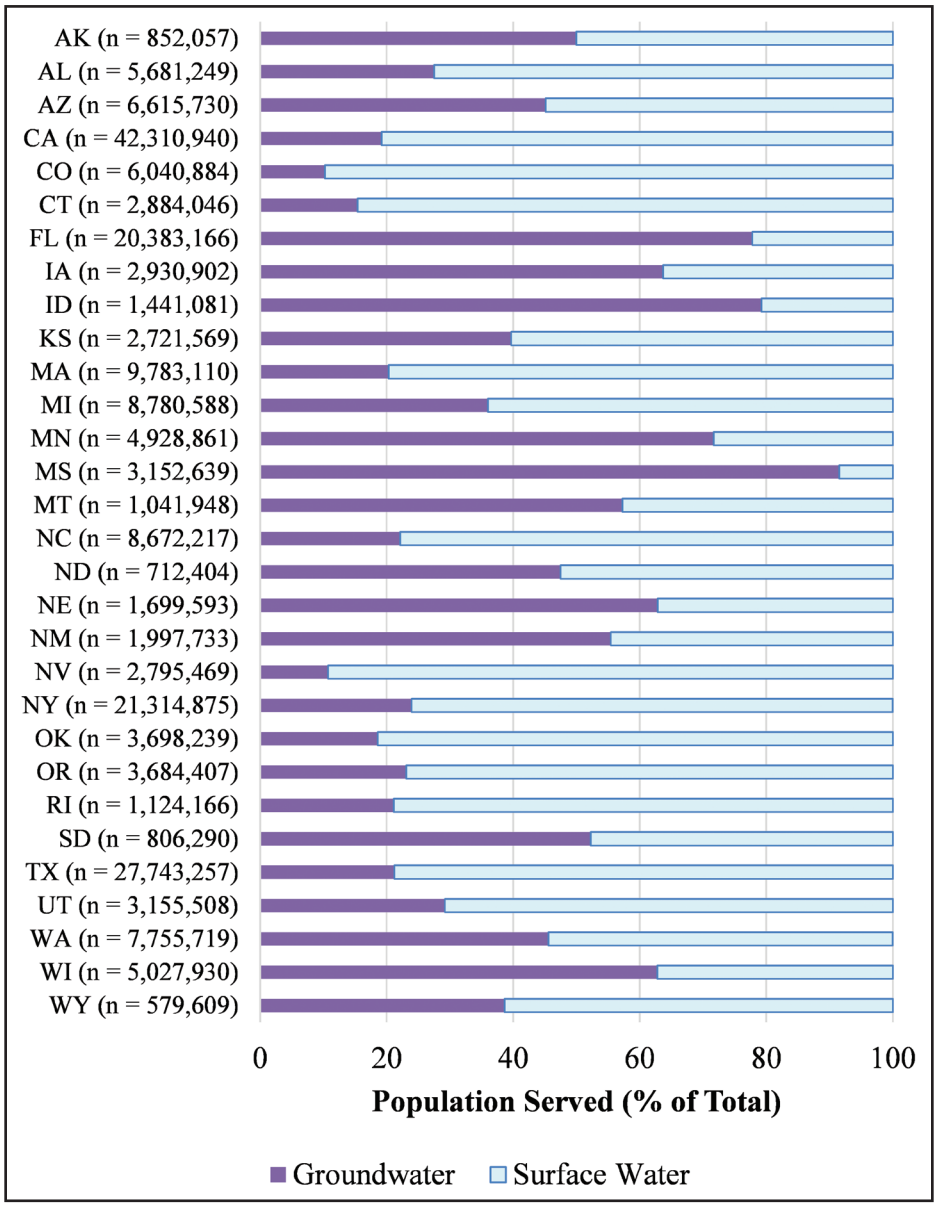

Figure 4. Non-tribal customer water source, by state.

Table 1. Drinking water violation points per year per 1,000 customers for non-tribal and tribal drinking water.

State	Non-Tribal	Tribal	Ratio (Tribal:Non-Tribal)
AK	5.40	2.82	0.5
AL	0.04	0.00	0.0
AZ	0.67	2.09	3.1
CA	0.27	1.08	4.0
CO	0.45	0.97	2.2
CT	0.80	0.00	0.0
FL	0.15	0.44	2.9
IA	0.56	0.94	1.7
ID	1.70	6.35	3.7
KS	0.24	9.56	40.6
MA	0.18	35.71	201.1
MI	0.60	0.37	0.6
MN	0.20	0.60	3.0
MS	0.18	2.11	11.4
MT	2.72	3.29	1.2
NC	0.46	0.00	0.0
ND	0.39	0.67	1.7
NE	0.96	2.27	2.4
NM	1.53	1.82	1.2
NV	0.29	11.53	39.8
NY	0.27	1.10	4.1
OK	1.85	1.12	0.6
OR	1.03	1.91	1.8
RI	0.35	50.00	143.6
SD	0.88	0.78	0.9
TX	0.65	0.11	0.2
UT	0.79	9.23	11.7
WA	0.35	4.73	13.5
WI	0.68	0.80	1.2
WY	1.30	1.35	1.0

Arizona, California, Iowa, Idaho, Minnesota, Montana, Nevada, Utah, and Wyoming at a greater percentage than non-tribal water customers. On the other hand, tribal drinking water quality was better in Alabama, Colorado, Connecticut, Florida, Kansas, Massachusetts, Michigan, Mississippi, North Carolina, North Dakota, Nebraska, Rhode Island, South Dakota, Texas, and Wisconsin, which all had state-wide MCL/TT violations, while none were reported on tribal lands. In addition, New Mexico, New York, Oklahoma, and Oregon had MCL violations that affected a greater population of non-tribal customers than tribal customers. The average percentage of customers in Indian Country affected by health-based violations was 8.6%, while that for non-tribal populations was 7.7% (Table 2, Figure 8).

Public Notice Violations

Public notice violations occur when the drinking water facility fails to notify customers of a SDWA violation (MCL exceedance) or for monitoring and reporting violations. Results showed that 25 of the 30 states had no public notice violations in Indian Country, while Arizona, California, Nevada, New Mexico, and Utah did. The violations in California and Nevada were due to failure to notify Indian Country residents of monitoring and reporting violations, and not due to MCL exceedances. Facilities in Arizona and New Mexico failed to notify tribal customers of violations of arsenic,

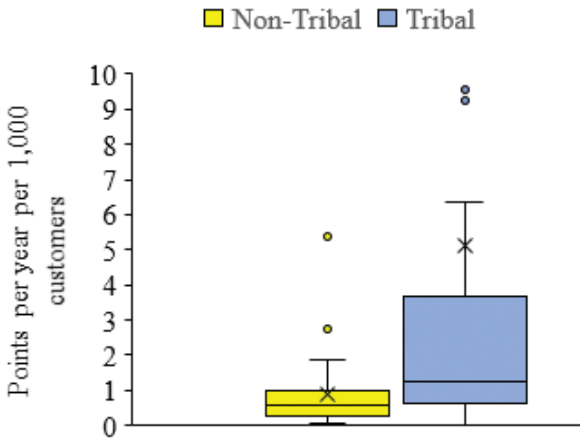

Figure 5. Drinking water violation points of non-tribal and tribal water, state aggregated. The difference is significant at $p < 0.05$.

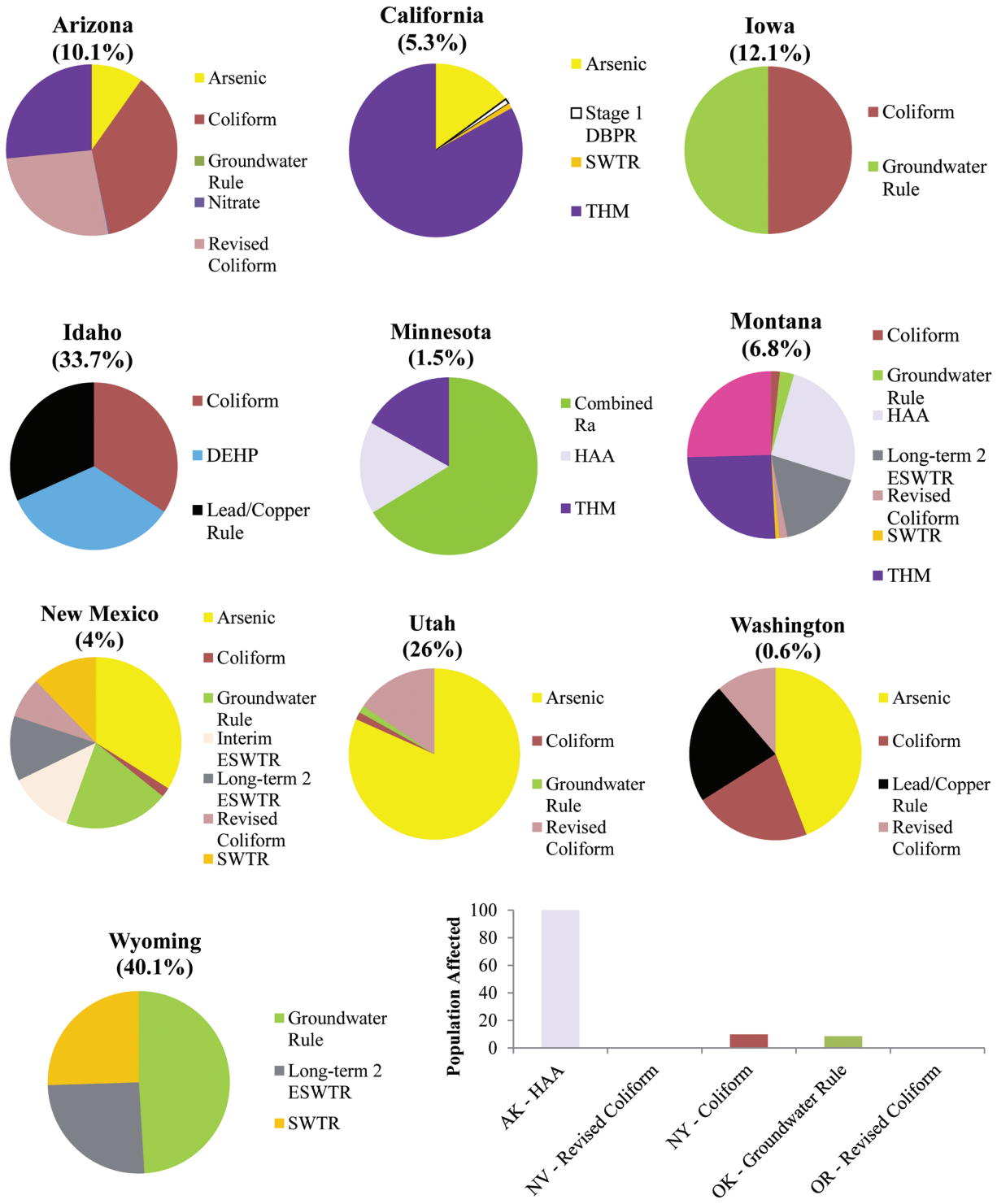

Figure 6. Health-based violations by state, with Indian Country population percentage affected in parentheses. Each pie chart is broken down by contaminant, and the bar graph shows states impacted by only one contaminant or rule violation. ESTWR = enhanced surface water treatment rule; SWTR = surface water treatment rule; HAA = haloacetic acid; THM = trihalomethane; Ra = combined radium; DEHP = diethyl hexyl phthalate; DBPR = disinfection by-product rule; NV = 0.3%; OR = 0.2%.

nitrate, total HAA, total THM, coliform, and revised coliform rules, with Arizona customers affected at a higher frequency than New Mexico customers. Facilities in Utah failed to notify the public of violations of the Stage 2 disinfectant and disinfection by-product rule (DBPR) and arsenic.

Arizona, California, Nevada, and Utah had public notice violations affecting a greater percentage of tribal customers than non-tribal customers. A number of states had public notice violations in non-tribal facilities (CO, CT, FL, IA, ID, KS, MS, NC, NM, OR, TX, WI), but no violations in tribal facilities (Table 2). Nationwide, public notice reporting was high for both Indian Country (97%) and non-Indian Country (97.3%), correlating to few violations.

Monitoring and Reporting Violations. Nearly two-thirds of the states analyzed had higher monitoring and reporting violations in Indian Country than in non-tribal facilities (Table 2, Figure 8). When averaged over the nationwide populations, monitoring and reporting violations affected 16% of non-tribal customers, while 32% of Indian Country drinking water customers were impacted.

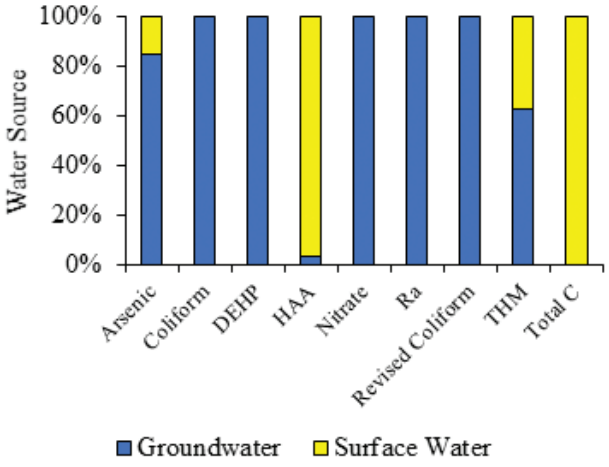

Figure 7. Contaminant by source water in Indian Country. Disinfection by-products (such as HAAs) form when carbon in the water source combines with chlorine or other halogens added during treatment for disinfection. Hence, HAA violations are more commonly associated with utilities relying on surface water sources. DEHP = diethylhexylphthalate; HAA = haloacetic acids; Ra = radium; THM = trihalomethane; C = carbon.

Analysis of Drinking Water Violations by Facility Size

The U.S. EPA defines a small drinking water facility as one serving less than 10,000 customers. Small drinking water facilities tend to have more violations compared to larger facilities (Rahman et al. 2010; Rubin 2013), and thus it was decided to analyze data according to facility size. As a first step, we looked at facility number and customers served in Indian Country. Of the 1,001 tribal drinking water facilities monitored under ECHO, 97.6% qualified as small treatment systems. The data set was then disaggregated by state, size (< or > 10,000 customers), and tribal/non-tribal facilities. The percentages of facilities with health-based, monitoring/reporting, and public notice violations were calculated for each state (Figure 9). For health-based violations, the facility average for tribal water was 10.9%, and 8.9% for non-tribal facilities. While the differences between non-tribal and tribal facilities were not statistically significant overall, individual state disparities exist covering the range (whiskers) and outliers (dots). We did not observe an increase in violations with smaller utilities, though the limited data set for tribal facilities that serve > 10,000 customers may have contributed to the lack of significance.

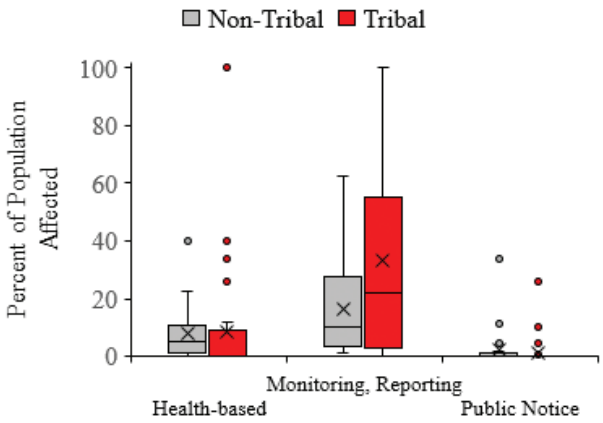

Figure 8. Percent of customers affected by drinking water quality violations. Tribal and non-tribal state data were aggregated in this analysis. The box encompasses upper and lower quartiles, the whiskers show the upper and lower range of data, the dots are outliers, the horizontal line is the median, and "x" is the average of the data set.

Table 2. Percentage of customers affected by drinking water violations by state.

	Health-based MCL/TT		Monitoring & Reporting		Public Notice	
State	Non-Tribal	Tribal	Non-Tribal	Tribal	Non-Tribal	Tribal
AK	9.7	100.0	24.8	0.0	0.1	0.0
AL	0.2	0.0	4.1	0.0	0.0	0.0
AZ	8.3	10.1	27.4	28.2	0.0	10.3
CA	3.4	5.3	9.0	14.5	0.2	1.1
CO	4.5	0.0	28.0	0.0	0.3	0.0
CT	0.4	0.0	41.9	51.1	1.1	0.0
FL	4.5	0.0	29.1	0.0	1.0	0.0
IA	9.7	12.1	1.4	12.1	0.2	0.0
ID	12.0	33.7	62.3	22.2	4.6	0.0
KS	3.5	0.0	7.9	70.5	1.2	0.0
MA	10.4	0.0	17.7	100.0	0.1	0.0
MI	1.1	0.0	3.7	6.9	0.0	0.0
MN	0.7	1.5	0.9	30.2	0.0	0.0
MS	3.9	0.0	3.2	100.0	1.3	0.0
MT	4.9	6.8	20.4	6.4	0.0	0.0
NC	5.2	0.0	10.2	0.0	1.9	0.0
ND	0.0	0.0	4.4	25.6	0.0	0.0
NE	22.5	0.0	2.9	2.8	0.3	0.0
NM	13.3	4.0	33.6	26.8	6.1	0.8
NV	0.1	0.3	2.4	48.9	0.0	4.3
NY	40.0	9.8	4.7	0.0	0.0	0.0
OK	18.8	8.4	41.0	2.5	0.0	0.0
OR	1.1	0.2	10.1	22.1	0.7	0.0
RI	0.1	0.0	3.0	100.0	0.0	0.0
SD	6.5	0.0	1.8	28.1	0.1	0.0
TX	5.8	0.0	20.1	87.5	11.4	0.0
UT	14.5	26.0	40.8	95.2	0.0	26.0
WA	17.1	0.6	13.4	66.9	0.0	0.0
WI	2.6	0.0	10.5	20.4	34.0	0.0
WY	6.8	40.1	5.8	20.8	0.0	0.0

Drinking Water Disparities

When analyzing drinking water disparities in under-served communities, many factors play a role, including source water, treatment facility type, and responsiveness to rule violations. In this data set, we have access to the source water type and violations of the SDWA, but not the facility, precise water source, and depth to water table for groundwater sources. We can compare tribal and non-tribal water demographics within the state, and so this poses the question, does tribal water quality reflect what is happening in the state, or is there a water quality difference that requires attention?

To assign a value to water quality disparities, we established a point-based per capita ratio that compares tribal and non-tribal violations. Tribal points per capita per year were divided by non-tribal values to obtain the ratio (R):

$$R_{disparity} = \frac{((Violation\ points,\ 5yr)\ /\ (5*state\ population))_{\text{Indian-Country}}}{((Violation\ points,\ 5yr)\ /\ (5*state\ population))_{\text{Non-Tribal}}}$$

A ratio greater than one indicates more EPA SDWA violations for Indian Country than for non-tribal lands, and a ratio greater than 1.5 ($R_{1.5}$) is equivalent to 50% more water quality violation points per capita in Indian Country. Using the $R_{1.5}$ cut-off, which was arbitrarily selected, we determined that there were evident water quality disparities in Indian Country for 60% of the states surveyed (Table 1). They include Arizona, California, Colorado, Florida, Iowa, Idaho, Kansas, Massachusetts, Minnesota, Mississippi, North Dakota, Nebraska, Nevada, New York, Oregon, Rhode Island, Utah, and Washington. Water quality data, based on points accrued, were better for tribal customers in Alaska, Alabama, Connecticut, Michigan, North Carolina, Oklahoma, South Dakota, and Texas. In Montana, New Mexico, South Dakota, Washington, and Wisconsin, violation points were similar in Indian and non-Indian Country.

Conclusions

These findings show there are water quality disparities in Indian Country as measured by points accrued due to drinking water violations. On an average point violation basis, which includes MCL, TT, public notice, and monitoring/reporting,

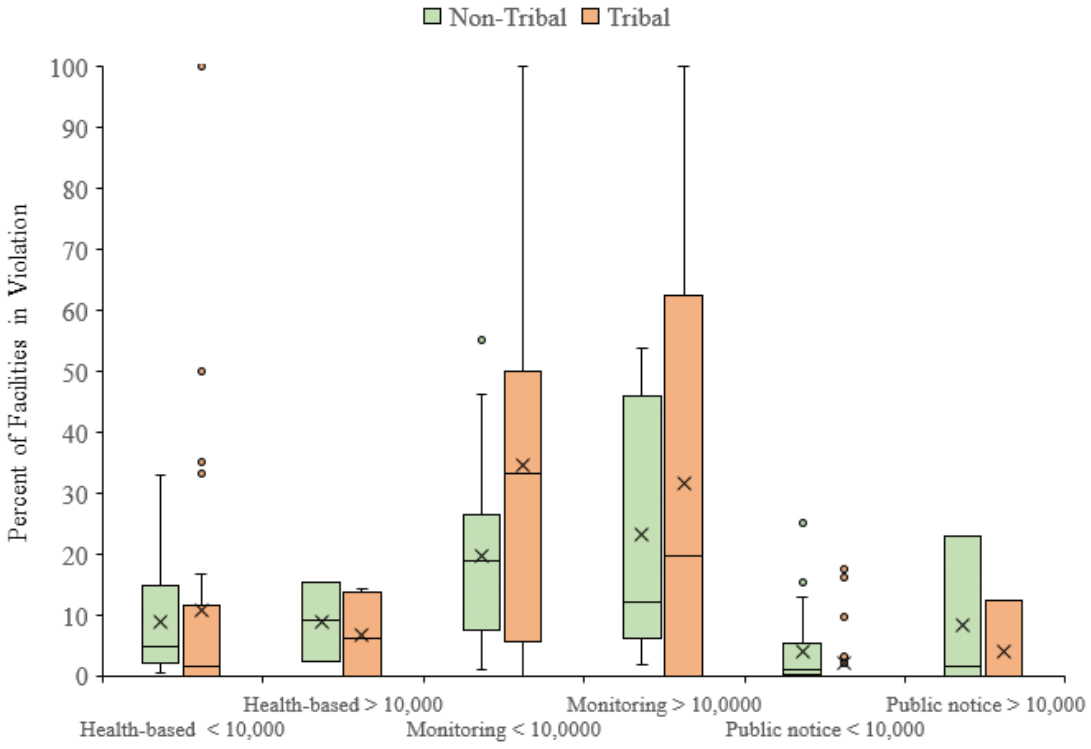

Figure 9. Percent of facilities with drinking water violations, by facility customer size.

a number of states had tribal facilities with poorer water quality compared to non-tribal facilities within the same state. An evaluation of specific rules showed little violation of public notice for both groups analyzed. There were greater differences when it came to violations of monitoring and reporting, with 32% of Indian Country facilities affected, whereas 16% of non-tribal facilities had similar violations. MCL violations affected some states more than others, though ultimately, the total point violation system projected the greatest apparent disparities. For facilities to reduce water quality disparity, monitoring and reporting must be addressed in addition to upgrades in treatment technology affecting the quality of produced drinking water. At a minimum, this will reduce violation points, bringing facilities to compliance.

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Tribal Economies: Water Settlements, Agriculture, and Gaming in the Western U.S.

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Abstract: This paper examines patterns in water rights quantification, agriculture, gaming, and economic characteristics across selected Native American nations in the United States (U.S.) to provide a perspective across tribal nations and regions. A unique set of data was analyzed, drawing from the U.S. Census Bureau, U.S. Department of Agriculture, court decrees, water rights data, and other sources. Fifty-one tribal nations are included in this study, based on availability of data on agricultural and economic indicators. Data analysis indicates the following: 1) tribes with quantified water rights also have higher agricultural revenue, 2) tribes which have quantified their water rights are more likely to also operate a casino, 3) tribes which have quantified their water rights tend to be more commonly located close to major cities, and 4) tribes which operate at least one casino have notably higher annual household income compared to tribes which do not. A number of interesting regional differences are observed: 1) Northwest tribes have significantly higher rates of water quantification than other regions, 2) Midwest tribes have the highest prevalence of casino operations compared to the other areas, and 3) the Southwest has the smallest proportion of tribes with casino operations. This paper identifies patterns across multiple tribal nations and across regions, and does not focus on establishing cause-and-effect. Causal relationships among tribal water quantification, farming, gaming, income levels, and unemployment will vary by location and tribe. Identifying cause and effect among different components of tribal economic development warrants further inquiry. The examination of patterns presented here illuminates interesting differences among tribal nations and regions, and provides a broad context for tribal leaders how best to cultivate sustainable, resilient economies and water resource management.

Keywords: *economic development, water rights, quantification, farming, casinos, water leasing*

Native American nations have legal entitlements to water resources in the United States (U.S.) and engage in active on-reservation water use and off-reservation water leasing. More than 50 tribes have secured over 10 million acre-feet per year (afy) of water through negotiated water settlements and/or through litigation (Landry and Quinn 2007). Tribal water rights were formally recognized by U.S. courts in 1908, when an irrigation project was being developed by the Fort Belknap Indian Reservation in Montana. During dry periods, the tribal project could not access water and the U.S. government sued upstream water users on behalf of the tribe in *Winters v. U.S.* (Landry and Quinn 2007). The Supreme Court affirmed that tribal nations have the right to use and manage water in order to fulfill the purposes of their land reservations. While tribes have strong legal entitlements to water, the quantification of those rights and provision of water supplies to tribal nations has been slow, costly, and painstaking, and continues as an ongoing process.

Over the last 50 years, many tribal nations have engaged in water settlement negotiations to quantify their water entitlements and secure funding for reservation water projects and economic development. A water settlement agreement typically involves negotiations between a tribal nation, federal agencies, states, water districts, and other water users in the area where the tribe is quantifying their water rights. Negotiated water settlements aim to resolve

conflict among water users by allowing parties to specify water allocations, provide water supply assurances, and reduce litigation. Many settlements explicitly authorize tribal nations to lease tribal water for use off-reservation (Colby et al. 2005; Stern 2015).

This article focuses upon three potential components of tribal economic development which are particularly relevant for tribal nations in the U.S.: water rights quantification and leasing, agriculture, and gaming. Sustainable economic development and effective policies are important in tribal nations' efforts to decrease poverty and unemployment rates. On average, a large disparity still exists between households in the national U.S. economy and households located on tribal reservations. Census data indicate that tribal households experience double the U.S. average unemployment rate and earn only 60 percent of the average U.S. household income (Rancier 2012; Davis et al. 2015; American Factfinder 2017).

Decisions by tribal nations to quantify water rights, to lease tribal water, and/or to develop infrastructure to deliver water to tribal homes, businesses, and farms provide one potential pathway for promoting tribal economic development (Waton 2015). In the U.S., tribal communities need to be federally recognized as tribal governments to formally claim water rights, so this option is not currently available to tribal communities which do not have this federal recognition.

In addition to facilitating access to water for reservation households and businesses, many Native American water settlements authorize off-reservation tribal water leasing. Tribal water leasing generally must be approved by the Secretary of the Interior, and state governments impose various conditions on tribal leases to protect state interests (Landry and Quinn 2007). Water quantification and leasing can offer tribes a valuable revenue source (Colby et al. 2005; Colby 2006; Cosens 2006; Landry and Quinn 2007; Killoren 2012; Bovee et al. 2016). Previous research has not systematically examined the interplay of tribal water rights quantification and tribal economic indicators. The economic effects of water rights quantification and leasing are not well understood.

This paper examines patterns across tribal nations in water quantification, agricultural earnings, and operation of casinos. Income levels and unemployment rates are accessible economic indicators for tribal economies and are used to identify patterns across selected U.S. tribal nations. The tribal nations included in this study were selected based on availability of relevant data. Data were collected from the U.S. Census Bureau, U.S. Department of Agriculture (USDA), water specialists, court decrees, news articles, and scholarly papers. Data were available for both 2010 and 2015 on tribal nations located in 12 states (Arizona, Idaho, Kansas, Montana, Nebraska, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming). The USDA agricultural data that are critical to this study are only available for 41 tribal nations in 2010 and 51 tribal nations in 2015. Therefore, the complete dataset consists of 92 tribal nations over the two time periods. Analysis is conducted using t-tests to detect statistically meaningful differences across tribal nations, regions, and time periods.

This overview and comparative analysis across tribal nations and regions provides a broad perspective that can assist tribal decision-makers in considering policies to further sustainable economies, resource governance and management, and resilience to pressures of climate change. This study is not intended to identify specific cause and effect relationships between tribal water rights quantification, agriculture, gaming, and economic indicators. Causality and interrelationships among these factors can best be understood by focused site specific studies.

Reservation Economies, Tribal Water Settlements, and Off-Reservation Leasing

Native American nations govern tribal reservations which are limited compared to tribes' pre-European land bases. Nevertheless, reservations provide a base from which tribal nations exercise sovereign governmental powers over natural resources and economic development (Tsosie 2006).

Not all tribes in the U.S. are federally recognized, nor do they all have a land reservation. Some tribes govern themselves and seek to preserve cultural traditions without either federal recognition or

a reservation land base. There are 567 federally recognized tribes across the U.S. (NCSL 2018). Tribes develop their economies through a wide range of activities, including agriculture, mining, and tourism. Some tribal nations pursue economic development by quantifying their water rights, developing infrastructure to deliver water, and leasing tribal water to earn revenue. Tribal reservation lands have unusual and sometimes complex ownership patterns. Reservation land is held "in trust" by the federal government and not available to serve as collateral for commercial loans. Tribal members and non-tribal members hold private land allotments within reservation boundaries in many tribal nations, posing complications for cohesive governance and management of reservation natural resources (Wood 2003).

Tribal nations' right to govern their water resources is affirmed through a long history of jurisprudence and Congressional action which traces back to the landmark 1908 *Winters v. U.S.* U.S. Supreme Court decision. To make effective use of their water, many tribal nations have elected to quantify their water rights through costly and lengthy litigation or through negotiated water settlements. Over 50 tribes in the western U.S. have quantified their water rights and more tribes are in the process of negotiating water settlements (see extensive reference list accompanying Table 3). The Ak-Chin Indian Community of the Maricopa Indian Reservation, the Confederated Tribes of the Colville Reservation, and the Spokane Tribe of the Spokane Reservation were some of the first tribes to quantify their water rights in the 1970s (Colby 2006; Rancier 2012; Chief et al. 2016; Cosens and Chaffin 2016; Tribal Water Uses in the Colorado River Basin 2016).

In many settlement agreements, the federal government and other parties provide funds to tribal nations for economic growth, community development, wildlife restoration, water acquisition, and water projects. Most settlements are partially funded by the federal government and involve in-kind contributions from tribes, states, cities, and other water users. In some cases, water is transferred or exchanged with non-Indian water users to provide adequate water to tribes. Each settlement is unique. In the San Luis Rey settlement, the state, local, and tribal parties shared the cost to provide water, while in the Animas-La Plata Project case the water users and the tribe shared the cost. The only two settlements fully funded by the federal government were the Ak-Chin Indian Water Rights Settlement (1984) and the Northern Ute Indian Settlement (1992) (Colby 2006; Rancier 2012).

Monetary payments to tribes can occur as part of settlement packages for various reasons: 1) as compensation for past damages to tribal resources, 2) in lieu of providing larger quantities of water to tribes, and 3) to aid in water infrastructure and economic development on tribal lands. Tribal nations persevere over many years to secure their water allocations and carefully weigh tradeoffs between water and money in settlement negotiations (Colby et al. 2005; Colby 2006).

Tribal water leasing occurs in various parts of the western U.S., particularly in the Colorado River Basin. The Colorado River Basin includes 20 tribal nations, portions of seven U.S. states, and parts of two Mexican states (National Water Census 2018). Urban areas concerned about future water shortages lease tribal water to meet growing demands. Tribes also lease water to off-reservation water users to improve water quality and reliability, and to support natural habitats (Nyberg 2014).

In 2016, tribal water leasing was estimated to transfer about 260,000 afy, with $19 million revenue annually (Bovee et al. 2016). As drought becomes more persistent, short-term and intermittent water leases may be attractive for tribes and non-Indian parties. These types of drought-triggered intermittent leases allow tribes to exercise their water rights and earn revenue while providing water to non-Indian users during dry periods (Colby 2006; Bovee et al. 2016).

While water leasing offers tribes access to revenue, it is only one of many options for generating economic activity and revenue. Tourism, gaming, resort development, fishing, ranching, farming, and mining are all methods by which tribes generate income from their land and water (Fletcher 2004; Rosser 2005; Navajo Nation Sales Tax 2006). In some cases, water rights quantification and leasing can support tribal economic development, livelihood opportunities on tribal lands, and tribal adaptation to effects of

climate change on tribal natural resources and communities (Marsh and Smith 2015; Stern 2015; Chief et al. 2016; Cosens and Chaffin 2016).

Methodology

Data

This study utilizes data from USDA's Agricultural Census Survey, the Census Bureau, and other sources. Data were analyzed for 41 tribes in the U.S. in 2010 and 51 tribes in the U.S. in 2015. Tribal nations included in these surveys have reservations located in 12 U.S. states across three regions (Southwest: Arizona, New Mexico, and Utah; Northwest: Idaho, Montana, Oregon, Washington, and Wyoming; and Midwest: Kansas, Nebraska, South Dakota, and North Dakota).

Most western states allocate state-governed water under the doctrine of prior appropriation, with senior water rights being the last to be cut off in times of shortage. Tribes are typically senior water right holders because water rights of tribal nations date back to the date their land reservation was established. This seniority gives tribal water entitlements a higher degree of reliability during drought and an added financial value in water leasing.

Irrigation is an important method of farming in the arid western U.S., and crop irrigation accounts for a large share of the nation's water use (Schaible and Aillery 2013; USDA Economic Research Service 2017). In order to focus on agriculture as part of tribal economies, this study only includes those tribes in the U.S. which had agricultural data available in the 2010 and 2015 USDA Agricultural Census Surveys. Economic data were collected from the Census Bureau and gaming data were collected from the National Indian Gaming Commission. Geographic and water data were collected from various sources to create a unique data set across selected western U.S. tribal nations.

A total of nine variables are examined in this paper: 1) *Value of Agricultural Products Sold*, 2) *Unemployment*, 3) *Income*, 4) *Education*, 5) *Population*, 6) *Proximity to Major City*, 7) *Casino*, 8) *Water Rights*, and 9) *Year*. Refer to Table 1 for reference to the variables used in this study, their definitions, and data sources. All dollar figures in this article have been adjusted to 2015 dollars, to be consist with the most recent (2015) financial data used in this study. The next subsections of this article discuss the data in detail.

Agricultural Data. The USDA National Agricultural Statistics Service released data from the Agricultural Census Survey in 2010 and 2015. The data were collected by mailing surveys to tribes in 2007 and 2012, respectively. The USDA mailed surveys to every tribal nation, aiming to obtain survey responses from every tribe (USDA 2011; USDA 2017). However, incomplete survey responses reduced the USDA tribal data to 41 western U.S. tribes in 2010 and 51 in 2015.

The USDA data provide the *Value of Agricultural Products Sold* variable, defined as the market value of agricultural products sold for each tribe. This represents the gross value of all agricultural products sold, before taxes or production expenses (see Table 2). The data have been adjusted for inflation to 2015 dollars. On average, across the tribes included in this study, tribal nations received about 59 million dollars a year from agricultural products between 2010 and 2015, with wide variation across tribes.

Population, Education, and Economic Data. Data for tribal reservations were collected in the U.S. Census Bureau American Community Survey (ACS). The ACS began data collection with tribal nations in 2006 and collected data for over 60 months. Data are available for 2010 and 2015, with 2010 data gathered from 2006 - 2010, and 2015 data gathered from 2011 - 2015. For simplicity, we refer to the first data period as 2010 and the second period as 2015.

To analyze U.S. Census Bureau economic data alongside the USDA agricultural data, this study places 2010 USDA Agricultural Census data (collected in 2007) with 2010 Census Bureau data (collected from 2006 to 2010) and 2015 USDA Agricultural Census data (collected in 2012) with 2015 Census Bureau data (collected from 2011 to 2015). The two time periods (2010 and 2015) provide information for a total of 92 observations; 41 tribes for 2010, with an additional ten tribes having necessary data for 2015. Table 2 reports the averages of the variables examined in this study.

Income and unemployment data, collected from the U.S. Census Bureau, are used as economic

Table 1. Variable names, definitions, and sources for data analyzed on tribal nations.*

Variable Name	N	Definition	Source
Value of Agricultural Products Sold	92	The gross market value of all agricultural products sold before taxes or production expenses in $1000. It is the total number of sales regardless of who received the payment i.e., partners, landlords, contractors, etc.	United States Department of Agriculture, Census of Agriculture
Unemployment	92	The percentage of the population 16 years and over who are actively seeking a job.	Census Bureau
Income	92	The mean family income in inflation-adjusted dollars for the year examined.	Census Bureau
Education	92	The percentage of the population who are high school graduates or higher.	Census Bureau
Population	92	The total population of the reservation.	Census Bureau
Proximity to Major City	92	If a reservation's address or it's tribal headquarters' address is located less than 50 miles of driving distance from a major city (Proximity=1) or if not (Proximity=0). A major city is defined as one of the top three most populous cities in one of the western states selected for this study, or one of the top ten most populous cities with at least 100,000 residents.	Address: Tribal website or Google Population of cities in each state: Demographics by Cubit Driving distance to major city (miles): Google Maps
Casino	92	If a tribe operates at least one casino (Casino=1) or if not (Casino=0).	National Indian Gaming Commission
Water Rights	92	If a tribe has quantified its water rights (Water Rights=1) or if not (Water Rights=0).	Various Sources
Year	92	If data were observed in 2010 (Year=0) or if data were observed in 2015 (Year=1).	-

*The names and locations of tribal reservations were established through the Census Bureau and the Bureau of Indian Affairs.

indicators in this study. The *Income* variable used in this study is the sum of all forms of earnings received per tribal household in inflation-adjusted dollars, for the years examined. The income data collected for 2010 are adjusted to 2015 dollars to be compared to income data in 2015. Census Bureau data indicate, on average, a household in the tribal nations included in this study earns about $48,000 a year.

The *Unemployment* variable shows the percent of individuals over the age of sixteen who are actively looking for a job, divided by all individuals currently in the labor force. The average unemployment level in the tribal nations included in this analysis was 17.27 percent between 2010 and 2015.

Education may help tribes increase household income and support job opportunities (Hopi Education Endowment Fund 2007). Education data were also collected from the Census Bureau and the *Education* variable is defined as the percent of individuals with at least a high school diploma. About 81 percent of individuals on the reservations examined in this study received a high school diploma.

Table 2. Variable means in 2010 and 2015.

Variable	N	Mean	Standard Deviation	Minimum	Maximum
Water Right (%)	92	40.22	49.30	0	100
Casino (%)	92	73.91	44.15	0	100
Unemployment (%)	92	17.27	7.52	5.00	40.00
Income ($)	92	48,013	9,457	24,723	79,576
Education (%)	92	80.65	8.15	55.80	97.20
Value of Agricultural Products Sold ($1000)	92	58,566	77,334	22	571,100
Population (%)	92	11,012	25,018	59	173,822
Proximity to Major City (%)	92	21.74	41.27	0	100

Population data were also collected from the Census Bureau. *Population* variable is the estimated total population on a tribal reservation. The Census Bureau contacts representatives of tribal governments to identify boundaries of tribal nations from the list maintained by the Bureau of Indian Affairs (U.S. Census Bureau 2018). For many tribal nations, a large portion of tribal members live off of the reservation and are not counted in tribal reservation populations by the Census Bureau (U.S. Census Bureau 2018).

Geographic Data. Geographic data were collected to examine how water rights quantification is affected by the proximity of a tribe to a major city. This study created the *Proximity to Major City* binary variable to investigate the relationship. A major city is defined by the authors as one of the top three most populous cities in a state, or one of the top ten most populous cities with at least 100,000 residents. The zip code for the tribal nation was found from the listed physical address on the tribe's website. Driving distance was calculated from the city's zip code to the tribal nation's zip code. If the distance to a major city was less than 50 miles driving, the tribe was assigned a one, and if greater than 50 miles, a zero was assigned.

Casino Data. Tribal nations take diverse pathways in considering and adopting gaming as part of their economic development strategy. In the 1970s, the development of card rooms and bingo halls began to emerge among tribal nations as a means to bring revenue and job opportunities. However, local and state governments were concerned with potential negative effects of gaming and posed various obstacles to tribal gaming. Today, tribal nations decide upon opening a casino and then work with nearby local governments and state government to consider impacts. Tribes sometimes pay for mitigation to open a casino. Casinos have caused some disparities and conflicts within tribal communities (Peters et al. 2015; Savio 2016).

Data on casinos were collected from the National Indian Gaming Commission's Gaming Tribes Report. To determine if the tribe had opened a casino after 2010, we examined the tribe's gaming ordinance date. The Indian Gaming Regulatory Act requires each tribe to have its gaming ordinance approved by the Commission before opening a casino. No tribe in this study had a gaming ordinance approval date after 2010, so the same casino data were used for both 2010 and 2015. The *Casino* variable is a binary variable where a one was assigned if the tribe operated at least one casino and a zero, if not. Seventy-three percent of all tribes included in this study have at least one casino. Data on the size of a tribal casino (such as the number of slot machines or the number of employees) would have been useful in this work. However, such data were not available (NIGC 2018).

Water Data. Water rights data were gathered from multiple sources: media articles, court decrees, settlement documents, scholarly papers, and interviews with tribal water rights specialists (Stone 2017). Water rights quantification through court rulings and by settlements approved by Congress are accompanied by public records and news coverage. If no information about a tribal nation's water rights could be found after an extensive search, we assumed the tribe did not quantify its water rights. The *Water Rights* variable is a binary variable. A one was assigned if the tribe quantified its water rights by the year indicated, and a zero if not.

Despite extensive searching, a comprehensive centralized data base on tribal water right quantification does not appear to be available. Table 3 summarizes data on tribal water rights, casinos, and proximity to major city for the tribes covered in this study to create a broad data set. About 43 percent of the tribal nations included in this study have quantified their water rights.

Analytic Methods

The data available to examine the economic development components of interest for this study are limited. Data on size of casinos, tribal water use patterns, and number and size of tribal businesses were not readily available. Moreover, the data exhibit only minor changes between 2010 and 2015. Proximity to a major city and casino is static during the two data periods. T-test analyses are utilized to examine patterns across tribal nations and to account for variables of interest that could not be observed due to absence of data.

T-test analyses in the paper examine difference in means in *Water Rights*, *Casino*, and *Proximity to Major City*. This analysis is used to indicate a statistically meaningful difference between groups of tribal nations and between regions.

First, we analyze the difference between tribes which have quantified their water rights and those which have not. This analysis assesses whether other variables examined in this paper systematically differ with water quantification, i.e., 1) *Value of Agricultural Products Sold*, 2) *Unemployment*, 3) *Income*, 4) *Education*, 5) *Population*, 6) *Proximity to Major City*, and 7) *Casino*. We compare based on the *Water Rights* variable, where one group of tribal nations is defined by having quantified water rights (*Water Rights*=1) and the other is defined by not having quantified water rights (*Water Rights*=0).

Second, we look at the difference in means between tribes which have no casino (*Casino*=0) and tribes that have at least one casino (*Casino*=1). This t-test looks at tribes' 1) *Value of Agricultural Products Sold*, 2) *Unemployment*, 3) *Income*, 4) *Education*, 5) *Population*, 6) *Proximity to Major City*, and 7) *Water Rights*. Lastly, we test whether differences exist between tribes who are located within 51 miles to a major city versus those who are not. We note differences that are statistically significant at a 90, 95, and 99 percent level. A statistically significant t-test result is determined by several factors, such as sample size.

Results

Patterns in Gaming, Water Rights Quantification, Agriculture, and Location

Analysis of data compiled for this study indicates tribes which have quantified their water rights are more likely to also operate a casino. Twenty-one of the tribal nations in this study have quantified their water rights through a formal litigation or settlement process, and 37 of the tribal nations in this study operate at least one casino. In 2010, the first period of this study, 20 tribes had quantified their water rights while 31 had not. By 2015, there was one new tribal water quantification, the Blackfeet Nation of Montana, bringing the total to 21 tribes which had quantified their water rights.

Figure 1 illustrates various combinations of activities in which the tribes included in this study are engaged. Only 5 of the 51 tribes in this study quantified their water rights without also operating a casino. Of the 51 tribes, 21 tribal nations operate at least one casino and have not quantified water rights. Nine tribes have neither quantified water rights nor operate a casino. Sixteen tribes have both quantified their water rights and operate at least one casino. Of the 16 tribes with both quantified water rights and a casino, half of them quantified water rights first and then opened a casino. The causal mechanisms for the relationship between water quantification and casinos vary from tribe to tribe. Further understanding of the patterns requires location-specific research. The analysis in

Table 3. Water rights quantification, casinos, proximity.

#	Tribal Nation	[1]Water Rights Document Name	Document Type	Passed	# of Casinos**	Proximity to Major City (miles)****
1	Blackfeet	Blackfeet Water Rights Settlement Act of 2015	Settlement	2015	2	111
2	Burns Paiute				0	132
3	Cheyenne River				1	322
4	Coeur d'Alene				3	34.8
5	Colorado River	*Arizona v. California*	Court Decree	1963	1	155
6	Colville	*Colville Confederated Tribes v. Walton*	Court Decree	1978	3	113
7	Crow	Crow Tribe Water Rights Settlement Act of 2010	Settlement	2010	2	80.7
8	Crow Creek				1	172
9	Flandreau Santee				1	42.9
10	Flathead	Salish and Kootenai Water Rights Settlement Act of 2016	Settlement	2016	2	68.6
11	Fort Belknap	Fort Belknap-MT Compact of 2001	Settlement	2001	1	78
12	Fort Berthold				4	374
13	Fort Hall	Fort Hall Indian Water Rights Act	Settlement	1990	0	12.3
14	Fort Mojave	*Arizona v. California*	Court Decree	1963	0	96
15	Fort Peck	Fort Peck-Montana Compact of 1985	Settlement	1985	0	169
16	Fort Yuma-Quechan	*Arizona v. California*	Court Decree	1963	0	181
17	Gila River	Gila River Indian Community Water Rights Settlement Act, Arizona Water Rights Settlement of 2004	Settlement	2004	3	16.8
18	Havasupai				0	235
19	Hopi				0	190
20	Hualapai				0	138
21	Lake Traverse				3	96
22	Lower Brule				1	185
23	Lummi	*U.S. and Lummi v. Washington Department of Ecology*	Court Decree	2007	1	102
24	Navajo Nation	(NM only) Navajo Nation San Juan Basin in New Mexico Water Rights Settlement Agreement of 2010	Settlement	2010	4	100
25	Nez Perce	Nez Perce Tribe - Snake River Water Rights Act of 2004	Settlement	2004	2	12.8
26	Northern Cheyenne	Northern Cheyenne Indian Reserved Water Rights Settlement Act	Settlement	1991	1	98.6
27	Omaha				2	79

Table 3 Continued. Water rights quantification, casinos, proximity.

#	Tribal Nation	[1]Water Rights Document Name	Document Type	Passed	# of Casinos	Proximity to Major City (miles)
28	Pine Ridge				0	338
29	Pueblo de Cochiti				0	22.1
30	Pueblo of Isleta				2	33
31	Pueblo of Jemez				0	35.5
32	Pueblo of Santo Domingo				0	32.3
33	Pueblo of Zuni	Zuni Indian Tribe Water Rights Settlement Act of 2003	Settlement	2003	0	150
34	Rocky Boy's	Chippewa Cree Tribe of the Rocky Boy's Reservation Indian Reserved Water Rights Settlement Act	Settlement	1999	0	28.1
35	Rosebud				1	219
36	Sac and Fox				2	81
37	Salt River Pima-Maricopa	Salt River Pima-Maricopa Indian Community Water Rights Settlement Act	Settlement	1988	2	4.5
38	San Carlos Apache	San Carlos Apache Tribe Water Rights Settlement Act	Settlement	1999	1	91.4
39	Santee Sioux				1	126
40	Spirit Lake				1	157
41	Spokane	*United States v. Anderson*, U.S. Ct. of Appeals, 9th Cir, 1984	Court Decree	1984	2	48.7
42	Standing Rock				2	300
43	Tohono O'odham	Arizona Water Rights Settlement of 2004	Settlement	2004	4	74.6
44	Tulalip				3	12.2
45	Turtle Mountain/ Trenton Indian Service Area				3	250
46	Umatilla				1	184
47	Warm Springs	Confederated Tribes of the Warm Springs Reservation Water Rights Settlement Agreement	Settlement	1997	1	67.1
48	Wind River	Wind River, Arapahoe, Shoshone, and Big Horn Litigation	Court Decree	1992	4	35.4
49	Winnebago				3	84.5
50	Yakama	Acquavella Adjudications	Court Decree	2006	1	180
51	Yankton				2	115

[1]Document references listed by # at the end of the References section.

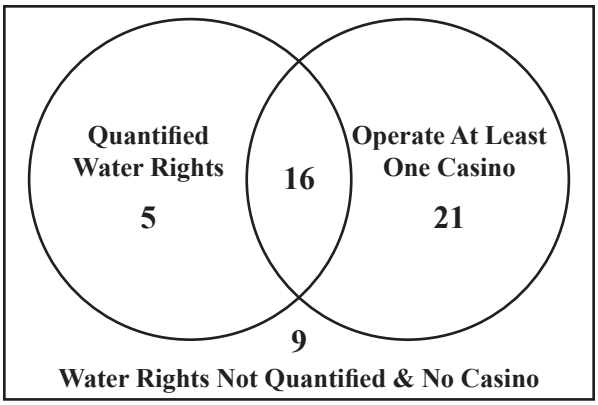

Figure 1. Diagram indicating number of tribal nations with quantified water rights and/or casinos, 2015. Total number of tribes = 51.

this paper examined patterns across multiple tribal nations and does not focus on establishing cause-and-effect.

Tribal nations with quantified water rights exhibit statistically significant differences from those without quantified water rights in terms of education, value of agricultural production, location relative to cities, and reservation population. Table 4 summarizes these results. Tribes with quantified water rights have an average of $47 million more in annual agricultural revenue than tribes without quantified water rights. Causal mechanisms need to be investigated on a location-specific basis. Some tribal nations may choose to quantify their water rights because they want to increase their agricultural production, and in other cases tribes which already have high agricultural production may quantify their water rights in order to protect their water access for farming. Future case-specific research can address these questions.

Tribes with quantified water rights tend to be more commonly located close to major cities than their counterparts without quantified water rights, at a 5 percent statistical significance level (Table 4). As tribal nations have larger populations, they are also more likely to have quantified their water rights. While the reasons for these patterns will differ by location, competition for water due to tribal lands proximity to cities may increase the likelihood of water rights quantification (Mauer 2016).

Another set of statistical tests compares tribal nations with a casino versus those without a casino, indicated in Table 5. The t-value test on income level for those with a casino is statistically significant at a one percent level. Tribes which operate at least one casino have a higher annual household income level by about $7,000, compared to tribes which do not. Also, tribes with at least one casino have higher population than tribes without a casino. There are no statistically significant differences in water rights quantification, unemployment, education, value of agricultural products sold, and proximity to major city between tribes which operate at least one casino and those which do not.

Casinos affect tribal economies by offering employment and increased revenue. Other unexamined factors may be contributing to the observed higher income. From 1988 to 2013, the number of tribal nations with casinos has increased. There are more than 440 tribal gaming operations in 31 U.S. states. Gaming revenue has increased from $100 million to $28 billion (Akee et al. 2015). Some researchers observe that gaming funds help improve life on reservations and help tribal governments move closer to fiscal independence (Mauer 2016; Douglas 2017). Over the past two decades, Akee et al. (2015) found that income increased overall for Native Americans living on reservations (both reservations with and without casinos) as more females entered the labor force, unemployment rates fell, and reservation housing quality rose. The Akee study used data from the 2011 U.S. Census which included Native Americans living on reservations in 48 contiguous states.

The last set of statistical analyses examines differences among tribal nations based on *Proximity to Major City* (Table 6). Tribes located close to a major city have significantly higher rates of quantifying their water rights and have higher unemployment levels than tribes located on more isolated reservations. Tribes located close to a major city are 21 percent more likely to have quantified their water rights. This could be due to more competition for limited water sources near cites, and that proximity to cities can make it more feasible to engage in water leasing to those cities.

Regional Differences

The regional location of tribes creates distinctive patterns related to several variables in this study. The tribal nations in this study are in 12 states that are grouped into three regions: Southwest (Arizona, New Mexico, and Utah),

Table 4. Water rights quantification - difference in means in 2010 and 2015.

Variable	Water Rights Not Quantified (N=55)	Water Rights Quantified (N=37)	Difference	t-value
[1]Casino (%)	72.73	75.68	-2.95	-0.31
[2]Unemployment (%)	16.56	18.31	-1.75	-1.10
[3]Income ($)	49,491	45,817	3,674	2.02**
[4]Education (%)	82.91	77.28	5.63	3.23***
[5]Value of Agricultural Products Sold ($1000)	39,593	86,768	-47,174	-2.51***
[6]Population	6,257	18,080	-11,823	-1.88*
[7]Proximity to Major City (%)	14.55	32.43	-17.89	-2.06**

Significance levels: *α = 0.1, **α = 0.05, and ***α = 0.01.
[1]Casino is the percentage of tribes with a casino.
[2]Unemployment is the percentage of people over the age of 16 who are actively seeking a job.
[3]Income is the mean annual household income.
[4]Education is the percentage of people who have attained a high school diploma or higher.
[5]Value of Agricultural Products Sold is the gross market value of all agricultural products sold before taxes or production expenses in $1000. It is the total number of sales regardless of who received the payment i.e., partners, landlords, contractors, etc.
[6]Population is the number of tribal members living on a reservation.
[7]Proximity to Major City is the percentage of reservations located less than 50 miles of driving distance from a major city, a city with population over 100,000.

Northwest (Idaho, Montana, Oregon, Washington, and Wyoming), and Midwest (Kansas, Nebraska, South Dakota, and North Dakota).

Figure 2 shows the regions compared with one another. Table 7 compares water rights quantification, casino, income, unemployment, education, and value of agricultural products sold across the regions. While the regions have similar unemployment levels, tribal education levels are statistically different from one another across all three regions. Southwest tribes have the lowest revenue from agricultural products (statistically significant at a one percent level). Northwest tribes have significantly higher rates of water quantification than the other regions (at a one percent level). Southwest tribes have the next highest rates of water quantification (significant at a one percent level).

The Midwest tribes have the highest prevalence of casino operations compared to the other areas. Over 90 percent of the tribes in the Midwest group operate at least one casino. The Southwest has the smallest proportion of casino operations, with less than 50 percent of tribes operating at least one casino. Differences between the Midwest and the Southwest related to casino operations are statistically significant at a one percent level. The Midwest region, which has no tribes in this study with quantified water rights, has the highest rates of casino operations. These regional differences likely involve political and economic factors not analyzed in this study. For example, higher rainfall in the Midwest leads to less dependence on securing irrigation water to sustain reservation agriculture, hence less pressure to quantify water rights. Tribal nations in different regions have

Table 5. Casino operation - difference in means in 2010 and 2015.

Variable	No Casino (N=24)	Casino (N=68)	Difference	t-value
[1]Water Rights Quantified (%)	37.50	41.18	-3.68	-0.31
[2]Unemployment (%)	19.30	16.55	2.75	1.55
[3]Income ($)	42,987	49,787	-6,801	-3.18***
[4]Education (%)	78.83	81.29	-2.46	-1.28
[5]Value of Agricultural Products Sold ($1000)	44,465	63,543	-19,078	-1.01
[6]Population	5,007	13,131	-8,124	-2.22**
[7]Proximity to Major City (%)	29.17	19.12	10.05	1.02

Significance levels: *α = 0.1, **α = 0.05, and ***α = 0.01.
[1]Water Rights is the percentage of tribes who have quantified their water rights.
[2]Unemployment is the percentage of people over the age of 16 who are actively seeking a job.
[3]Income is the mean annual household income.
[4]Education is the percentage of people who have attained a high school diploma or higher.
[5]Value of Agricultural Products Sold is the gross market value of all agricultural products sold before taxes or production expenses in $1000. It is the total number of sales regardless of who received the payment i.e., partners, landlords, contractors, etc.
[6]Population is the number of tribal members living on a reservation.
[7]Proximity to Major City is the percentage of reservations located less than 50 miles of driving distance from a major city, a city with population over 100,000.

faced different political dynamics with respect to both gaming and water rights.

Discussion and Summary

Tribal nations consider various economic strategies to bring jobs and improved income to tribal members and reservation economies, identifying their nation's comparative strengths and the potential role of their tribal natural resources (Harvard Business School 2018). In the western U.S., tribal nations often have senior water rights and valuable agricultural and gaming opportunities. Water rights quantification, agriculture, and gaming operations appear to be linked among the tribal nations examined in this study. The reasons for this linkage likely vary from tribe to tribe, and may reinforce areas of tribal specialization and emerging cluster strength for economic development on reservations (Harvard Business School 2018).

For the tribal nations in this study, those tribes which have quantified their water rights have significantly different characteristics than tribes which have not quantified their water rights. Tribes with quantified water rights had an average of $48 million more annual agricultural revenue than tribes without quantification. Tribal nations with quantified water rights also had higher population levels, greater proximity to cities, lower education levels, and lower income levels. Casino operations increase average household income for tribes, with a high level of statistical significance.

Across the 51 tribes examined in this study, there is a consistent relationship between tribal water rights quantification and higher agricultural revenue. Many tribal nations with active farming choose to pursue quantification, knowing that

Table 6. Proximity to major city - difference in means in 2010 and 2015.

Variable	Not Located Close to a Major City (N=72)	Located Close to a Major City (N=20)	Difference	t-value
[1]Water Rights Quantified (%)	34.72	60.00	-25.28	-2.06**
[2]Casino (%)	76.39	65.00	11.39	1.02
[3]Unemployment (%)	17.95	14.83	3.12	1.66*
[4]Income ($)	47,210	50,903	-3,693	-1.56
[5]Education (%)	80.38	81.60	-1.22	-0.59
[6]Value of Agricultural Products Sold ($1000)	62,542	44,254	18,288	1.17
[7]Population	11,866	7,939	3,927	1.08

Significance levels: *α = 0.1, **α = 0.05, and ***α = 0.01.
[1]Water Rights is the percentage of tribes who have quantified their water rights.
[2]Casino is the percentage of tribes with a casino.
[3]Unemployment is the percentage of people over the age of 16 who are actively seeking a job.
[4]Income is the mean annual household income.
[5]Education is the percentage of people who have attained a high school diploma or higher.
[6]Value of Agricultural Products Sold is the gross market value of all agricultural products sold before taxes or production expenses in $1000. It is the total number of sales regardless of who received the payment i.e., partners, landlords, contractors, etc.
[7]Population is the number of tribal members living on a reservation.

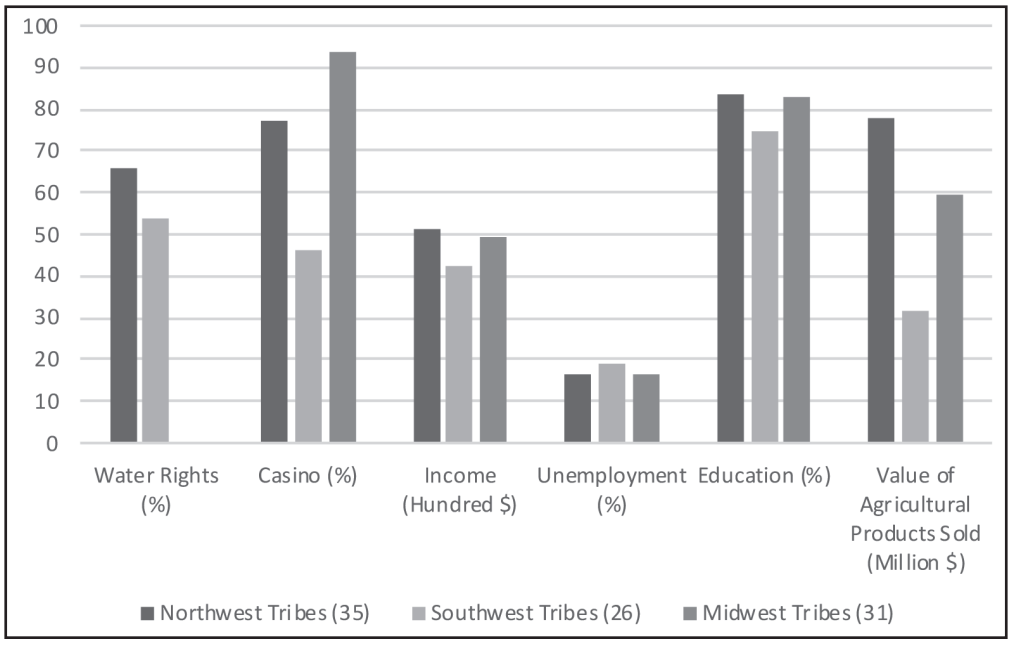

Figure 2. Variables differentiated by regional location of tribal nations.

Table 7. Variables differentiated by region in 2010 and 2015 (92 observations).

	Northwest Tribes (N=35)	Southwest Tribes (N=26)	Midwest Tribes (N=31)
Water Rights (%)	65.71***	53.85*	0.00***
Casino (%)	77.14	46.15***	93.55***
Income (Hundred $)	51.16***	42.28***	49.28
Unemployment (%)	16.68	19.27	16.26
Education (%)	83.43***	74.37***	82.77**
Value of Agricultural Products Sold (Million $)	77.96	31.68***	59.22

Significance levels: *α = 0.1, **α = 0.05, and ***α = 0.01.

secure access to significant quantities of water are essential for their irrigated farming. Also, tribes engaged in irrigated farming may be more likely to quantify their water entitlements because the Practicably Irrigable Acreage (PIA) standard (used for many years by the courts to quantify tribal water entitlements) is readily applicable to tribes with irrigated farms. The PIA standard quantifies tribal water rights based on the amount of acreage on the reservation that is feasible for irrigated agriculture (Colby 2006; Brougher 2011).

In this study, tribes located less than 50 miles of driving distance to a major city had significantly higher percentage employment rates and average household income. Reservations located closer to cities are more likely to quantify their water rights. This may be due to a number of interrelated factors. Water rights quantification is costly and time consuming. For tribes located closer to cities, there may be greater regional demand on limited water resources. This competition for water may stimulate both the tribes and nearby cities to quantify tribal water rights in order to provide more certainty in regional water supply planning.

Statistical comparison found that Midwest tribes included in this study have a higher proportion of reservations operating casinos, but a lower proportion of tribal nations with quantified water rights, compared to the other two regions. Northwest and Southwest tribes examined in this study have similar percentages of water rights quantification and casino operation. Understanding the direction of causality requires site-specific analyses. It is uncertain whether water rights quantification encourages tribes to operate a casino, or tribes which desire to operate casinos seek water rights quantification. Water rights quantification and gaming operations for tribal nations are linked to economic development opportunities. These two activities may stimulate one another and jointly increase business activity on tribal nations.

Each tribal nation faces a unique set of factors that influence tradeoffs between pursuing water rights quantification, gaming, and agriculture. The patterns across tribes summarized in this article reflect the diversity of these pathways. A few more examples are highlighted here. The 2004 Arizona Water Settlements Act includes quantification of Gila River Indian Reservation and the Tohono O'odham Nation water rights and leasing provisions with nearby cities for mutual economic benefits (Tohono O'odham Settlement 2003; Bark 2009; USBR 2018). Both tribes operate a casino and are engaged in commercial agriculture. Years after quantifying water rights in the 1990 Fort Hall Indian Water Rights Agreement, in 2014 the Shoshone-Bannock Tribe negotiated agreements with junior-water rights holders to address water supply shortfalls for non-Indian water users. In addition to gaming and farming enterprises, the Shoshone-Bannock Tribe is implementing a tribally managed water bank to address Snake River

instream flow and groundwater replenishment needs of concern throughout the area (Bovee et al. 2016). Similar lease agreements and water management innovations are active or under negotiation with other tribal nations to provide water for environmental needs, urban growth, and agriculture.

While the data set assembled in this study provides an opportunity to look broadly across tribal nations at water rights, farming, gaming, and reservation economies, much more research on these themes is warranted. Due to absence of more widespread data, only 51 tribal nations were included in this study and patterns observed in this study cannot be assumed to extend to a broader set of tribes. Causal relationships between water quantification and reservation economies are complex, location-specific, and require more exploration. Figure 3 highlights multiple economic inter-relationships that need to be considered.

Results from comparisons among the tribal nations and regions included in this study highlight the complexity of relationships between water, gaming, farming, and reservation economic development. Consideration of these patterns can help tribes design policies to create sustainable tribal economies and to protect and manage tribal land and water. We hope those examining these important themes in the future will have access to more comprehensive data that includes many more tribal nations, and data generated through collaborations which recognize tribal governments as sovereign managers of information and natural resources.

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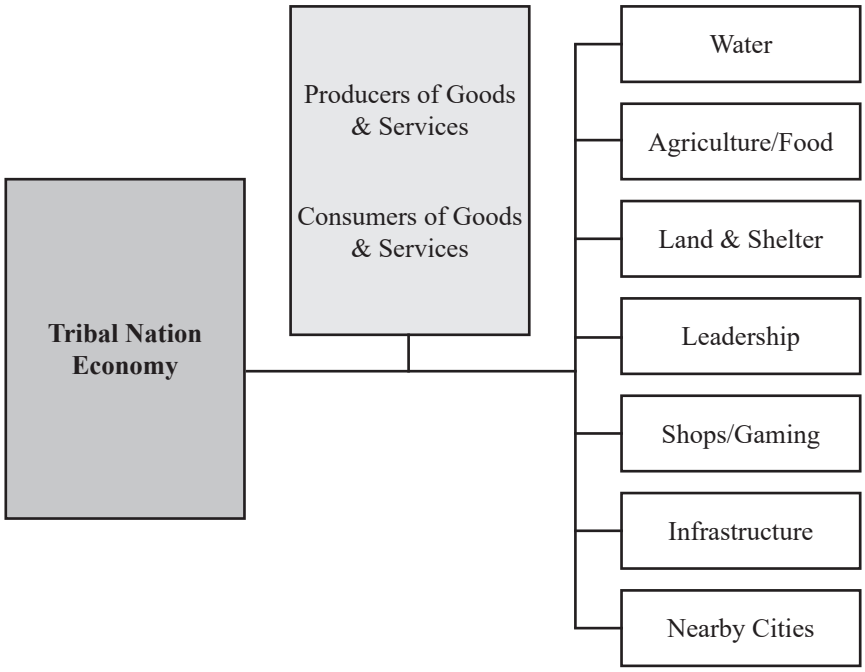

Figure 3. Components of tribal economic development.

books, including *Negotiating Tribal Water Rights*.. She may be contacted at bcolby@email.arizona.edu.

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Assessing Tribal College Priorities for Enhancing Climate Adaptation on Reservation Lands

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Abstract: On reservation lands, tribal colleges and universities (TCUs) are key to preparing indigenous communities to adapt to the effects of a changing climate. The original mission of TCUs, to improve access to higher education and to sustain the cultural heritage of indigenous people, facilitates close ties between TCU faculty and staff and the indigenous communities they serve. Since 1994, the land-grant status of TCUs allows access to limited federal funds in support of research, education, and outreach to improve food security, natural resource management, and rural quality of life, while expanding public access to higher education to underserved populations in remote rural areas. This study was designed to assess the priorities for enhancing climate adaptation on reservation lands. It summarizes the results of an assessment implemented at the 2016 Annual First Americans Land-Grant Consortium Conference. Study participants included faculty, administrators, outreach educators, support staff, and students representing 25 of the 37 TCUs in the United States. Results from this national assessment suggest that in order for TCUs to effectively meet the climate adaptation needs of indigenous communities, additional fiscal and human resource investments are necessary. Specifically, this includes fiscal support to enhance climate science teaching, research, and professional development programs. Additional goals include creating or expanding food-sovereignty programs, increasing community outreach education, investigating climate change impacts on water resource quality, access, and related ecological services, and exploring renewable and alternative energy opportunities.

Keywords: *higher education, outreach, climate resilience, land-grant, indigenous people, needs assessment, tribal lands, food sovereignty*

Indigenous communities in the United States are increasingly recognized as being among the most vulnerable to climate change impacts on water resources (IPCC 2012; Cozzetto et al. 2013; Bennett et al. 2014). Increasing global temperatures have adverse effects on reservation lands, impacting ecological and landscape health, economic livelihoods, water quality and quantity, and traditional and cultural practices (Doyle et al. 2013; Bennett et al. 2014). The Intergovernmental Panel on Climate Change (IPCC) suggests that the number of areas affected by drought and earlier snowmelt will likely increase, adversely affecting water supplies available for municipal, industrial, and recreational use, wildlife habitat, as well as energy and food production (IPCC 2012; Mankin et al. 2015). For tribal lands located in the western United States, climate impacts include extreme drought and/or flooding events (Dettinger et al. 2015). Increasing water demand to sustain steady urban population growth adds to the complexity of water supply and management issues tribes face (Cozzetto et al. 2013). Indigenous communities located in coastal regions currently face imminent displacement from their homes due to extreme weather events forced by climate change influences (Marino and Lazrus 2015).

Acutely aware of and often vocal about the threats posed by climate change, indigenous people continue to call for further investigation into the impacts of climate change on their communities. The National Congress of American Indians (2017)

continues to identify mitigating negative climate change impacts on indigenous communities among their top priorities. Even when ecological coherence exists, these impacts may be disparate at local and regional scales due to socio-cultural and political diversity among tribes (Bennett et al. 2014). Additionally, climate adaptation planning on tribal lands may require integrating indigenous traditional knowledge and worldviews with Western science (Cochran et al. 2013). This encourages community-specific climate impact investigations and adaptation initiatives, as well as collaborative efforts combining multiple forms of knowledge such as Western science and traditional knowledge.

Given the unique opportunities that tribal colleges and universities (TCUs) already provide, including culturally relevant research and education programming, TCUs may play a prominent role in enhancing the capacity of indigenous communities to adapt to the effects of a changing climate. These institutions primarily serve indigenous populations situated in rural, remote, and historically underserved communities that lack access to higher education (American Indian Higher Education Consortium 1999). The original mission of TCUs, to improve access to higher education and to sustain the cultural heritage of indigenous people, which honors an integrated worldview, facilitates close ties between TCU faculty and staff and the communities they serve (American Indian Higher Education Consortium 1999). Similar to the 1862 and 1890 land-grant institutions created by the Morrill Act, the 1994 TCUs are responsible to the indigenous communities they serve to improve quality of life through their teaching and outreach programs (Baird 1996). Furthermore, individual tribal governments create, charter, and control their own TCUs, thus are accountable for ensuring that TCUs address and support the unique and changing needs of sovereign tribal nations and reservation communities (American Indian Higher Education Consortium 1999).

TCUs are uniquely situated to educate and prepare professionals to enhance climate adaptation planning initiatives on reservation lands. Previous studies suggest that integrating traditional knowledge and cultural values into science education programs can enhance the engagement and retention of students with indigenous backgrounds (Semken 2005; Palmer et al. 2009; Reano and Ridgway 2015). Land-grant TCUs do this inherently through classroom instruction and extension outreach programs that promote self-efficacy, assist in identifying personal goals, enhance student skills, and encourage family relationships and connection with cultural practices (Keith et al. 2017). This ensures a culturally sensitive environment that also directly engages current and future TCU students, which has been shown to improve student success in the natural resource disciplines (Sloan and Welton 1997). This is particularly important given that Western science-based natural resource education programs often pose unique challenges to college students with indigenous backgrounds that include different ways of learning and knowing (Gervais et al. 2017).

Utilizing existing research and education frameworks that encourage community engagement may strengthen tribal capacity to assess climate change impacts, but the ability for TCUs to educate needed personnel may be limited. The student enrollment rate in science, technology, engineering, and math (STEM) fields at TCUs is rising. There was a 92% growth rate in these disciplines between the 2003-2004 and 2009-2010 academic years, yet only nine TCUs currently offer bachelor degrees in these fields (American Indian Higher Education Consortium 2012; Page 2017).

With nationally identified climate resilience research priorities (National Congress of American Indians 2017), it can be argued that TCUs have a land-grant responsibility to the Native American population to enhance tribal capacity to address these priorities. While this point is upheld considering TCUs depend on federal funding to operate, individual TCUs in collaboration with their respective tribes establish local research and education priorities (Nelson and Fry 2016). Acting at local levels to establish institutional priorities is not only an important component of tribal sovereignty and self-determination, but paramount in ensuring climate adaptation and resilience initiatives are relevant to local communities (Bennett et al. 2014).

Recognizing that TCUs have the potential to educate a climate literate workforce in a culturally

relevant manner, this study assesses TCU research and education priorities related to climate change adaptation on tribal lands at a national scale. Asking individuals most closely associated with TCUs to identify these priorities provides insight into critical higher education needs of indigenous communities that must be addressed in order to enhance tribal capacity for climate adaptation on tribal lands. This study aims to identify strategies and barriers related to TCU research, teaching, and outreach to support climate adaptation planning on reservation lands. It assesses priority trends that may be associated with an individual's role with a TCU or the location of a TCU. Understanding these priorities may help TCU personnel to direct their institutional fiscal and human resources more strategically to strengthen program areas that are needed most.

Methods

In order to better understand TCU needs, researchers developed a questionnaire to assess TCU priorities related to teaching, research, and outreach goals to support climate adaptation on tribal lands. The questionnaire featured 12 Likert-type scale questions encompassing a broad spectrum of potential goals and strategies to help support climate change adaptation on reservation lands. Critical to the development of these question items was the input of 1862 land-grant faculty with extensive research and outreach experience on reservation lands, in addition to input from faculty representing the First Americans Land-Grant Consortium (FALCON). Because very little baseline data or peer-reviewed studies are available on these topics as they relate to TCUs, this expertise ensured that question items were appropriate for corresponding TCUs with similar teaching, research, and outreach responsibilities. A panel of experts external to the study reviewed the resulting survey instrument, further refining the wording and sequencing of question items to improve readability and validity. The authors incorporated the suggested revisions into the final instrument.

We maintain the resulting question items, although specific, align with the recommendations resulting from previous climate change vulnerability and adaptation studies focused on indigenous issues (Cochran et al. 2013). These recommend conducting interdisciplinary analyses of impacts and honoring multiple forms of knowledge. Given the small size of the target population and challenges with accessing these individuals, the survey instrument was not pre-tested prior to its administration. To help overcome this limitation, we outline several data analysis strategies in the results section.

Researchers administered the assessment during a plenary session at the Annual FALCON Conference in November 2016. As a non-profit, professional association, sanctioned by the American Indian Higher Education Consortium (AIHEC) Board of Directors, FALCON represents the issues and interests of administrators, faculty, and staff at 1994 TCUs. TCU administrators, faculty, and students are uniquely situated to have insights into the needs and priorities of their institutions. Administering this assessment in partnership with FALCON members afforded a unique opportunity to solicit the participation of many TCUs across the United States, providing insight into Native Americans' higher education needs specific to localized climate adaptation strategies on reservation lands. This is considered a convenience sampling method, which limits our ability to ensure the sampled population is proportionately representative of each subset of the overall target population. While our target population was TCU faculty and administrators, we also include student responses in our results. We prioritized this sampling location to ensure national representation of TCU faculty and administrators.

Participants received a one-page questionnaire that featured 12 Likert-type scale question items. In order to gain additional insight from TCU faculty and administrators, we included a qualitative open-ended question in the survey that asked respondents to identify their top three priorities in addressing climate change and climate adaptation planning through teaching, research, and outreach. This question allowed participants to provide priorities in their own words that were not featured in the Likert-type scale question items. This also helps overcome uncertainty related to administering a survey that was not pre-tested on the target population. This question item helped

gain additional insight into the breadth of climate change adaptation issues that TCU faculty, staff, and students face. Two demographic question items were included to delineate if the respondent was a student or faculty, and identify their TCU's geographic location.

We presented an overview of the assessment, answered any questions from the participants, and asked them to complete the questionnaire and return it to us. Participants were instructed to omit their names or any identifying marks and to leave their completed questionnaires on conference tables. We secured the services of a proctor to gather and return to the authors completed surveys placed in a sealed envelope. This procedure ensured anonymity of the participants.

Data Limitations

There are very little baseline data available about our target population, yet such data can provide critical insight into the needs and priorities related to enhancing climate adaptation on reservation lands. A total of 59 (n = 59) respondents completed the questionnaire, representing 25 of the 37 (68%) TCUs in the United States. This sample of primary data is rare largely because there are challenges that exist with recruiting indigenous populations located in rural areas to participate in survey studies. The sample is reasonably representative of the perspectives of TCU faculty and administrators, however, given there are only about 450 TCU administrators and 1800 TCU faculty nationwide (American Indian Higher Education Consortium 2012). The overall sample size, n = 59, is relatively small, making statistically significant extrapolation and conclusions challenging even in the presence of substantive significance (Vogt 1993). Therefore, while a conventional threshold for statistical significance is a 95% Confidence Interval ($p < 0.05$), for this study we apply a 90% Confidence Interval ($p < 0.10$) when we used Pearson Chi-square tests to determine statistically significant correlations (Hawkes and Marsh 2004). Further, we maintain that a 90% Confidence Interval is an acceptable statistical significance threshold given the purpose of this study, indicating participants' demographic background has a 90% chance of correlating with their responses to other questions. We assert that the following statistical test results pertaining to correlation analysis, while informative, are exploratory. Additional data collection from an increased sample size is necessary to establish causal relationships and, in addition to the survey instrument described here, should include focus groups comprised of key informants. Such informants might represent the 12 of 37 TCUs not represented in this assessment and include a cross-section of TCU administrators, faculty, and students.

Results

The resulting data were analyzed using IBM Statistical Package for Social Sciences (SPSS) Version 24.0 as well as Microsoft Excel Version 14.7.3. Cronbach's coefficient alpha (CCA) was calculated to estimate internal consistency (instrument reliability) of the 12 Likert-type scale items. The Cronbach score for the 12 items was high ($r = 0.943$), indicating high internal consistency between variables (Carmines and Zeller 1979).

Of the 59 respondents, 12 worked in an administrative role, 12 were TCU extension outreach educators, 11 were support staff, 7 were faculty instructors, 7 were students, and 10 assessment participants chose not to respond to this particular question item. In order to use these demographic data for additional analysis, results for this question were aggregated as follows: individuals serving in an administrative capacity (Administrator + Support Staff, n = 23), individuals serving as faculty or educators (Extension Educator + Faculty Instructor, n = 19), and students (n = 7). We used this grouping strategy to identify whether a statistically significant correlation exists between respondents' roles at their respective TCU and their ranking of priority needs to enhance TCU capacity for conducting effective research, education, and outreach to support tribal climate adaption on reservation lands.

Based on data from the 2009-2010 American Indian Measures for Success Fact Book, a proportional distribution of our target population would be a 1:4 ratio of administrators to faculty (450:1800) (American Indian Higher Education Consortium 2012). Our sample population contains 23 administrators and 19 faculty members. While this could skew our overall priority results toward

perspectives of administrators, our results indicate that a statistically significant correlation only exists between TCU role and three of the 12 Likert-type scale item results. Correlations between demographic question items and priority question items are reported in each table.

Since the respondent pool represents 68% of the total TCUs and provides a relatively small number of participants per TCU, we aggregated responses two ways for the purposes of cross-correlation analysis. That is, we created a variable based on TCU location within established United States Geological Survey (USGS) water resource regions at a scale of hydrologic unit code (HUC) 2. This grouping was based on the assumption that general environmental and ecologic coherence exists among TCU populations located in the same water resource region. We assume that communities within similar environments share similar climate change impacts. Natural boundaries, such as water resource regions, offer more ecologic coherence as opposed to political boundaries, such as states. The percentage of TCUs located in each watershed is as follows: Missouri River (32.1%), Lower Colorado River (20.8%), Great Lakes (17.0%), Rio-Grande River (11.3%), Arkansas White Red (7.5%), Upper Mississippi River (3.8%), Souris-Red-Rainy (3.8%), and Pacific Northwest (3.8%).

We created a second aggregate variable by grouping TCU locations by general aridity in order to test correlations that may arise due to similar water related issues. This variable is an aridity scale based roughly on the average annual precipitation by water resource region (National Institute of Food and Agriculture 2015; NOAA National Weather Service 2017). The distribution of responses represented by this aggregate variable is as follows: arid (32.1%), semi-arid (35.8%), and non-arid (32.1%). These two new aggregate demographic variables were used to conduct a cross-correlation analysis of the data.

Respondents were asked to prioritize teaching, research, and outreach goals necessary to strengthen climate adaptation on tribal lands based on their respective experiences and perspectives. They were provided with 12 goals and instructed to assign priorities for each, using a Likert-type scale of 1 (very low priority) through 5 (very high priority). Mean scores were calculated for the 12 goals. The goals and ranked mean scores in descending order (highest to lowest priority) are illustrated in Table 1. Ranking these goals by mean score provides insight into the top priorities of TCUs from the perspective of faculty, staff, and students. All 12 goals were rated as high priority, each receiving a mean score of 3.5 or higher. Furthermore, six of the 12 goals had a mean score of at least 4.0, indicating a very high priority.

In order to conduct cross-correlation tests for statistical significance, we reduced participant responses to the 12 Likert-type question items from a five-item to a three-item scale. The resulting three-item scale is as follows: low priority (very low priority + low priority), neutral (same), and high priority (high priority + very high priority). Correlation results were determined by asymptotic significance (p) values resulting from a Pearson Chi-square test conducted for each question. As stated in *Data Limitations*, because the overall n-value of responses for this dataset is relatively small, and because this study is exploratory in nature, we used a Confidence Interval of 90% (significance rating of $p < 0.10$) rather than the conventional threshold of 95% ($p < 0.05$) to determine the statistical significance of our correlations (Hawkes and Marsh 2004).

Looking at the results of the Likert-type scale data (Table 1), the top two prioritized goals are: *increasing funding to tribal colleges to support teaching, research, and outreach focused on climate science, adaptation, and related subjects* ($m = 4.41$) and *supporting ongoing development of tribal college and tribal agency professionals* ($m = 4.36$). For the highest ranked goal, there was no significant correlation with respondent demographic information, indicating that this is the highest ranked goal regardless of TCU role or location. This is not the case for the second ranked goal in which respondents differed in their priority selection depending on both their TCU role and the general aridity of the watershed in which their TCU is located. Additional correlative results are reported alongside the ranked mean scores in Table 1.

While the Cronbach alpha score for the 12 items was high ($r = 0.943$), indicating high internal consistency between variables, it is not a measure of dimensionality. Recognizing that our

Table 1. Mean scores for tribal college and university (TCU) teaching, research, and outreach priorities and results of cross-correlations by TCU role and TCU location aridity.

Rank	Topic	Mean Score	Standard Deviation
1	Increasing funding to tribal colleges to support teaching, research, and outreach focused on climate science, adaptation, and related subjects	4.41	0.98
2	Supporting ongoing development of tribal college and tribal agency professionals	4.36[ab]	0.73
3	Enhancing tribal food security through improved water management on tribal lands	4.19	1.04
4/5	Strengthening tribal economies through innovative water resource uses	4.04[a]	1.10
4/5	Identifying adaptation strategies that complement ongoing traditional indigenous practices	4.04	0.97
6	Assessing the impacts of climate change on tribal lands and water resources	4.00[a]	0.98
7	Identifying climate adaptation strategies that address issues unique to tribal lands and water	3.99	0.97
8	Identifying traditional indigenous practices that inform tribal climate adaptation strategies	3.93[a]	1.09
9/10	Building/strengthening working relationships with 1862 land-grant university faculty and students	3.91	1.00
9/10	Assessing the impacts of climate change on tribal economies	3.91	1.12
11	Financing implementation of tribal climate adaptation plans	3.88	1.18
12	Exploring climate adaptation plans and strategies through annual tribal climate summits	3.65	1.21

Rating code: 1 = very low priority; 2 = low priority; 3 = neutral; 4 = high priority; 5 = very high priority.
[a] Significance = $p < 0.10$, TCU role (administration, faculty, student).
[b] Significance = $p < 0.10$, TCU location aridity (arid, semi-arid, non-arid).

12 Likert-type question items could be grouped into smaller dimensions, we organized the topics into four similar categories and calculated and ranked resulting mean scores. We determined these categories through a q-sorting method by creating a group comprised of three individuals external to the survey response group who represent tribal members interested in climate adaptation initiatives on reservation lands (Stephenson 1953). These individuals, while not directly representing our target sample group, shared similarities in their understanding of the 12 topics. Their grouping of the topics, therefore, reasonably related to that of our survey respondents. We provided these study participants with notecards outlining the 12 Likert-type scale question topics and asked them to sort similar topics into one of four groups. Each participant grouped the 12 topics similarly. These four groups are depicted in Figure 1. Mean scores and standard deviations were calculated for each topic group. While these new groups offer less detail than the individual 12 topics used in our analysis, the priorities more accurately represent the broader concepts. *Capacity building for tribal colleges and universities* is the group with the highest priority (m = 4.224), followed by *traditional knowledge uses* (m = 3.982), *land use impacts and adaptation strategies* (m = 3.960), and *tribal economic impacts* (m = 3.940), respectively. These results indicate that the 12 topics may provide sufficient dimension to be considered individually.

To test for correlations on these four topics, we

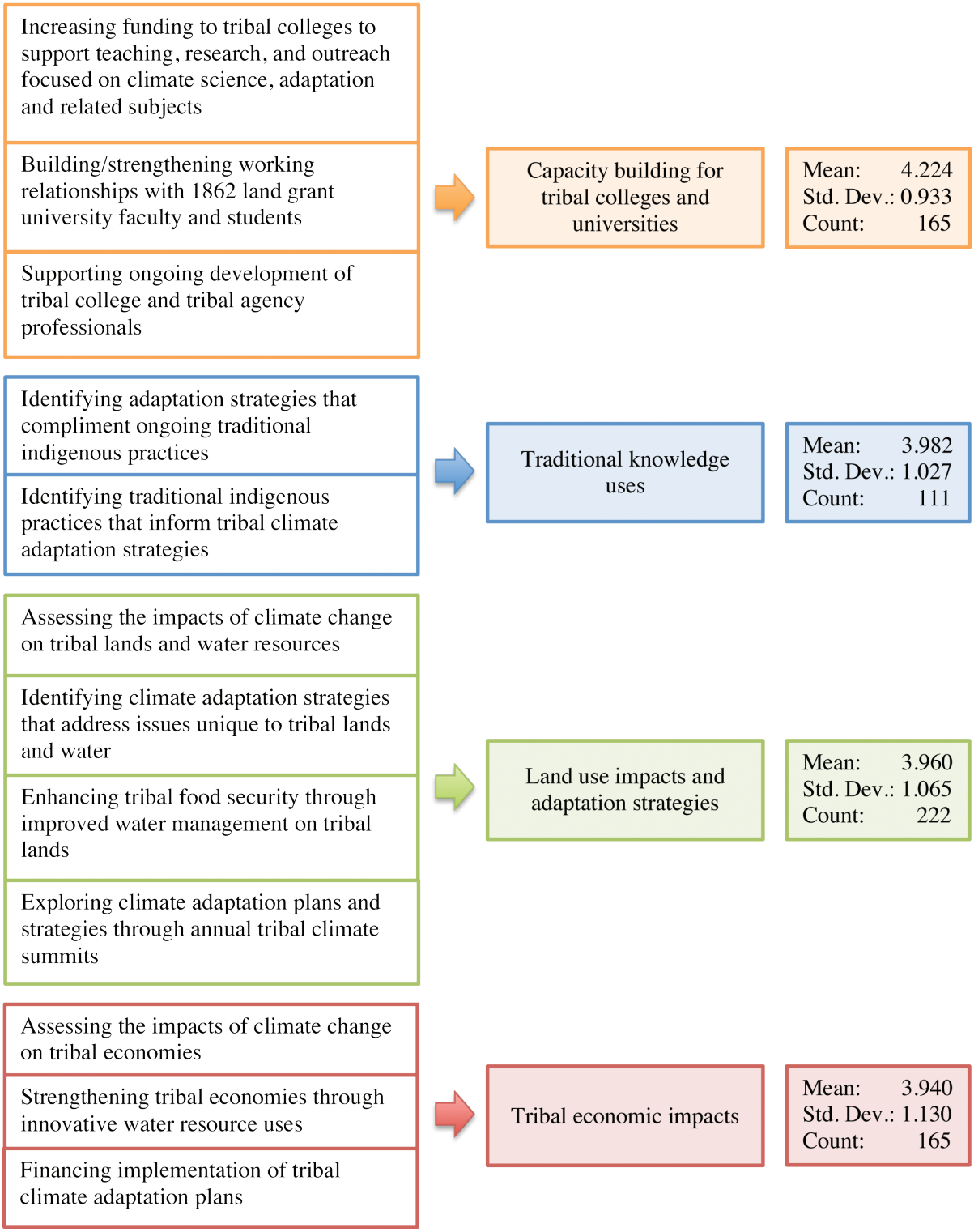

Figure 1. Tribal college and university (TCU) priorities for enhancing climate adaptation efforts on reservation lands. Dimensional grouping of original 12 Likert-type scale question items and associated mean ranking based on survey responses.

calculated the mean scores for each new group per survey, and assigned each response as either a priority (having a mean of 3.5 or greater on a scale of 1 to 5), or no priority (having a mean score of less than 3.5). For example, three topics make up the new group, *capacity building for tribal colleges and universities*. If a respondent indicated a 3, 4, and 5 on the original Likert-scale topics, respectively, their mean score for the new group would be a 4. This participant would then be assigned as indicating this new group is a *priority*. If a respondent indicated a 2, 3, and 3, respectively, their mean score for the new group would be 2.67 indicating *no priority* for this group. Researchers used the Pearson Chi-square test for correlations between these new groups and respondent demographic responses. Of these new groups, *land use impacts and adaptation strategies* is the only topic that has a significant correlation with an individual's role at his/her TCU ($p = 0.042$).

Participants were also asked to write their top three climate change adaptation priorities on tribal lands. This open-ended question item was included to probe for additional insight and to identify goals or needs that may have been inadvertently omitted from the 12 Likert-type scale question items featured in this study. Open-ended questions, as opposed to closed-ended and/or Likert-type scale questions, provide the opportunity to respond in detail and reduce potential for survey error associated with forcing participants to choose answers from a limited menu of choices (Patton 2002; Thorne 2016). In order to analyze these qualitative data, each response was *selectively coded* as belonging to one of six goals, illustrated in Table 2. That is, selective coding provided the most appropriate method to analyze these qualitative data, where one or more themes were developed to express the grouped content. Selective coding and enumerated grouped responses facilitated a cross-correlation analysis with participant demographic data (Miles et al. 2014).

The resulting six additional coded priorities or goals illustrate keywords and/or concepts cited most frequently. For example, nearly half (47.9%) of respondents described featured phrases or words relating to "food sovereignty and adaptive agriculture." These included terms such as "food sovereignty," "food security," "gardens," and "adaptive agriculture." Therefore, these written responses were coded as *food sovereignty and adaptive agriculture*. Only seven of the 104

Table 2. Additional tribal college and university (TCU) priorities to enhance climate adaptation on tribal lands and cross-correlations with TCU location by USGS Water resource region.

Rank	TCU Priorities to Support Climate Adaptation	N	Percent	Percent of Cases
1	Research Education Support and Capacity Building	24	24.2	50.0
2	Food Sovereignty and Adaptive Agriculture	23	23.2	47.9
3/4	Community Engagement and Collaboration	16	16.2	33.3
3/4	Water Quality and Quantity Issues [a]	16	16.2	33.3
5	Ecologic Interactions and Services	14	14.1	29.2
6	Renewable and Alternative Energy Opportunities	6	5.8	12.5
	Total	99*	100.0	206.3

[a] Significance $p < 0.10$, TCU location within USGS Water Resource Region (Missouri River, Lower Colorado River, Great Lakes, Rio-Grande River, Arkansas White Red, Upper Mississippi River, Souris-Red-Rainy, and Pacific Northwest)

*Note: The assessment resulted in 104 total individual written responses. These responses were reduced to 99 during data coding due to individual participants giving multiple responses belonging to a single one of the six coded priorities.

written responses did not directly relate to one of the six emergent coded groups. Since these few responses reasonably related to one or more of the six coded groups, however, they were categorized as belonging to one of these groups. For example, "It [climate adaptation] is mentioned [at our TCU] but not a priority," is one of these seven responses. Assuming that climate adaptation is mentioned but not as a priority may be due to limited resources available. Therefore, this response was categorized as belonging to a group of responses coded as *research education support and capacity building*.

Looking at the results shown in Table 2, a third of participants (33.3%) prioritized addressing water quality and/or quantity issues as a goal, which tied for third in overall ranking, along with increasing TCU engagement and collaboration with communities (33.3%). There is a statistically significant correlation ($p < 0.059$) between TCU location within a USGS water resource region (e.g., Missouri River, Lower Colorado River, Great Lakes, Rio-Grande River, Arkansas White Red, Upper Mississippi River, Souris-Red-Rainy, and Pacific Northwest) and whether or not respondents prioritized water resource issues in the open-ended question item as noted in Table 2. This indicates that participants differed in their responses depending on the location of their TCU within a water resource region. Because the open-ended question item generated multiple qualitative responses, even when similarly coded as groups, results for the cross-correlation between these group responses and demographic information are reported as percentages in Table 3, instead of by calculating asymptotic significance. While no statistical significance analysis was calculated for these correlative results, substantive significance may exist between participant responses and their demographic backgrounds.

Discussion

The results of this study suggest that TCU faculty, staff, and students who responded to this assessment perceive climate change adaptation as a priority for indigenous communities. They

Table 3. Cross-correlation analysis of additional tribal college and university (TCU) priorities by TCU role and TCU location aridity factor.

TCU Priorities to Support Climate Adaptation	TCU Role (%)			TCU Location (Aridity) (%)		
	Admin.	Faculty	Student	Arid	Semi-Arid	Non-Arid
Research Education Support and Capacity Building	60.0	33.3	40.0	50.0	62.5	38.5
Food Sovereignty and Adaptive Agriculture	40.0	66.7	60.0	43.8	62.5	38.5
Community Engagement and Collaboration	25.0	26.7	60.0	37.5	25.0	30.8
Water Quality and Quantity Issues	35.0	33.3	40.0	37.5	18.8	46.2
Ecologic Interactions and Services	30.0	40.0	0.0	18.8	31.3	46.2
Renewable and Alternative Energy Opportunities	15.0	6.7	20.0	18.8	6.3	7.7

Note: The results reported here represent the percentage of participants by TCU role and location (e.g., arid, semi-arid, or non-arid climates) whose responses to the open-ended question resonated with the goals as listed. Percentages do not add to 100% because respondents were asked to give multiple responses to this individual question item.

also indicate that TCUs lack the fiscal and human resources necessary to enhance the capacity of indigenous communities to implement effective climate change adaptation planning and action. In fact, when provided with a list of goals to rate or the opportunity to describe priority goals in their own words, respondents identified as their top priority increased funding for TCU research, education, and outreach to this end. When grouped with other topics related to capacity building of TCUs to contribute to climate adaptation initiatives, participants indicated this issue as the highest priority. This priority was also supported by participants when given the option to list open-ended priorities.

Many strategies exist to help TCUs build the capacity of indigenous communities to adapt to climate change, yet options are limited by the extreme funding constraints under which TCUs currently operate (Nelson and Frye 2016). TCUs currently receive the majority of their operating funding from Federal resources, yet receive only a fraction of the per-student funding compared to other federally-funded minority-focused colleges and universities (American Indian Higher Education Consortium 2012). The total number of TCUs and their enrollments continue to grow over time, but federal land-grant funding, accounting for inflation, has remained relatively stable since 1994 as illustrated in Figure 2. TCUs are forced to hire more adjunct faculty rather than full-time faculty in order to meet the growing student enrollment of their institutions (American Indian Higher Education Consortium 2012).

Our results from the open-ended question item suggest that participants in administrative roles (60.0%) were more likely to provide responses resonating with *research education support and capacity building* as compared to faculty (33.3%) and students (40.0%). This result is not surprising given that administrators of higher education institutions typically are more familiar with fiscal constraints than are faculty and students. However, this result may indicate an opportunity to increase communication concerning existing fiscal constraints to ensure that resources are expended

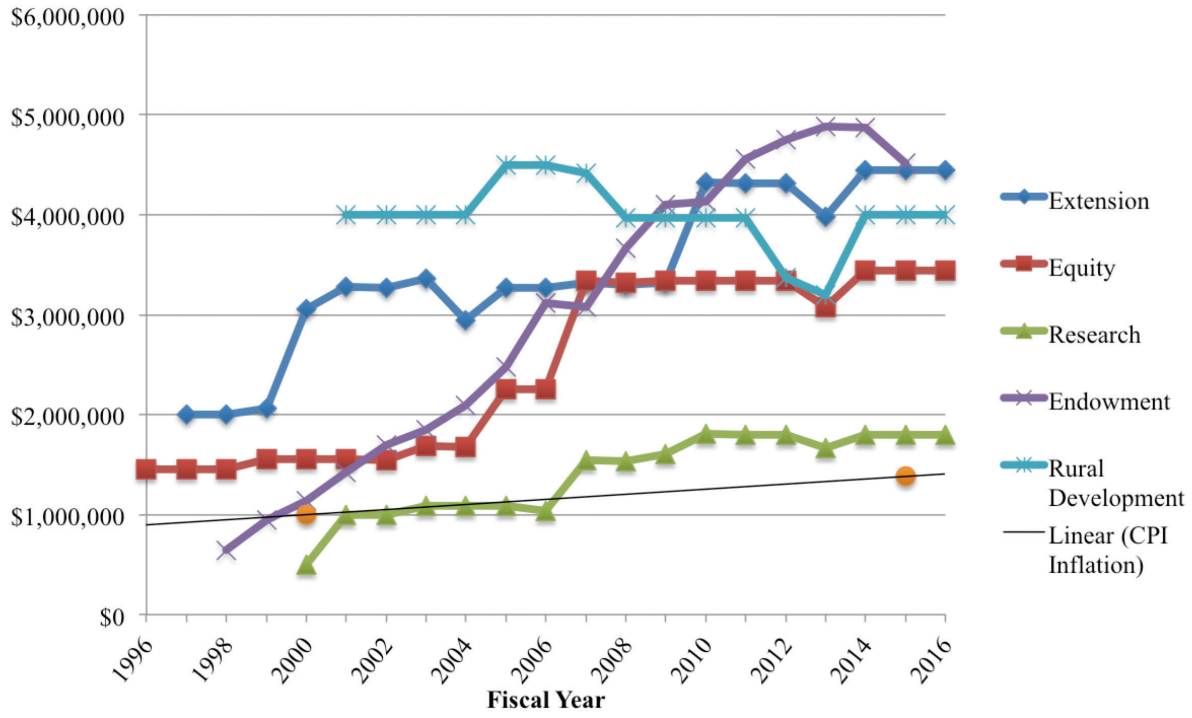

Figure 2. USDA National Institute of Food and Agriculture (2015) funding of 1994 tribal colleges and universities (TCUs). Equity funds support credited course instruction and related student services. Endowment refers to capacity funds; interest earned from endowment funds is distributed to TCUs based in part on student enrollment and is allocated to support the land-grant mission. The Community Facilities Program allocates rural development funds.

strategically to support the climate adaptation futures of reservations.

In the environmental sciences, it is imperative that research and education at the collegiate level be tailored to encompass a comprehensive analysis of climate adaptation issues unique to indigenous communities on reservation lands. TCU officials appear to be aware of this need by indicating community engagement and collaboration among their top priorities. This may likely remain one of the most challenging aspects of adaptation planning. However, through effective collaboration with tribal nations, researchers and educators can overcome these barriers (Chief et al. 2016). Given their proximity to remote and rural indigenous communities, existing relationships, and land-grant status, TCUs have the potential to be very important local resources to support indigenous climate adaptation initiatives.

Respondents in arid regions (37.5%) and non-arid regions (46.2%) were more likely than respondents in semi-arid regions (18.8%) to prioritize *water quality or quantity issues* in their open-ended priorities. While these two groups are on opposite sides of the aridity spectrum, water resource issues nevertheless are important. This may also suggest that TCUs in semi-arid environments are more likely to have their water quality and quantity needs met than those in arid and non-arid environments. Climate change effects on water resources threaten a range of reservation livelihoods from basic human health and survival to ecosystem services and large commercial agricultural operations (Cozzetto et al. 2013). Results from this study illustrate that goals related to water resource issues are frequently assigned a high priority for TCU teaching, research, and outreach initiatives. Unfortunately, the Salish Kootenai College currently is the only TCU in the United States that offers students a four-year bachelor's degree program in hydrologic sciences. Access to the financial resources necessary for TCUs to expand existing or offer new programs in hydrologic science and related STEM fields is critical to meet the growing needs of indigenous communities in adapting to climate change.

Aside from *building the climate adaptive capacity of indigenous peoples*, *food sovereignty and adaptive agriculture* was the most frequently identified priority goal to support adaptation on reservation lands. Nearly half of participants mentioned this as their *additional* top priority. This may suggest that TCU administrators, faculty, and students are most concerned with the impacts of climate change on the physical well-being of indigenous communities as expressed in their ability to access quality foods on reservations. In particular, TCUs located in semi-arid environments reported *food sovereignty and adaptive agriculture* more frequently (62.5%) than did participants located in arid (43.8%) and non-arid (38.5%) environments.

The issue of tribal food security and sovereignty dates back to the creation of reservations during the nineteenth century. While many indigenous communities on reservation lands have experienced historical and contemporary challenges in accessing fresh, nutritious foods, climate change will likely exacerbate this struggle. On the Navajo Nation, recent outreach programs to expand home and school gardens have been linked to healthier lifestyles as demonstrated by community members (Lombard et al. 2014). In this arid environment, access to water resources to sustain these practices in the future, due to rising temperatures and increasing drought aridity of these lands, may pose significant barriers to adaptation efforts to ensure food sovereignty. Because self-sufficient, small-scale agriculture is a traditional practice for many tribes, including the Hopi and Pueblo tribes, communities in the southwestern United States, for example, may promote sustainable agriculture practices as their top priority to enhance climate resiliency.

In other areas where cultural sustenance practices relate primarily to hunting, fishing, and gathering practices, promoting crop and/or animal husbandry agriculture to ensure food sovereignty may not be as widely accepted. Instead, concerns about food sovereignty in the face of climate change may relate more directly to ecological health. This may contribute to the different responses pertaining to *ecological interactions and services,* where 46.2% of the responses represented TCUs located in non-arid environments as compared to respondents located in arid (18.8%) and semi-arid (31.3%) environments. For example, for the members of the Swinomish Nation located

in the Pacific Northwest, where fish comprise the primary traditional food, continued access to fishing grounds not only guarantees their nutrition but demonstrates their cultural resilience as well (Donatuto et al. 2011).

The Equity in Educational Land-Grant Status Act of 1994 authorized the U.S. Congress to assign land-grant status to TCUs. The United States Department of Agriculture National Institute of Food and Agriculture (USDA NIFA) provides annual funding to TCUs to diversify agriculture and land-use programs (Baird 1996). Early education programs, which began with $50,000 'equity grants' awarded in 1996, stemmed from locally identified needs of reservation communities on which these institutions are located (Young 1996). Expanding funding to support and expand these ongoing programs could help build the capacity of TCUs to support tribal adaptation to climate threats to food and agriculture.

Conclusion

There are many challenges in assessing the needs and priorities of TCUs, such as their remote locations and the lack of baseline data. This study offers exploratory methods to pursue these research objectives as they relate to climate adaptation initiatives on tribal lands. Future research to explore these priorities further should examine the depth, breadth, rigor, and variance of TCUs' existing STEM and related climate science curricula. A review of existing curricula may help to inform development of new curricula and enrich existing curricula aimed at preparing future tribal leaders to refine, implement, and objectively evaluate climate adaptation initiatives unique to their reservation communities. Future research should also investigate additional topics impacting the ability of tribes to adapt to a changing climate. These topics include reservation land tenure issues, water right entitlements and settlements, economic dependency on natural resources, and other environmental and ecological impacts to tribal economies, livelihoods, and quality of life. Multi-disciplinary research approaches are necessary to assess the full breadth of these issues affecting the capacity of indigenous communities to adapt to climate change impacts on tribal lands.

Our study suggests that promoting tribal climate adaptation on reservation lands is a priority at TCUs. The results reveal several specific topics that are of the highest concern to TCU faculty, administrators, and students, such as creating or expanding food-sovereignty programs and exploring climate impacts to water resources. In each analysis of our survey data, however, concerns about fiscal constraints and the capacity of TCUs to contribute to tribal climate adaptation needs rose to the top priority.

Given the potential for TCUs to work collaboratively with indigenous communities to promote climate resiliency, addressing these priority needs could prove to be extremely beneficial for the indigenous communities that TCUs serve. A recent economic report suggests that TCUs contribute to the United States economy with notable returns on investments (American Indian Higher Education Consortium 2015). In 2009, TCUs added an estimated 76.2 million to the economy of Montana, the only state with fully accredited TCUs on each Native American reservation (Stockwell 2016). Increased federal funding allocated directly to TCUs is long overdue and essential to strengthening the long-term path for TCU sustainability and expansion.

The path forward for indigenous communities under current threats of climate change is much like their respective paths that epitomize a history of survival. In fact, tribes have a long and rich climate adaptation history that includes creating new technologies, applying traditional ecological knowledge, adopting diverse food resources, and even undergoing short and long-term migrations (Gautam et al. 2013). These examples illustrate the timeless environmental and cultural resiliency of indigenous people. Indigenous communities are more likely to foster innovative solutions to climate-induced impacts on water resources when tribal, federal, and TCU leaders work together to better understand and support community identified adaptation priorities and needs.

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Climate Change in the Lumbee River Watershed and Potential Impacts on the Lumbee Tribe of North Carolina

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Abstract: A growing body of research focuses on climate change and Indigenous peoples. However, relatively little of this work focuses on Native American tribes living in the Atlantic Coastal Plain of the United States. The Lumbee Tribe of North Carolina is a large (60,000 member) Native American tribe located on the Coastal Plain in present day North Carolina (U.S.). The tribe has deep connections to the Lumbee River, which flows through a watershed dominated by extensive forested wetlands. In this paper, I outline key issues associated with climate change and water in the region, and I use long-term climatic and hydrologic datasets and analysis to establish context for understanding historical climate change in the Lumbee River watershed. Downscaled climate model outputs for the region show how further changes may affect the hydrologic balance of the watershed. I discuss these changes in terms of environmental degradation and potential impacts on Lumbee culture and persistence, which has remained strong through centuries of adversity and has also experienced a resurgence in recent years. I close by acknowledging the especially vulnerable position of the Lumbee Tribe as a non-federal tribe that lacks access to certain resources, statutory protections, and policies aimed at helping Native American tribes deal with climate change and other environmental challenges.

Keywords: *hydroclimate, hydrology, streamflow, wetland, drought, flood, Hurricane Matthew, environmental policy, Indigenous peoples*

Anthropogenic climate change has major implications for all facets of society, but Indigenous peoples and their cultures are uniquely vulnerable to rapid and globally unprecedented climate change experienced in the 20th and 21st centuries (Houser et al. 2001; Maldonado et al. 2013). Indigenous peoples, who constitute an estimated 5% of the global population (Callison 2017), often have deep cultural connections to specific places, forged through centuries of occupation and interaction with particular landscapes and waterways (Pierotti and Wildcat 2000). Spiritual sites, archaeological resources, and natural features form a rich mosaic that is unique to each tribe and often central to Indigenous identity. Climate change poses a distinct threat to Indigenous peoples by disturbing places and disrupting processes critical to culture, history, economics, sovereignty, and other facets of Indigenous identity (e.g., Turner and Clifton 2009).

Within the United States (U.S.), Native American tribes have already experienced loss and degradation of cultural landscapes and natural resources as a result of climate change. These impacts stem from climate-related phenomena such as thawing and erosion of arctic permafrost, erosion and subsidence of coastal barrier islands, and unprecedented drought in the American West (Ford et al. 2006; Turner and Clifton 2009; Cozzetto et al. 2013; Maldonado et al. 2013). The body of research documenting climate change impacts on Indigenous peoples is growing, yet relatively little work focuses on the experiences of Indigenous peoples in the southeastern U.S. To help address this deficiency, this work focuses on climate change within the southeastern U.S. from the perspective of ecological and cultural resources of significance to the Lumbee Tribe.

The Lumbee Tribe, which has approximately 60,000 enrolled members, is centered in a

predominantly rural part of North Carolina's Atlantic Coastal Plain. The tribe maintains close cultural and socioeconomic connections to specific places within the watershed of the tribe's namesake river. Particular streams and wetlands play important roles in Lumbee culture and history (Dial and Eliades 1975; Locklear 2010; Lowery 2010). Through its impacts on streams, wetlands, and other natural resources, climate change presents challenges for the Lumbee that are similar to challenges faced by many other Native American tribes. However, unlike most tribes discussed in climate change and water resources literature, the Lumbee do not have a reservation or full federal recognition as a Native American tribe by the United States government. From this perspective, the situation of the Lumbee is common to many Native American tribes currently located in the southeastern U.S., many of whom also lack full recognition by the federal government and do not have federal trust lands. Although more than 40 Native American tribes are presently recognized by their respective southeastern state governments (NCSL 2017), these tribes lack access to federal statutory protections and many of the federal resources intended to assist tribes in climate adaptation and related efforts. Thus, in addition to facing many of the same climate change and water resource challenges as other Indigenous peoples, these tribes face additional policy-based vulnerabilities stemming from their status as non-federally-recognized tribes.

This article examines climate change in the region occupied by the Lumbee Tribe, paying special attention to historical and projected changes in temperature and precipitation. The article places these changes in the context of ecological and cultural factors important to Lumbee people. In doing so, the article broadens the discussion of climate change and Indigenous peoples to include the southeastern U.S., a region where physical climate change is as complex as the social and policy factors impacting tribes' abilities to adapt to change. Before discussing climate change and its implications for the Lumbee, I provide a brief overview of water and climate in the southeastern U.S., followed by contextual information about the Lumbee Tribe.

Overview of Water and Climate in the Southeastern United States

The southeastern U.S. has long been considered a "water rich" region (Sun et al. 2005; Chen et al. 2012). From the earliest periods of human occupation through the mid-19th century, human settlements of the region were organized along major rivers and estuaries, which provided sustenance as well as transportation. Until the mid-20th century, surface water and groundwater were considered abundant and sufficient to meet the needs of growing populations and industries. The highest elevations of the southern Appalachian Mountains receive, on average, 2500 mm or more of annual precipitation (Swift et al. 1988), and this precipitation helps sustain headwater streams of major river basins throughout the region (Nippgen et al. 2016; Singh et al. 2016). The driest parts of the Piedmont and Atlantic Coastal Plain regions receive approximately half as much precipitation as the Appalachian Mountains (Dreps et al. 2014). To meet growing societal demands for water, major reservoirs were constructed along Piedmont rivers during the 20th century to capture runoff from mountains and store it for human use (Sun et al. 2008). Major droughts and water shortages have occurred within the past few centuries, but water managers and decision makers often considered these events to be anomalous.

In recent decades, however, the accelerating pace of climate change and an increasing demand for water by growing populations reveal that the southeastern U.S. is not immune to climate-related water crises. Major regional droughts during the early 21st century highlight the vulnerability of the region's water supplies, particularly in urban areas, which tend to rely on surface water reservoirs. Rapidly growing populations surrounding Atlanta, Charlotte, and other cities test the ability of surface water reservoirs to satisfy the competing needs of cities and downstream ecosystems during even minor droughts.

Groundwater, which serves as the primary water source for half of North Carolinians, is also sensitive to climatic variation (Anderson and Emanuel 2008). Little is known about long-term groundwater trends in this region, but throughout the southeastern U.S., including North Carolina's

Coastal Plain, groundwater is increasingly used as a water source for large-scale crop irrigation (Sun et al. 2008). Thus, across the southeastern U.S., surface water and groundwater management face challenges on both the supply side, in terms of climatic variability, and on the demand side, in terms of growing populations and the intensification of agricultural activity.

The perception of the southeastern U.S. as "water rich" is complicated by recent research revealing that a high level of climate variability, particularly precipitation variability, is not only typical of the region, but has increased in magnitude during recent decades. For example, long-term precipitation data from the southern Appalachian Mountains show that droughts have increased in severity and frequency over the course of several decades while rainfall distributions simultaneously became more extreme (Laseter et al. 2012; Burt et al. 2017). For the region as a whole, the increasing variability of precipitation presents a range of management and ecological challenges related to agriculture, forestry, aquatic ecosystems, and urbanization (Vose and Elliott 2016).

The widening envelope of climatic variability underscores a looming problem associated with water, climate, and society in the southeastern U.S. Specifically, population growth and associated infrastructure are dependent upon abundant water supplies arriving in a predictable fashion, yet climate change disrupts the narrative of predictability by increasing the temporal variability of precipitation required to sustain groundwater and surface water supplies. Managers and decision-makers are thus faced with mounting problems at both wet and dry extremes of climate-related events. They must ensure adequate water supplies as the duration and frequency of droughts increase, and they must deal with growing flood risks as storms intensify. The Lumbee Tribe and other Indigenous groups of the Southeast experience many of the same challenges as the region as a whole; however, because of longstanding cultural connections to specific water bodies and wetlands, Lumbee people face additional challenges related to the potential for climate change to disrupt their relationships with these important places.

Overview of the Lumbee Tribe and its Relationship with the Lumbee River

The Lumbee Tribe is centered along the Lumbee River in present-day Robeson and adjoining counties in the inland portion of North Carolina's Coastal Plain (Figure 1). The tribe shares its name with the river, a blackwater stream that flows through Robeson County and eventually drains into the Great Pee Dee River in South Carolina (Locklear 2010). County, state, and federal governments as well as many local residents refer to the river as "Lumber," a name that was created by state legislation in 1809 (Locklear 2010), but the Lumbee Tribal Council passed an ordinance in 2009 to refer to the river as "Lumbee" in accordance with certain tribal oral traditions (Lumbee Tribe 2009). This work refers to the river as "Lumbee" in adherence to the naming convention in the 2009 tribal ordinance.

The Lumbee River and its tributaries are flanked by wide, forested floodplains dominated by bald cypress (*Taxodium distichum),* tupelo (*Nyssa sp.*), and other wetland tree species. Extensive riverine wetlands of the Lumbee River and its tributaries dissect otherwise flat and sandy uplands of the Coastal Plain (Figure 1). The spatial heterogeneity imposed by alternating streams, wetlands, and sandy uplands contributes to the status of the entire region as a global hotspot for biodiversity (Noss et al. 2015). Before commercial logging, which cleared many of the floodplain wetlands, and prior to the arrival of railroads in the 19th century, this wetland-dominated landscape was perceived as inhospitable by many outsiders and provided Lumbee people with isolation from encroaching settlers (Lowery 2010).

With approximately 60,000 enrolled citizens, the Lumbee Tribe is currently the largest Native American tribe in the eastern U.S. Most tribal members live within or near the Lumbee River watershed. Ancestors of the Lumbee and other Native American tribes have occupied the watershed for at least six thousand years (Knick 2008). Disease, colonial wars, and settler encroachment (e.g., Jennings 2013; LeMaster and Wood 2013) caused major upheaval among Indigenous societies across the southeastern

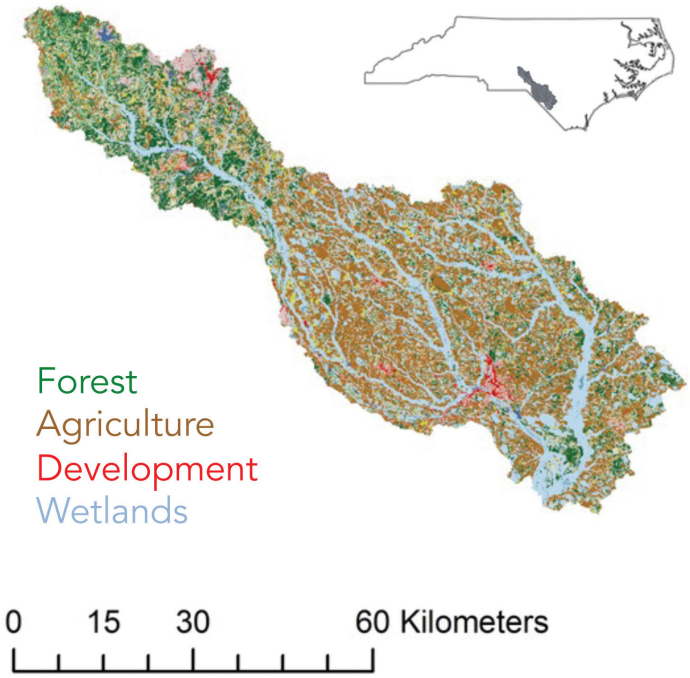

Figure 1. The Lumbee River watershed, delineated above USGS station number 02134500. Land cover shows extensive riparian wetlands and patchwork of agriculture, forests, and development in uplands. Inset shows Mountain, Piedmont, and Coastal Plain physiographic regions, along with Southern Coastal Plain climate division. Land cover data are adapted from the National Land Cover Dataset, 2011 (Homer et al. 2015). Inset shows location of watershed within North Carolina.

U.S., and these events likely spurred migration of Indigenous peoples to the Lumbee River watershed during the 18th century (Blu 2001). Migrating remnants of tribes joined Indigenous peoples already living along the river, and a unified group began to emerge as an amalgamation of these tribes beginning in the mid-18th century (Lowery 2010). The state of North Carolina recognized the group as a single Native American tribe in 1885 (Sider 2003). From the early 19th century through the mid-20th century, the emerging community faced various challenges to its survival, including disfranchisement, forced military labor, and racial segregation. These actions had mixed consequences for the tribe, but Lumbee people generally view these as strengthening forces.

The Lumbee Tribe has no treaty with the federal government, but a federal law passed in 1956 (Public Law 84-570) acknowledged Lumbee people as Native Americans. The same law simultaneously barred the Lumbee from accessing benefits and services otherwise available to fully-recognized tribes. Thus, as a political entity, the tribe lacks many of the protections that federal environmental statutes and other laws afford to fully-recognized tribal nations. These protections stem primarily from the federal government's trust responsibility toward federally recognized tribes and are often enshrined in treaties between tribes and the federal government. For example, many treaties allow tribes to retain access to specific places, including rivers, coastal zones, or landforms, for hunting, fishing, or other purposes (Goodman 2000; Mulier 2006). Although treaties are binding on both tribes and the federal government, tribes often find themselves the sole defenders of treaty rights, "re-reminding" government agencies of their responsibilities through legal actions or activism (Norman 2017).

Federal executive orders and laws such as the National Historic Preservation Act (NHPA, Public Law 89-665) require federal agencies to consult formally with tribes during actions that may affect a tribe's present-day or ancestral territories

(NEJAC 2000; ACHP 2017). Ideally, consultation allows federal agencies to understand how regulated projects could adversely affect tribes and their resources (Routel and Holth 2013). Consultation potentially serves as a powerful tool to protect tribal interests, but its record in practice is mixed, due to inconsistent or incomplete implementation among agencies (Routel and Holth 2013). Recent controversies surrounding the Dakota Access Pipeline and other infrastructure projects affecting tribal territories also highlight the perils associated with incomplete or insincere consultation (Emanuel 2017; Norman 2017; Whyte 2017). Notwithstanding problems with the observance of treaty rights or implementation of consultation, these tools offer some degree of protection to federally recognized tribes seeking to protect their landscapes and waterways.

The Lumbee Tribe's lack of full federal recognition means that agencies have no statutory requirement to engage formally with the tribal government when making decisions about regulated projects that potentially impact landscapes and waterways of importance to Lumbee people. This is true whether project impacts are cultural, environmental, or both. Lumbee people may, of course, petition the government individually as citizens, landowners, or other stakeholders. As a tribe, however, Lumbee people currently lack a collective voice as an Indigenous group in federal decision-making, including decisions concerning their land and water resources.

Although the Lumbee Tribe does not have a reservation or land in trust with the federal government, the tribal government and individual tribal members collectively represent a large block of present-day landowners within the Lumbee River watershed. The tribal government owns and manages more than 200 hectares (ha) of land on behalf of the tribe, most of which lies adjacent to the Lumbee River. Thousands of individual tribal members are private landowners within the Lumbee River watershed, and many of them identify strongly with particular communities situated near specific tributaries and their adjacent wetlands. These communities are known colloquially as swamps, and they are important markers of identity within the Lumbee Tribe. Tribal members continue to practice and pass down local knowledge concerning flora and fauna of these swamps, including knowledge about hunting and fishing, foraging, plants with medicinal and religious significance, and materials used for basket-making, pottery, and other practices (e.g., Boughman and Oxendine 2003). Other elements of Lumbee culture, including music traditions and concepts of "home," emerged in the communities associated with the Lumbee River's tributary swamps (Maynor 2002; Maynor 2005). Moreover, the Lumbee River itself serves as a powerful cultural and spiritual symbol and a unifying institution for Lumbee people (Dial and Eliades 1975; Locklear 2010). The river, its wetlands, and their flora and fauna frequently appear in Lumbee cultural imagery. One prominent example is found in Lumbee artwork and crafts (e.g., patchwork quilts, dance regalia, jewelry), which often symbolize the radiating base of a longleaf pine (*Pinus palustris*) cone.

Historically, Lumbee people farmed corn, tobacco, and other crops on small, upland homesteads (Dial and Eliades 1975). Adjacent streams and wetlands supplemented farming with food and other resources. However, pressures from growing regional populations, civil infrastructure (e.g., highways), and the intensification and industrialization of agriculture, have strained these historical and cultural connections in the 20th and 21st centuries. Nevertheless, Lumbee people continue to identify strongly with the river and with its tributary swamps. Because of the close connection between Lumbee people and the river, some aspects of Lumbee culture are especially vulnerable to the impacts of climate change on water resources. To understand how climate change potentially affects the tribe, it is first necessary to understand historical climate trends in and around the Lumbee River watershed. It is also necessary to examine projections of future climate conditions for the region.

Historical and Projected Climate Change in the Lumbee River Watershed

The Lumbee River watershed is situated in North Carolina's Southern Coastal Plain climate

division. Mean annual air temperature (MAT) for the climate division is 16.6°C, and mean annual precipitation (MAP) is 1276 mm according to spatially aggregated climate station observations made during the 119-year period, 1895–2013. These data are provided online by North Carolina's State Climate Office (SCO 2017). The Southern Coastal Plain's climate is temperate and seasonal; mean air temperatures are lowest in January (7°C) and highest in July (26°C). Precipitation exhibits slight seasonality, with more precipitation in July on average (170 mm) than in any other month (Figure 2). There are no simple, multi-year trends in annual air temperature or annual precipitation based on several decades of historical data for North Carolina's Southern Coastal Plain climate division (SCO 2017).

One important characteristic of the region's climate is that summer precipitation and summer air temperature have covaried for most of the past century, with warm conditions typically accompanied by dry weather, and cool conditions coinciding with wet weather. In particular, mean August temperature and total August precipitation were inversely correlated for 30-year time periods defined by a moving window beginning in the 1890s and ending in the early 2000s (Figure 3). The correlation peaked between about 1920 and 1950. Since the mid-20th century, however, the strength of this correlation has deteriorated, and there has been no significant correlation for a 30-year window since the 1977-2007 period.

One interpretation for the deteriorating relationship between multi-year August temperature and precipitation is that the North Atlantic Subtropical High (a.k.a. Bermuda High) has trended westward since the mid-20th century, increasing the likelihood that summer conditions in the region will be influenced by warm, moist air from the Gulf of Mexico (Li et al. 2012). However, warm and dry continental conditions may dominate during years in which the Bermuda High lies farther east (Li et al. 2013). The increasing likelihood of warm and wet summer conditions in the Coastal Plain through a westward trend of the Bermuda High may explain the breakdown in correlation between summer temperature and precipitation observed through much of the 20th century. As summer precipitation becomes decoupled from temperature, the seasonality of rainfall becomes less predictable, exacerbating ecological and management issues associated with both surface water and groundwater availability.

Long-term surface water records include a United States Geological Survey (USGS) stream gage (Site Number 02134500, drainage area 3176 km^2) on the Lumbee River, which has been in continuous operation since 1929 (Figure 4). Annual runoff for the Lumbee River watershed averages approximately 360 mm per year, which is approximately 28% of mean annual precipitation. Streamflow responds to storms distributed throughout the year, whereas baseflow exhibits strong seasonality, with high baseflow typically occurring during winter and low baseflow occurring during summer. Annual minimum flows typically occur during late summer and early fall, when long, dry spells are common. Annual maximum flows usually occur during winter or spring, except in years when tropical storms bring heavy, intense rainfall during summer or fall. On average, tropical storms make landfall along North Carolina's southern coast once every two to four years (Keim et al. 2007), and in these years both annual maximum and annual minimum flows may occur within a matter of weeks.

A recent study of nearly 1000 long-term, USGS stream gages by Rice et al. (2015) found no significant trends in mean annual streamflow amount or intra-annual variance for the Lumbee River between the 1940s and 2000s. The study did, however, identify a weak, non-significant decline (<1 mm/yr) in mean annual streamflow during the same period (Rice et al. 2015). A more detailed look at streamflow records from the USGS stream gage shows that certain low flow percentiles have experienced significant changes through time between 1929 and present. In particular, the 5th and 10th lowest flow percentiles have declined significantly during 40-year time periods defined by a moving window between 1929 and 2016 (Figure 5). These two flow quantiles have fallen at rates of approximately 0.4 m^3s^{-1} and 0.5 m^3s^{-1} per decade, respectively.

The Coupled Model Intercomparison Project Phase 5 (CMIP5, Meinshausen et al. 2011) provides global projections of temperature, precipitation, and other variables through the year

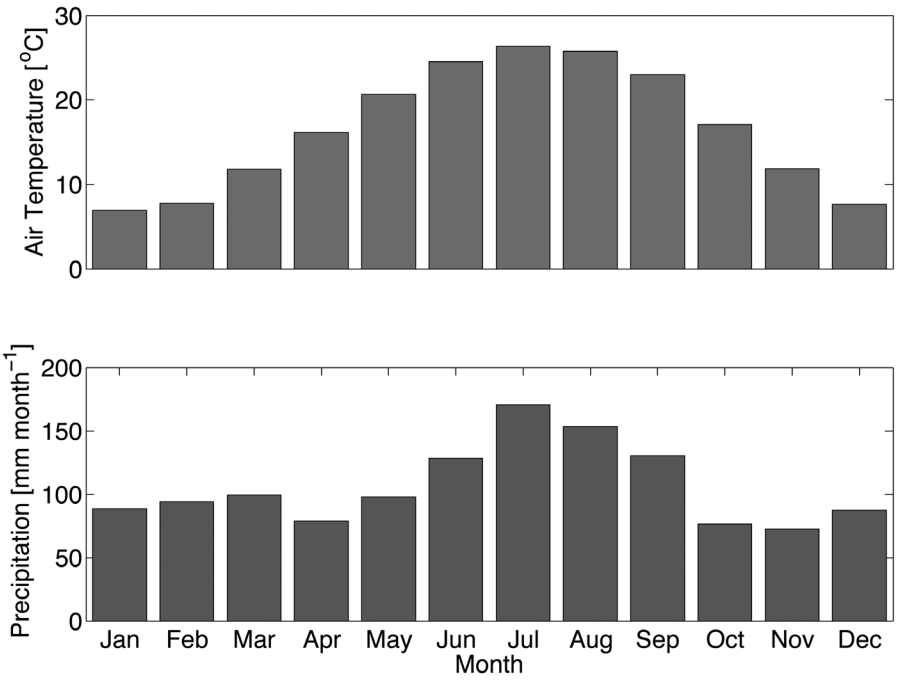

Figure 2. Historical (1895-2013) climate of North Carolina's Southern Coastal Plain (SCO 2017), including mean air temperature (top) and cumulative precipitation (bottom) for each month.

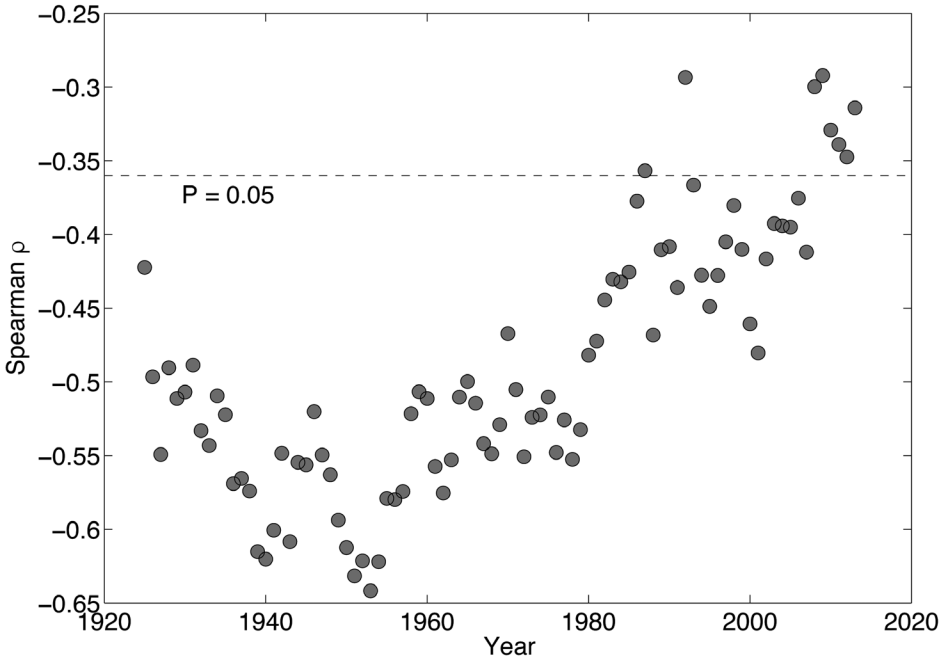

Figure 3. Spearman's rank correlation coefficient between mean August temperature and total August precipitation. Circles indicate the last year of a 30-year period. Values below the dashed line have significant correlations ($P < 0.05$), and values above the dashed line have non-significant correlations ($P \geq 0.05$).

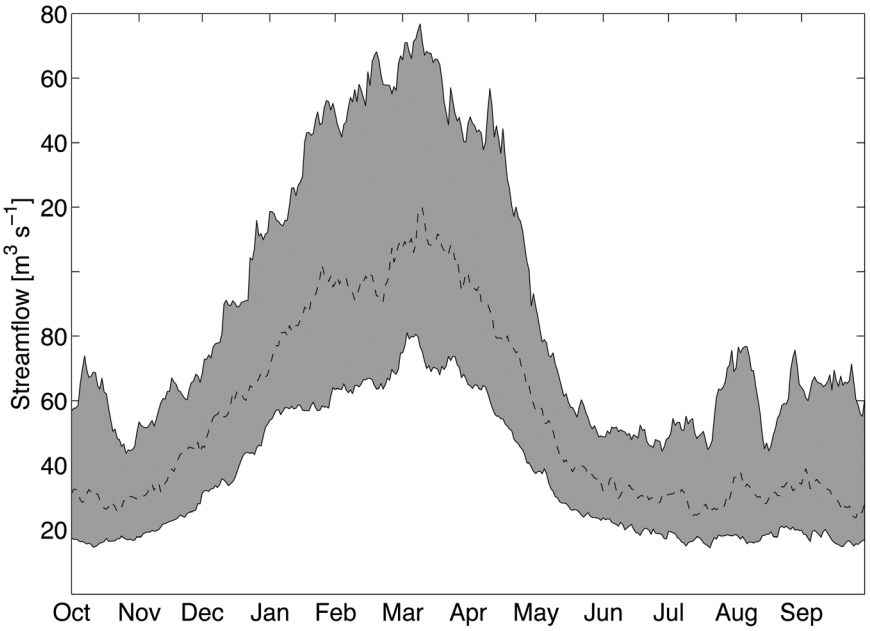

Figure 4. Streamflow on the Lumbee River (USGS station number 02134500). Gray shading shows the interquartile (25th – 75th percentile) range for daily streamflow during the 87-year period of record, October 1, 1929 – September 30, 2016. Dashed line shows median daily streamflow for the same period.

2100. These models are spatially coarse, but the Multivariate Adaptive Statistical Analog (MACA) downscaling method described by Abatzoglou and Brown (2012) and accessed at https://climate.northwestknowledge.net/MACA/ provide detailed, regional projections that can be used to assess climate change for basins of similar size to the Lumbee River watershed. Under a "business-as-usual" emissions scenario (RCP8.5), downscaled MACA results from four CMIP5 models (CSIRO, GEM2-CC, GEM2-ES, and MIROC) reveal that North Carolina's Southern Coastal Plain, which includes the Lumbee River watershed, is likely to experience a significant increase in air temperature by the mid-21st century compared to the 1990s. An ensemble mean of the downscaled model projections shows that mean annual temperature will likely increase from 16.8°C during the 1990s to 19.6°C by 2050, an increase of 2.8°C. Although temperatures are projected to increase during each month of the year, the increases are greater during the growing season (May – September) than during the winter (Figure 6). July temperatures are expected to increase the most under RCP8.5 projections, rising approximately 3.5°C between the 1990s and 2050. Under this scenario, a typical mid-21st century July in North Carolina's Southern Coastal Plain could resemble the present-day climate of the Gulf Coastal Plains surrounding Houston, Texas, a region located approximately 500 km away and five degrees of latitude southward.

The projected temperature increase during the growing season is noteworthy from the perspective of the Lumbee River's hydrologic balance. Consumptive demands for soil water by vegetation are high at the peak of the growing season. Higher growing season temperatures have the potential to increase vegetation productivity (Sage and Kubien 2007) and also to increase evapotranspiration (Emanuel et al. 2007a), but only as long as sufficient soil water is available to satisfy vegetation demand (Emanuel et al. 2007b). With much of the watershed's forested vegetation occupying low-lying floodplains (Figure 1), increased temperature during the growing season is likely to cause greater amounts of precipitation to be partitioned to evapotranspiration, rather than to streamflow or to groundwater recharge.

Although models generally agree on projected temperature increases for the region surrounding the Lumbee River watershed under the RCP8.5

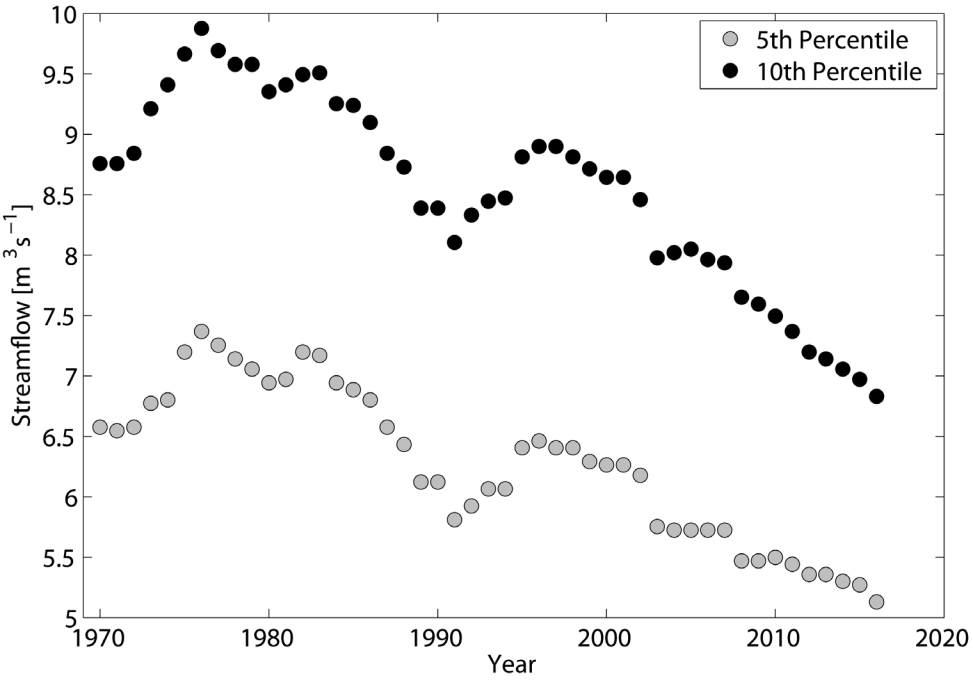

Figure 5. Fifth (gray) and tenth (black) lowest streamflow percentiles for the Lumbee River (USGS station number 02134500) show significant declines through time. Both trends are significant, with the 5th percentile trend having Kendall's $\tau = -0.74$ ($P < 0.001$) and the 10th percentile trend having Kendall's $\tau = -0.72$ ($P < 0.001$). Circle location indicates the last year of a 40-year period.

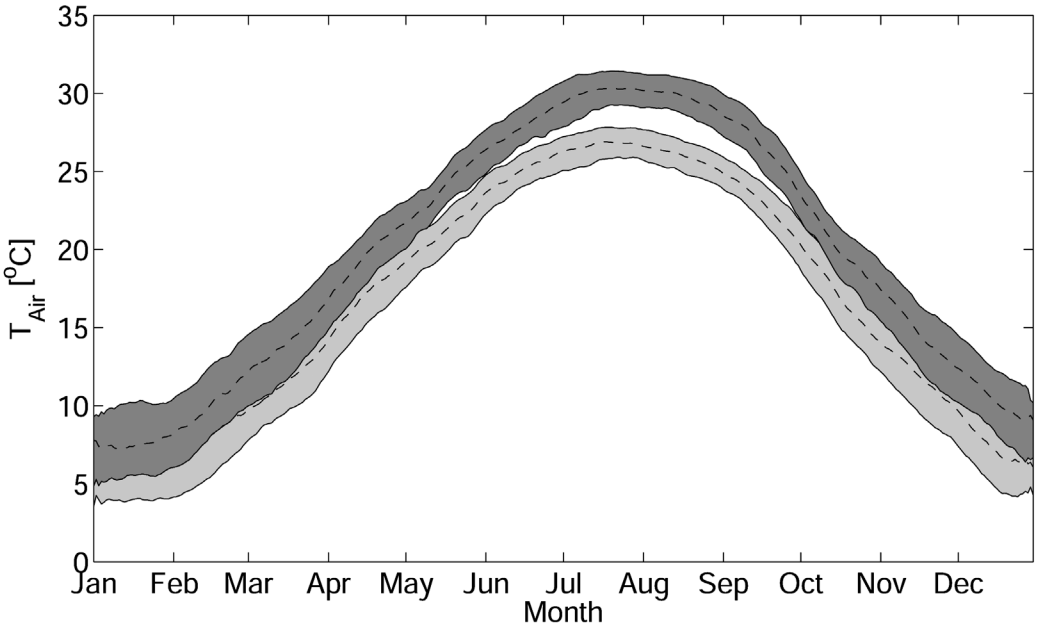

Figure 6. Historical (light gray) and projected (dark gray) air temperatures for the Southern Coastal Plain of North Carolina, which includes the Lumbee River watershed. Model results were downscaled for North Carolina following Abatzoglou and Brown (2012). Shaded regions within solid lines show the envelope of CMIP5 RCP8.5 results for four models listed in text. Dashed line shows ensemble mean.

scenario, precipitation projections are less certain in terms of magnitude and direction of change. This is due, in part, to the high degree of interannual variability in regional precipitation. Given existing trends of increasing precipitation variability in the region (Laseter et al. 2012; Vose and Elliott 2016; Burt et al. 2017) and the complex interplay between temperature and precipitation in a changing climate (Trenberth 2011), process-based models or other numerical tools are required to forecast how projected climate change is likely to impact the streamflow and recharge in the Lumbee River watershed.

Implications of Climate Change for the Lumbee Tribe

The Lumbee Tribe has strong historical, cultural, and socioeconomic ties to the Lumbee River, and climate change has the potential to modify hydrological and ecological conditions along the river, across its connected wetlands, and within its watershed in ways that have serious implications for the tribe. Perhaps most importantly, rising temperatures can expose wetlands to heat and water stress (Erwin 2009). Model simulations from nearby watersheds in South Carolina show that water table elevations and streamflow decrease with rising temperatures (Dai et al. 2010). If rising temperatures combine with longer periods of time between storms, as observed elsewhere in the southeastern United States (Laseter et al. 2012; Burt et al. 2017), wetland ecosystems of the Lumbee River watershed could experience drought-related vegetation damage or die-off. Rising air temperatures coupled with decreased canopy cover could result in elevated water temperatures and concomitant dissolved oxygen declines in streams.

The increasing severity of storms observed elsewhere in the region (Laseter et al. 2012; Burt et al. 2017) compounds potential drought-related problems by increasing the probability that the same wetland and aquatic ecosystems will also be impacted by floods. Shifts in erosion and sediment transport associated with climate change are poorly understood in the southeastern U.S. outside of coastal environments (e.g., Michener et al. 1997); however, there is a possibility that an increase in the severity or frequency of tropical storms and hurricanes could influence sediment transport processes along the Lumbee River. For example, I observed massive sediment deposits left by the Lumbee River following record flooding after Hurricane Matthew in 2016 (Figure 7a-b). On the whole, the region's aquatic and wetland ecosystems are susceptible to degradation due to sediment transport and other issues associated with both extreme flooding and increased streamflow variability (Meitzen 2016).

Increasing variability of precipitation also has implications for industrialized agriculture, which has become more prominent in the North Carolina Coastal Plain in recent decades (Yang et al. 2016). In particular, swine operations often dispose of partially treated wastewater by applying it to unsaturated soils. Increasing variability of precipitation and soil water content can mean less predictability for waste disposal schedules through land application. Intense storms and hurricanes can also cause breaches or unintentional releases of nutrients and pathogens from waste lagoons (Wing et al. 2002). As storm frequencies and intensities change in the future, so will risks associated with accidental releases of these waste products.

Climate-related degradation of wetlands and streams within the Lumbee River watershed can impact the Lumbee Tribe in multiple ways. Individual tribal members who hunt, fish, and forage along the main stem of the river or in its tributary swamps are participating in cultural practices that have persisted for centuries among the Lumbee and their ancestors (Dial and Eliades 1975). Likewise, some Lumbee people continue to practice centuries-old spiritual traditions of baptizing and worshipping at specific locations on the Lumbee River. These locations, along with nearby Lumbee churches, cemeteries, and family home-places, intertwine with streams and wetlands to form a distinct cultural landscape. Given the prominent role of water in this cultural landscape, climate change has the potential to alter the character of this landscape in unpredictable ways if wetlands degrade or transition to other ecosystems, or if floods alter stream channels or damage infrastructure (e.g., Figure 7c).

In recent decades, tribal members have established efforts to renew traditional crafts,



Figure 7. Photos of Robeson County, NC in the months following Hurricane Matthew reveal the extent of sediment transport and deposition by the Lumbee River and damage to local infrastructure by flooding. Sand deposits remained along streets and yards in low-lying parts of Lumberton, Robeson County's largest town, several weeks after the storm (a, b). Flooding destroyed bridges and culverts throughout the Lumbee River watershed, closing some local roads for months after the storm (c).

ceremonies, and other practices that rely on access to and resources obtained from the Lumbee River and its adjacent wetlands. If the ecosystems and landscapes that support these activities are degraded or destroyed as a result of climate change, it will become increasingly difficult for Lumbee people to pursue these particular facets of identity or to renew other cultural practices. Some of these renewal efforts began during the past several years, ironically, during the same period in which downscaled climate forecasts (e.g., Abatzoglou and Brown 2012) began to highlight the regional vulnerabilities of streams and wetlands to climate change. Important components of Lumbee identity and culture are inextricably connected to these vulnerable streams and wetlands, and climate change may therefore have lasting cultural impacts on future generations of Lumbee people.

On the other hand, both recent cultural renewal efforts and longstanding Lumbee traditions may heighten awareness of environmental degradation and spur stronger actions by the tribe to prepare for and adapt to expected climate change. Actions might include adaptation plans and partnership networks that help ensure the tribe's ability to thrive, culturally, in a changing climate, a concept that Whyte (2013) refers to as "collective continuance."

Lumbee people face many challenges to collective continuance as an Indigenous group. Some of these challenges stem from centuries of sustained colonialism and are shared by

Indigenous peoples worldwide. Other challenges relate to the tribe's lack of access to specialized training, programs, and resources reserved for federally-recognized tribes. Nevertheless, by realizing collective continuance (i.e., by putting culturally relevant strategies into practice), the Lumbee Tribe has the potential to meet the challenges of climate change head-on. The tribal government, organized under a constitution that emphasizes "educational, cultural, social, and economic well-being of Lumbee people" (Lumbee Tribe 2000), has shown potential to work within existing constraints to address community needs from a culturally relevant perspective. Some tribal initiatives, including energy assistance and hurricane recovery, have clear connections to climate change and leverage resources that do not depend on the tribe's federal recognition status. In these and other ways, the tribe is already beginning to meet some of the challenges of climate change.

Conclusion

The Lumbee River and its adjacent wetlands are important components of identity and culture to the Lumbee Tribe. Climate change is expected to impact the Lumbee River watershed by increasing air temperatures and potentially altering the temporal variability of precipitation. Changes in atmospheric conditions are already evident over the past several decades, as are changes in streamflow on the Lumbee River itself. Hydrologic change, particularly declining low flows and potentially more variable flows, has the potential to degrade wetland and aquatic ecosystems. Environmental degradation poses risks to the Lumbee Tribe, including cultural loss resulting from deteriorating wetland and stream conditions. However, cultural resurgence, occurring simultaneously with climate change, offers opportunities for Lumbee people to recognize these risks and prepare for changes in culturally relevant ways.

Relatively little research on Indigenous peoples and climate change has focused on Native American tribes living in the Atlantic Coastal Plain. The case of the Lumbee Tribe adds geographic breadth to discussions of Indigenous peoples and climate change, and it also highlights the uniquely vulnerable position of Native American tribes who have deep cultural connections to specific water-dependent landscapes of the southeastern U.S. Many of these tribes lack resources and statutory protections useful for adapting to and preparing for climate change, but opportunities remain for these tribes to meet climate-related challenges in culturally appropriate ways.

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Perspectives on Water Resources among Anishinaabe and Non-Native Residents of the Great Lakes Region

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Abstract: Climate change and human population growth could reduce household water availability in the historically water-rich Great Lakes region. It is critical to understand human-water relationships in advance of policy actions that could result from reduced water supplies. Research on household water conservation typically occurs in a reactionary nature, in settings that are already water-stressed. Furthermore, few studies involve Native American perspectives on this important topic. We used semi-structured interviews to assess residents' perspectives of Great Lakes water resources and views on household conservation, involving distinct samples of Native American and non-Native residents. Although interviewees deeply value the region's water resources, few practice household conservation or plan to do so in the future. Few perceive others in the region as conserving water. Beliefs about water-related problems are focused more on water quality than supply. Native American interviewees expressed deeper spiritual values toward water than non-Native interviewees. Findings can help inform policy and outreach strategies and provide a rich foundation for follow-up quantitative research testing the Theory of Planned Behavior's ability to explain household conservation intentions in the Great Lakes region.

Keywords: *Great Lakes, water, conservation, Native American, Anishinaabe, theory of planned behavior*

Water is extremely sacred in the culture of North America's Great Lakes Anishinaabe ("First People"; also commonly referred to as Ojibwe or Chippewa). Themes involving water pervade countless Anishinaabe traditional stories, including those involving creation and migration. Water is the blood that flows through Mother Earth to nourish and purify her (Benton-Banai 1988; Reynolds 2003). The Anishinaabe migration to the Great Lakes region followed a prophecy to seek wild rice (*manoomin*), the food that grows on the water, which was historically abundant throughout the region (Johnston 1976; Benton-Banai 1988). Water-dwelling animals and plants are particularly sacred and greatly influenced historical lifeways. For instance, the location and abundance of various fish species often determined seasonal movements of tribes to ensure critical sustenance throughout the year (Ettawageshik 2008; McGregor 2012; Gagnon 2016). Northern white cedar (*giizhik*) and many other medicinal plants require wetland habitats, as does the black ash (*aagimaak*) historically used for baskets and many other goods.

Anishinaabe worldviews involving water are not relegated to history; numerous contemporary examples show that water remains sacred. Female symbolism associated with water is expressed through women's ongoing role as keepers of the water (Reynolds 2003; McGregor 2005, 2012, 2013; Ettawageshik 2008; Szach 2013; Whyte 2014; Kozich 2016a, 2016b). Despite challenges, members of many tribes are simultaneously rediscovering traditions and exercising treaty rights through fishing, including traditional spear-fishing (Ettawageshik 2008; Gagnon 2016). Wild rice remains a healthy, staple food and its annual planting and harvesting endures as a sacred

tradition across the Great Lakes region (Reynolds 2003; GLIFWC 2007, 2008; Kimmerer 2013). Across the Great Lakes region, tribes appear to be increasingly expressing sovereignty through their own natural resource management, particularly involving water resources (GLIFWC 2018).

While Anishinaabe lifeways are inexorably linked to the abundant Great Lakes water resources, there are reasons to be concerned about water's local-scale sustainability in light of contamination events, increasing human demands, and climate change (USEPA 2014; IJC 2016a; GLIN 2018). Negative impacts to water resources could affect household water availability, in addition to cultural lifeways. Residents of Flint and Bay City, Michigan have faced major disruptions to their water service due to contamination and problematic infrastructure (IJC 2016a). Increasing human demands, including excessive groundwater withdrawals, have impacted water availability in many municipalities (IJC 2016a). Eutrophication of Lake Erie – likely due to agricultural runoff and climate change – has increased waterborne disease risk for residents of many municipalities (Patz et al. 2008; IJC 2016a). With over 30 million residents dependent on Great Lakes water, it is critical to increase our knowledge of residents' perspectives on water-related topics (USEPA 2014; Floress et al. 2015; IJC 2016a, 2016b). Across all Great Lakes cultures, it is currently unclear how residents may react to policy actions calling for conservation. This paper begins to fill knowledge voids related to Great Lakes residents' views on water, including Anishinaabe and non-Native perspectives on household conservation.

As is true in most geophysical contexts, Great Lakes households play a key role in regional conservation planning. In times of scarcity they are typically early targets for conservation policies through measures such as lawn-watering restrictions, drought-tolerant landscaping requirements, and penalties for high use – particularly compared to economically-critical sectors such as agriculture, industry, and energy (Harlan et al. 2009; Great Lakes Commission 2013; USEPA 2015; Wittwer 2015). As the public supply sector contributes to 34% of Great Lakes water use, households may cumulatively hold the greatest potential towards meeting established basin-wide conservation goals (IJC 2016a).

Water conservation is further heightened as a key component of the 2008 Great Lakes-St. Lawrence River Basin Water Resources Compact. The Compact is a state and federal law that prescribes how regional stakeholders will work collaboratively to ensure the sustainability of Great Lakes water resources (Great Lakes-St. Lawrence River Basin Water Resources Compact 2008; Council of Great Lakes Governors 2015). States and provinces bounding the Great Lakes are required to develop and submit water conservation plans every five years (Great Lakes-St. Lawrence River Basin Water Resources Compact 2008). Insight on residents' water-related perspectives and conservation behaviors is critical for agency personnel tasked with developing and implementing these plans.

In the scientific literature, examinations of household water use reveal few consistent trends describing who conserves and why. Studies often report conflicting relationships between water use and traditionally-examined demographic variables such as income, age, or gender (Hurlimann et al. 2009; Jorgensen et al. 2009; Russell and Fielding 2010; Fielding et al. 2012). For instance, some researchers have found higher-income households likely to use more water, while others have found them likely to use less because they can afford to install water-saving appliances or fixtures (Lam 1999; Millock and Nauges 2010). Older residents are typically more inclined towards water conservation but they also spend more time in the home, leading to higher household water use (Lyman 1992; Fielding et al. 2012). Women tend to be more environmentally conscious than men but they often use more water by taking longer and more frequent showers (Domene and Sauri 2006; Makki et al. 2011).

The inconsistency of demographic variables to explain household water use has led to the call for research frameworks focusing on socio-psychological variables over demographic ones (Randolph and Troy 2008; Russell and Fielding 2010; Farrelly and Brown 2011; Heberlein 2012; Floress et al. 2015). The Theory of Planned Behavior (TPB) is one such framework that has been used to examine many environment-impacting behaviors, including recycling, littering, industrial pollution,

energy conservation, agricultural practices, and participation in landowner management programs (Armitage and Conner 2001).

As Figure 1 shows, the TPB proposes that intentions to perform a behavior are determined by three variables: attitudes towards the behavior, perceived social norms surrounding the behavior, and perceived control over the performance of the behavior (Ajzen 1991). Intentions to perform a behavior will be high if these three factors all support the performance of it (Ajzen 1991; Fishbein and Ajzen 2010). Regarding household water conservation, the TPB predicts that conservation is most likely for individuals who perceive the ability to conserve, perceive that important others approve of conservation, and have a positive attitude towards conservation. All TPB variables have been shown as effective predictors of household water conservation, although most studies occurred in water-stressed contexts (Lam 1999, 2006; Trumbo and O'Keefe 2001; Clark and Finley 2007). Little is known about the ability of the TPB or other theoretical models to predict household water conservation in contexts historically perceived as water-rich. Gaps in our understanding of Great Lakes residents' perspectives on water limit the ability of water managers to effectively promote household conservation.

The broad objective of our research is to more fully understand the range of variables influencing intentions to conserve household water in the Great Lakes region, including potential differences across cultures. This paper describes a qualitative examination of water-related perspectives to serve as a rich foundation for follow-up quantitative studies based on the TPB. The inclusion of Anishinaabe perspectives provides insight from a population typically under-represented in the scientific literature and speaks to potential differences in the ways water is valued. Findings provide valuable insight for policy-makers, regional water managers, and those tasked with developing pro-conservation messages to the public.

Methods

We conducted semi-structured interviews with residents in five Great Lakes sub-regions to gain a richer understanding of viewpoints on water resources (Fig. 2). Study areas were chosen simply to provide a useful snapshot of the region as a whole, with varying population sizes and distances from the nearest Great Lake. Interviews with Anishinaabe residents occurred on or near reservations of the Keweenaw Bay Indian Community (Keweenaw Peninsula) and the Bay Mills Indian Community (Sault Ste. Marie), as part of study areas in Michigan's Upper Peninsula (U.P.). Table 1 shows details about each interview location.

Interviews were conducted between 2014 and 2017, with a minimum of seven interviews at each study area. Interviews at each site were conducted over a minimum of three days,

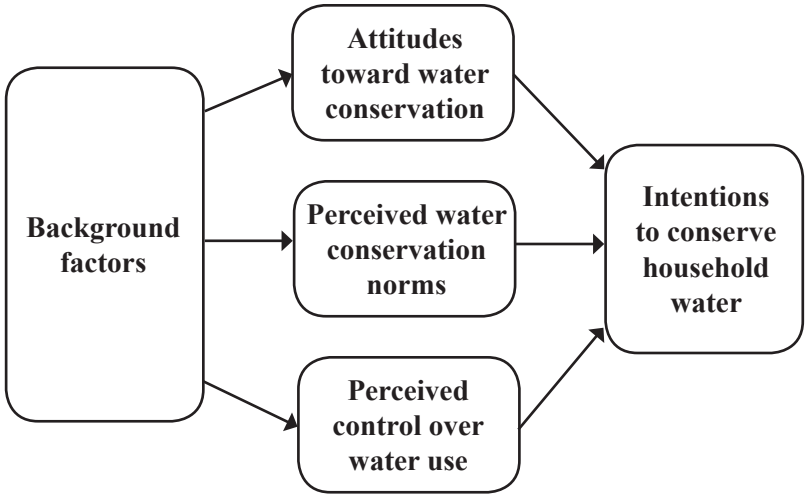

Figure 1. Conceptual model based on the Theory of Planned Behavior (Ajzen 1991).

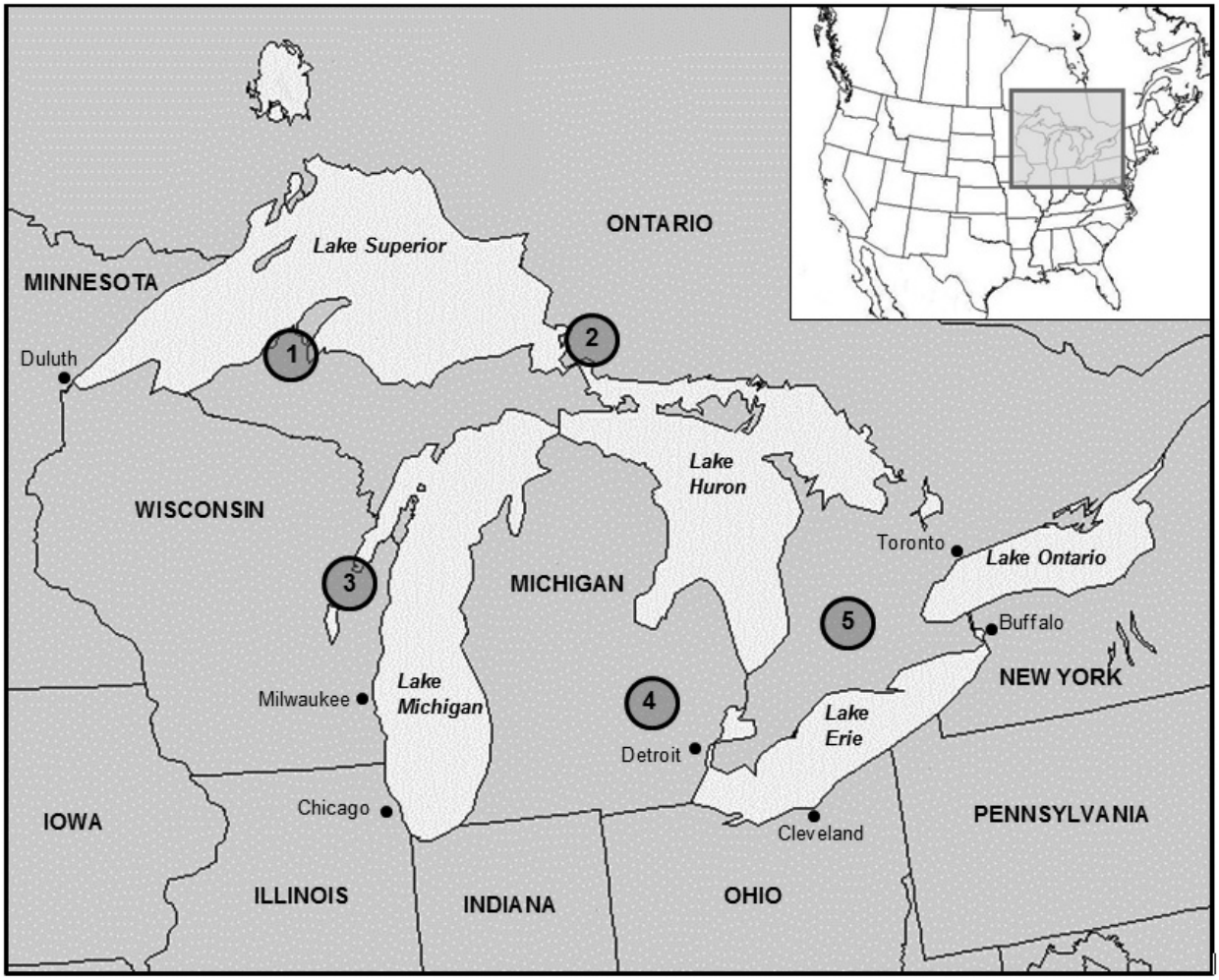

Figure 2. Research study areas: (1) Keweenaw Peninsula; (2) Sault Ste. Marie; (3) Green Bay; (4) southeastern Michigan; and (5) rural southern Ontario (Image: Kozich). Interviews with Anishinaabe residents occurred in areas 1 and 2.

including at least one weekday and one weekend day and at various times throughout each day. We used convenience sampling to solicit interviews, randomly approaching residents in public settings while seeking balanced representation across gender and age. Outdoor interview settings included downtown sidewalk benches, college campuses, and other open gathering places. Indoor interviews occurred in coffee houses and eateries, shopping centers, bookstores, and libraries. To avoid over-sampling in leisure environments, we also conducted interviews in settings likely visited as part of day-to-day routines, such as grocery stores, gas stations, and post offices. Rural Anishinaabe residents were interviewed at a tribal college, community center, and powwow. In total we approached 65 residents, yielding 60 who agreed to be interviewed (including 20 Anishinaabe interviewees). As shown in Table 2, participants were fairly similar to the greater regional population across key characteristics, aside from cultural identity.

Our interview sampling methodology and size were not designed to produce findings generalizable to the broader population; this objective will be addressed through a follow-up quantitative mail survey. Instead, our goal was simply to capture a rich range of water-related perspectives that exist across the region, following Becker (1998), to serve as a valuable foundation for the survey while providing useful insight for policy-makers and water district managers.

Table 1. Details of interview study areas.

Study area	Number of interviews	Population (2010)	Approximate distance to Great Lake
Rural Keweenaw Peninsula area			
Houghton/Hancock, Michigan	9	11,644	15 km
L'Anse/Baraga, Michigan (Anishinaabe community)	10	3,392	<1 km
Sault Ste. Marie area			
Sault Ste. Marie, Ontario	7	79,800	5 km
Sault Ste. Marie, Michigan (Anishinaabe community)	7	14,144	5 km
Urban Green Bay area			
Metropolitan Green Bay, Wisconsin	7	306,241	5 km
Urban southeastern Michigan area			
Metropolitan Flint, Michigan	4	425,790	85 km
Waterford, Michigan	3	73,150	65 km
Rural southern Ontario area			
Woodstock, Ontario	4	37,765	60 km
Chatham, Ontario	5	44,074	20 km
Tilbury, Ontario	4	4,809	10 km

(Data sources: U.S. Census Bureau 2010; Statistics Canada 2011)

Interview questions focused on water and lifeways in the Great Lakes region, concerns about water resources, and perspectives on household water conservation (Appendix 1). Questions designed to enrich follow-up quantitative studies were linked to key elements of the TPB, including conservation-related beliefs, norms, and attitudes and intentions to conserve in the future. Through the semi-structured format we welcomed interviewees to share stories, elaborate on topics of particular interest or concern, and raise points not addressed by our pre-determined list of questions. The average interview lasted 30 minutes, and all interviews were digitally recorded and transcribed verbatim. Transcripts were first analyzed and coded at the item (question) level; upon completion of item-level coding, similar codes were grouped into themes and sub-themes to identify important patterns across interviews (Babbie 1995; LeCompte and Schensul 1999). These patterns are reflected in the key themes described in our results.

Results

Analysis of interview transcripts resulted in the identification of the following key themes expressed by interviewees: (1) water characterizes "the way of life" in the region; (2) interviewees are more concerned about water quality than water quantity; and (3) differences in water-related values exist between Anishinaabe and non-Native residents. Each theme is elaborated upon in the paragraphs that follow. Percentages related to interviewee responses are included simply for reporting transparency and to indicate salience of issues across interviewees; they are not intended to be generalizable to the regional population.

Water Characterizes "the Way of Life" in the Region

Most interviewees are long-time residents of the Great Lakes, with an average residence time of 26 years. When asked how long they have lived in the

Table 2. Demographic characteristics of interviewees (N=60) versus Michigan, Wisconsin, and Ontario populations.

Category	Interviewees	Michigan residents	Wisconsin residents	Ontario residents
Male	47%	49%	50%	49%
Female	53%	51%	50%	51%
Age[1]				
18-39	40%	40%	35%	34%
40-59	38%	33%	39%	39%
60+	22%	27%	26%	27%
Cultural identity				
Native American	33%	1%	1%	2%
Not Native American	67%	99%	99%	98%
Educational attainment				
Some high school	7%	8%	6%	13%
High school diploma	33%	32%	31%	28%
Some college	30%	32%	33%	30%
Bachelor degree or higher	30%	26%	27%	29%
Residence				
House/mobile home	67%	72%	67%	61%
Apartment/condo	33%	23%	30%	38%
Residential water service				
Municipal water supply	75%	71%	65%	80%
Private well water supply	25%	29%	35%	20%

[1]Age data for states/provinces after removing percent of population below age 18.
(Data sources: U.S. Census Bureau 2010; Statistics Canada 2011)

region, the most common response was "my whole life." Most interviewees also live close to water and are accustomed to viewing or interacting with it as part of daily life; 52 of 60 (87%) said that they live one kilometer or less from a significant water body and view it at least once a week. Anishinaabe and non-Native interviewees alike described the region's water resources as an essential component of their lifestyles:

> *I grew up between two lakes. Water's always been an important part of my life. I can't imagine not living near water. When I think of Michigan and the Great Lakes region, I just always think of water. I took swimming lessons when I was four or five years old. When I was growing up, we fished, being that we lived right there on the lake. My dad always took me up north to the U.P. for fishing, with all the clean lakes and streams everywhere you turn. Now whenever I have a day off and have some free time, I think 'where's the nearest body of water I can get to?'* (Interviewee #37; non-Native)

I enjoy spending time around the water, sitting by the water, walking by the water. I think about all the fresh water we have – the abundance of water around us – when I think of the Great Lakes. I just think of how much people around here enjoy living near the water because of the beauty of it. I just think we are fortunate to live in an area where there's so much fresh water. (Interviewee #44; Anishinaabe)

As the above quotes demonstrate, interviewees emphasized the abundance of water as uniquely characteristic of the Great Lakes region. Many compared the region's typical scenery to other parts of the country where one can drive for hours without seeing water. When asked to describe what comes to mind when they think about the Great Lakes region, 40 interviewees (67%) focused on the abundance, cleanliness, and variety and of water features. One remarked, "It's hard to miss it; you see water everywhere you look" (Interviewee #17; non-Native). Another used the example of Lake Superior to illustrate the vastness of the area's water:

The size of Lake Superior – that you can drive for hours, and it's still Lake Superior. My grandchildren have Lake Superior in Marquette. And then they come here to visit, and this is still Lake Superior. And they just can't believe it could possibly be that big. (Interviewee #42; non-Native)

Interviewees used many examples to describe the aesthetic features characteristic of the region. Forty-two (70%) discussed the serenity that water provides and specifically used the words "peace," "quiet," "space," or "relaxation" in their responses. Interviewee #54 (Anishinaabe) summarized this notion concisely, stating "I feel very happy to live near the water because water is very calming and soothing and helps me to relax." Over half discussed sounds, smells, or textures associated with the water in addition to its visual appeal. One remarked on the unmistakable purity of the water by saying, "When you're near the water, you can always smell it in the air; it's a very fresh feeling" (Interviewee #5; non-Native).

Water-related recreation is very important to all interviewees, many of whom integrated comments about recreation at several points throughout their interviews. All 60 said they engage in water-related recreation at least once per month, and over two-thirds (42) said they do so at least once per week. Many described these activities as so central to their lifestyles that they would not enjoy living in an area that lacks abundant water. When asked what water-related recreational activities they engage in, most interviewees listed several. The most commonly-cited activities include water-related walking/sightseeing (75%), visiting beaches (65%), fishing (63%), and camping/picnicking near water (60%).

Many explained how water plays important roles in their daily or weekly routines beyond recreational excursions. Forty-four interviewees (73%) described seeking water for activities that do not involve direct engagement with it; commonly-cited examples include using waterfront parks, trails, or seating areas as locations to exercise, read, eat lunch, or otherwise take a relaxing break. Like this interviewee, many go out of their way to do things near water simply "because it's there":

I've lived in Chatham since 1993 and I just love to come down here and bring a bottle of water or stop at Tim Horton's and get a coffee or ice-cap or something. I'll just sit here for an hour or so in the afternoon. I don't fish. I don't swim anymore. I'm too old – I'd just sink. But I'll come down here by the river and sit for a couple hours just shooting the breeze. (Interviewee #30; non-Native)

Water also strongly influences interviewees' family vacations, camping trips, and other similar traditions that happen on a seasonal or annual basis. Many explained how family traditions involving water are among their most deeply-valued and memorable life experiences. These examples occurred through stories by 44 interviewees in response to a broad question about "anything that makes the region's water resources special." Many who described memorable childhood experiences involving water said they now carry on these traditions with their own children, as shown by this interviewee:

Vacation time, spending time on the Great Lakes, camping, going fishing. You know, you go and enjoy the water. I remember lots of

family vacations growing up and chances to be out with friends. And it's always like, 'Yeah, we're heading up north' or 'Yeah, we're going to go out in the water here.' Between fishing, lodging, recreational places, a lot of people have cabins up north. You know, growing up I heard that phrase a lot –'going up north'. And now I do that with my own kids. (Interviewee #7; non-Native)

Interviewees Are More Concerned About Water Quality than Quantity

Interviewees expressed many concerns about the region's water resources, typically focusing on water quality rather than supply. Their remarks were in response to the open-ended question, "Please share any concerns you may have about water in our region." Of the 10 most frequently cited concerns, seven can be described as pollution, including intentional dumping/littering (cited by 63%), industrial pollution (52%), sewage discharge (43%), and inadvertent nonpoint pollution (43%). Only seven interviewees specifically mentioned concerns about reduced water availability.

Many water quality concerns were based on personal observations. Of the 38 interviewees who discussed intentional dumping or littering, 31 elaborated with at least one specific example of something they had witnessed firsthand. In some study areas we heard consistent stories among interviewees about local water issues that could warrant follow-up investigation by local personnel. For instance, nine of 10 interviewees in one Anishinaabe community described perceived pollution issues at a local power plant. In the southern Ontario study area, all 13 interviewees described problems with agricultural runoff, like this interviewee who provided a detailed account:

Out where I live, there's a pig farm across the road. And every time it rains, there's about 500 acres that just runs downhill into the ditches, into the crick, and eventually it ends up in the lake. I see it. And when they spread the manure on the fields, they're supposed to turn it under within 48 hours. Sometimes they do and sometimes they don't. And they can't control the rain. I've even seen the bedding from the pig farm floating down through the ditches. And when they're moving the manure from one farm to another, the paved road that they used is so covered in poop that you can't drive on it. If you do, it sticks to the bottom of your car and stinks for weeks. (Interviewee #23; non-Native)

Few expressed confidence in the ability of government regulators to control pollution into water bodies, intensifying perceptions of uncontrolled pollution. For example, among the 31 interviewees who discussed industrial pollution, 27 believe that discharges into water are rampant and that facilities are not adequately regulated by government agencies.

As household water conservation is a key theme of our research, we designed interview questions to link to variables in the conceptual model (the TPB), beginning with questions about current water use and conservation behaviors. We found very few interviewees to have already adopted significant conservation measures in their homes. Thirty-one (52%) admitted that they regularly engage in highly-consumptive outdoor uses such as gardening, lawn watering, or car washing. Only nine (15%) told us that they re-use water, had installed at least one water-efficient appliance or fixture, or had discontinued specific uses (e.g., lawn watering) for the purpose of conservation. None of the remaining 51 provided an example of a significant conservation measure they have adopted beyond small steps like turning water off while they brush their teeth. Most discussed their habits in vague terms such as "We try not to waste it" or "We don't leave it running." Like the interviewee below, most appeared to believe that they are no more wasteful than others:

Let's put it this way, I don't over-use water. We have plenty and I'm probably average when it comes to that. I mean, do I leave a faucet running and walk away, or leave the hose running and walk away? No. I just have these normal practices. (Interviewee #6; non-Native)

The interviewee above clearly spoke to water-use norms, which was the next topic on our question list. We asked interviewees if they believe other people in the region are doing anything to conserve water. Only four of 60 confidently replied "yes," while 38 believed others do not conserve and 18 were unsure (typically claiming that they do not pay

attention to others). The phrase "They take it for granted" was mentioned repeatedly at this point in our conversations, with many interviewees sharing stories about neighbors' water-wasting behaviors. When asked if they feel any social pressures to conserve water, only five interviewees said "yes."

We asked interviewees about their ability to reduce water use in their home, linking to the TPB variable of perceived control. Forty interviewees (67%) indicated a perception that they lack the ability to adopt conservation measures because it would require uncomfortable lifestyle changes or because there are too many water-users to oversee in their household. Regarding conservation attitudes, 31 stated that it seems unnecessary because water is abundant or inexpensive. Regarding intentions to conserve in the future, only seven of 60 described intentions to conserve water in the future by citing a specific example such as eliminating outdoor use or installing efficiency-improving technologies. An additional 13 (22%) merely used vague language such as "I could use less." The remaining 40 interviewees expressed no intentions whatsoever to conserve in the future.

Differences in Water-Related Values Exist between Anishinaabe and Non-Native Residents

We discovered an undeniable trend across the Anishinaabe residents we interviewed, as all 20 spoke about significant cultural and spiritual values involving water. Similar perspectives were shared by only two of 40 non-Native interviewees, who briefly mentioned prayer among the activities they do near water.

Eighteen of 20 Anishinaabe interviewees spoke specifically (and typically at great length) about water's role in traditional creation or migration stories. Thirteen repeated the identical phrase – that their ancestors were instructed by the Creator to find "the place where food grows on the water" – which is a common reference to the wild rice that was historically abundant across the Great Lakes region. Like the interviewee below, most identified water as the single most significant aspect of their ancestral homeland:

> *This is where our people have been for countless generations. We came here because it is the place where food grows on the water. The water makes up the life in our bodies and supports the rice and the rice nourishes us. Everything is connected and it all starts with water. Water is everywhere in our traditional stories, our ceremonies, our songs, and our prayers. I don't hold anything against non-Natives; they just don't realize this and they don't think about water the way we do. Water is life and it's a gift from the Creator. We have to take care of it. We have to not pollute it and not waste it.* (Interviewee #58; Anishinaabe)

In keeping with traditional values, many Anishinaabe interviewees also spoke of the role women play in the care of water resources. Seventeen of 20, like the one below, described the traditional and contemporary importance of women as leaders in the protection and management of water resources:

> *The women were the water-keepers; we were the ones to care for the water. I'm happy that we have so many women doing important work nowadays at the NRD [Tribal Natural Resource Department], but I think overall our women need to get together more to care for the water. Whether it's just getting together for water ceremonies or walks or praying for the water or being the ones to speak up and be community leaders, that's what we need to do. It's the women that need to lead the way.* (Interviewee #54; Anishinaabe)

Relating to another traditional value, 15 Anishinaabe interviewees (75%) included in-depth discussions of the cultural significance of local fishing resources. Although many non-Native interviewees also mentioned fishing, they did so only as an example of an important recreational or economic activity and not as something that holds cultural or spiritual value. Anishinaabe interviewees, by contrast, typically shared stories of fishing's historical role in shaping lifeways in the region:

> *You know, traditionally we're a fishing people. You don't see it as much now, but back in the day it was one of the main reasons we lived here. We'd catch smelt and brookies in the streams and everything you can imagine from the big lake [Lake Superior]. Year-round – ice fishing and spearing too – the fish*

determined where we lived any time of the year. As seasons changed we'd move around to different camps to follow the food. Fish are a healthy meal and there were always plenty, like the buffalo to the Plains people. So yeah, I'd say they're sacred to us in ways that non-Natives don't really relate to. It's why we have our own hatchery and stock the waters ourselves. If we didn't have fish, a major part of our cultural identity would be gone. (Interviewee #46; Anishinaabe)

As Anishinaabe interviewees described human relationships with water, most (80%) discussed its role as a life-giving entity that deserves respect and reciprocity (e.g., several made references to tribal water management and fish-stocking programs). Many elevated water to a status equal to or exceeding that of humans. While many non-Natives also made references to water as a life-giver or as a connecting force in nature, they tended to speak strictly in ecological terms. Typical Anishinaabe interviewees, like the one below, included deep spiritual perspectives that illustrate substantially different worldviews than non-Natives:

We just had so much respect for everything in our environment. Everything was family – the trees, birds, rocks, plants, water, the sun – it was all family and because of that we had the upmost respect for it all. You don't want to harm your family, and because they give to us, we rely on everything in the natural world for us to live. When we would take we would always give something back –tobacco – because we knew we were dependent on it all. Water doesn't depend on us, but we depend on it to survive. So we value the water, we love the water, we need to pray for the water, the water gives us life, and the water has a spirit. Without water we would not have life. There was always that reverence and respect for it, and we wouldn't ever take it for granted. (Interview #44; Anishinaabe)

While differences in values were clearly evident between Anishinaabe and non-Native interviewees, fewer differences were noted in conservation attitudes or norms. Similar proportions in both groups considered themselves not to be water-wasters and agreed that most others in the area do not conserve. The only noteworthy difference we found between groups involves specific behaviors – none of the 20 Anishinaabe interviewees said they use household water for gardening, lawn-watering, or car-washing (compared to 31 of 40 non-Native interviewees who do).

Discussion

Among the key themes we identified, the most prevalent involves the deep bond interviewees feel with the region's water resources (i.e., place attachment), which has been noted in other recent research (Floress et al. 2015; IJC 2016b). This theme was very strong across Anishinaabe and non-Native interviewees alike, although Anishinaabe interviewees described numerous additional spiritual and cultural values associated with water. All interviewees, however, were very engaged in discussions of how their lives are influenced by the region's water; they provided rich descriptions of recreation, stories about family traditions, and emphasized the importance of serenity associated with water. While these deep values tended to dominate interview discussions and represent an important background factor in our research, they do not appear to translate to water conservation motivations.

References to the region's water quality greatly overshadowed those about supply. Interviewees' deep concerns about intentional pollution are consistent with findings from other studies (IJC 2016b). It is interesting that these concerns appear to linger, likely from historical media images, despite the fact that actions resulting from the 1972 Clean Water Act have largely addressed chronic point-source pollution in the region. Furthermore, we anticipated that the historically-low Great Lakes surface water levels of 1998-2013, which had been widely-reported in the mainstream media, could have garnered meaningful attention in our interviews (NOAA 2015). This was not the case, as low water levels were rarely mentioned. The prevailing belief shared by interviewees appears to be that there is plenty of water to go around and that calls for conservation are unfounded. Follow-up research could more closely investigate residents' sources of information on regional environmental issues as a potential addition to conceptual models;

we did not address this topic in our interview questions.

Interview findings provide initial qualitative insight on relationships between TPB variables (attitudes, perceived norms, perceived behavioral control, and intentions to conserve) that will be examined quantitatively through follow-up survey research. For instance, few interviewees expressed positive attitudes toward household water conservation, with most stating that it would require uncomfortable lifestyle changes or that it does not seem necessary. Findings also indicate a potential link between perceived norms and conservation, as only four of 60 interviewees believe others in the area are conserving. Forty interviewees alluded to issues of control by stating that it would be difficult to monitor the water use of other family members. Therefore according to the TPB, if few interviewees feel a positive attitude, few feel that others conserve, and most perceive difficulties with conservation in their household, it should be no surprise that only seven of 60 interviewees said they intend to conserve more water in the future (Ajzen 1991; Fishbein and Ajzen 2010).

Another factor possibly related to conservation intentions involves awareness and understanding of water-related issues. While our findings indicate that water conservation is not a salient issue among interviewees, a possible explanation could be that issues related to water supply in the region are not well-communicated by scientists and water resource managers to the general public stakeholders. For instance, several interviewees who had spent time in comparably arid regions mentioned the frequency of outreach messages in those areas intended to encourage residents to cut back on water use. They remarked they had not seen or heard the same types of messages here in the Great Lakes region. This perception could influence water-conservation norms in the region, which we found almost nonexistent among our interviewees. As mentioned, we did not inquire about sources of information in interviews.

We found substantial differences in the ways Anishinaabe and non-Native residents value water. While this finding was not surprising, we anticipated that Anishinaabe values could result in differences in conservation behaviors. This may be the case regarding current water use – no Anishinaabe interviewees reported that they are heavy users of outdoor water – but other factors could be involved too, including water services available in Tribal housing, different lawn/landscaping norms in Tribal neighborhoods, or fewer resources to afford higher water bills. We largely found similarities across interviewee groups regarding conservation-related attitudes, norms, and intentions. We suspect that the primary difference we found – that few Anishinaabe interviewees intend to reduce their future household water use – is because they already use less than typical non-Native residents based on an absence of consumptive outdoor use. This question will be addressed in detail in the follow-up survey, giving respondents the opportunity to indicate the extent to which they could "use less water than they already do."

Anishinaabe residents interviewed shared deep cultural values regarding the spiritual significance of water, while non-Native interviewees emphasized the aesthetic, recreation, and economic value of water. Anishinaabe perspectives on human-nature relationships far exceeded those shared by non-Native interviewees, speaking to the connectedness of the natural world (including humans), the respect that all things in nature deserve, and the notion that all life depends on water. They referenced traditional stories and beliefs that emphasize the central role of water in Anishinaabe lifeways. Based on our interview findings, however, it is unclear how these traditional values could be related to current perspectives on water conservation. While few spoke of their own personal need to increase conservation, some (astutely) suggested that as long as household wastewater is properly treated in rural northern Michigan, it can be safely returned to nature to be used again. No non-Native interviewees made this link when suggesting that there is "plenty of water to go around" in the region. This topic will be further examined in follow-up research.

Conclusion

The semi-structured interviews we conducted were valuable as a preliminary step in identifying potentially important ideas for future studies. Qualitative findings will guide future modeling efforts and the development of a quantitative mail

survey to test the ability of the TBP to predict and explain household water conservation in the Great Lakes region. Specifically, we gained preliminary insight about perspectives that were most salient among interviewees, and future work will examine linkages between these variables and conservation intentions.

Perspectives shared by interviewees provide rich insight beneficial to resource managers and policy-makers as they develop proactive water management strategies, particularly with conservation policies in the region likely to expand in the future. Effective management of any natural resource depends on a thorough understanding of the people whose behaviors impact that resource.

Findings also benefit outreach personnel who wish to encourage greater conservation behaviors among residents in the region through public informational campaigns. The social information we gathered, combined with findings from follow-up quantitative studies, will help personnel develop effective messaging strategies by better-understanding their target audience.

While our findings contain policy implications and help address a knowledge gap involving perspectives on water conservation in the Great Lakes region, our work could ideally be enhanced by further studies in states we did not include due to time and scope limitations. We also encourage follow-up research with Anishinaabe residents, as their perspectives tend to be overlooked in the scientific literature.

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Appendix 1

Interview question list. Demographic data were collected on a paper questionnaire accompanying the informed consent documents completed by each interviewee.

1. How long have you lived in the area?
2. How close do you live to any water body? What's it like? How often do you see it?
3. Do you enjoy spending time around water? What do you like to do? How often?
4. What comes to mind when you think about the Great Lakes region? Is there anything about the area that makes it special?
5. Please share any concerns you may have about water in our region.
6. Do you think the government(s) are doing enough to protect our water? If not, what do you think should be done?
7. What are your thoughts on Great Lakes water

and any traditional cultural values of the people of the region? [e.g., traditional Native values, religious/spiritual values, etc.]

8. Do you think the same values are being expressed by residents today compared to past generations? How is it similar or different?
9. Do you participate in any cultural, spiritual, or religious activities involving water? Please explain.
10. Is there anything you'd like to share with the general public about what our water means to you personally?
11. Do you use household water for outdoor activities like watering the lawn, gardening, washing cars, and so forth?
12. Do you do anything in particular to try to conserve water in your household? If so, please elaborate.
13. Do you feel social pressures to conserve household water?
14. Do you think other people in the area are doing anything to conserve water?
15. Do you believe you have the ability to reduce water use in your household?
16. Do you plan to take any steps to conserve water in the future? If so, how?
17. What is your neighborhood like? Rural, urban, or suburban? Do you live in a house or apartment?
18. Are you on city water or a well? What do you think about your water, like the rates, quality of water, and so forth?
19. Is there anything you'd like to add? Do you have any questions for us?

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Navajo Nation, USA, Precipitation Variability from 2002 to 2015

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Abstract: Due to its semi-arid climate, the Navajo Nation, situated in the southwestern United States, is sensitive to small changes in precipitation. However, little information on patterns and causes of rainfall variation is available for this sparsely populated region. In order to study stability and variability over time, this study characterized hydroclimatic changes for the Navajo Nation over timescales of months to years based on data from 90 sites from 2002 to 2015. This research will help local water managers identify related precipitation areas within the region, compare Navajo Nation precipitation with climate indices to ascertain larger-scale atmospheric contributors to precipitation in the Four Corners region, and support future water planning in this understudied region. A vector quantization method, called *k*-means clustering, identified five sub-regions of contrasting precipitation climatology. The regions differed in the timing, magnitude, and relative importance of the winter and summer peaks comprising the bimodal precipitation regime of the area. Correlation examination of spatial and temporal trends of precipitation variability with three climate indices revealed strong winter precipitation relationships to the Pacific North American teleconnection pattern for all regions; summer precipitation teleconnections were weaker and more variable; however, modest correlations with Pacific Decadal Oscillation were observed. Climate field analysis indicates that cold-season precipitation is enhanced by intensification of the Aleutian Low with a storm trajectory into the southwest United States; warm season precipitation is enhanced by poleward shift of the North American monsoon ridge.

Keywords: *Four Corners region, southwestern U.S., climate, hydrometeorological network*

Future climate change is expected to exacerbate variability in precipitation and water resources in many parts of the world. These changes are likely to affect the amount, timing, and intensity of precipitation, possibly increasing the incidence of extreme flooding and drought events (CCSP 2008; Dominguez et al. 2010; Trenberth 2011; Nania et al. 2014). The particular region of our study lies within several recognized Native American reservations. Marginalized populations, including Indigenous peoples, are particularly vulnerable to climate change impacts due to the location of their homelands and ways of life (Redsteer et al. 2013; Wildcat 2013; Bennett et al. 2014; Nania et al. 2014).

The Navajo Nation is a federally recognized tribe whose political boundaries lie within Arizona, New Mexico, and Utah, and the characteristics of the lands they inhabit as well as their resource-based livelihoods cause them to be particularly vulnerable to climate change impacts (Cozzetto et al. 2013). The Navajo Nation has a land base of over 70,000 square kilometers (Navajo Nation Department of Water Resources 2003; Garfin et al. 2007). Nania et al. (2014) suggest the most important resource on the Navajo Nation is water. Navajo Nation residents, wildlife, livestock, and vegetation are highly dependent on water resources including precipitation, surface, ground, and spring waters for vitality (Navajo Nation Department of Water Resources 2003; Novak 2007; Redsteer et al. 2010; Navajo Nation Department of Water

Resources 2011). Navajo livelihoods dependent on water resources include irrigation farming, dry land farming, and ranching (Navajo Nation Department of Water Resources 2003; Navajo Nation Department of Water Resources 2011). Water dependent environmental components significant to Navajo culture are wildlife and plants used for traditional practices. Energy industries, including coal mining and thermoelectric power generation stations, remove water from surface and ground waters for their processes; these industries provide the Navajo Nation with economic revenue (Nania et al. 2014). Monthly, seasonal, and interannual changes in precipitation directly impact ecosystems of the Navajo Nation through a variety of interconnected effects such as groundwater recharge, frequency of dust migration, strength of winds, flow in ephemeral and perennial streams, plant and animal populations, wildfires, change in vegetative cover, and possible alterations in species composition (Hereford et al. 2002; Redsteer 2011).

The climate for the Four Corners region consists of a bimodal summer and winter precipitation distribution, separated by dry spring and fall seasons (Crimmins et al. 2013). Winter season precipitation is derived primarily from synoptic frontal systems originating from the Pacific Ocean, whereas summer moisture arises from localized convection associated with the southwestern summer monsoon. According to the Navajo Nation Water Management Branch's Water Monitoring and Inventory (WMBWMI) Section data, average annual precipitation in the region ranges from approximately 15 centimeters in lower elevation areas to over 40 centimeters in higher elevation areas. Major topographic features, including Navajo, Lukachukai, and Chuska Mountains, are responsible for orographic precipitation (Navajo Nation Department of Water Resources 2003), and combined with summer and winter circulation patterns across the area, are factors that contribute to the spatial and temporal distribution of rainfall throughout the Navajo Nation (Mathien 1985). The Navajo Nation's average annual temperatures vary between 4.4° Celsius in higher elevations to 10° Celsius in valleys and lowlands (Garfin et al. 2007). Given the large size and climatic diversity of the area, there is great potential for climate and environmental change to affect future sustainability for members of the largest land-based tribe, the Navajo.

Various groups have attempted to examine the Navajo Nation's precipitation patterns and changes; however, these studies (Navajo Nation Department of Water Resources 2003; Garfin et al. 2007; Crimmins et al. 2013) have not analyzed data with a level of spatial and temporal resolution necessary to assess variation in precipitation patterns across the area and potential climatic controls on this variation. The Technical Review of the Navajo Nation Drought Contingency Plan – Drought Monitoring, for example, estimated the Standard Precipitation Index for the Navajo Nation using monthly precipitation data from Parameter-Elevation Regressions on Independent Slopes Model (PRISM) gridded climate data to estimate wetness and dryness (Crimmins et al. 2013; PRISM Climate Group 2013). Crimmins et al. (2013) acknowledged that their study provided climate division values useful for drought monitoring at a large-scale spatial resolution but not at the Chapter and Agency levels (corresponding to rural communities and regional areas, respectively), where allocation of resources for water management and water-related environmental impacts occur. Characterization of precipitation at a finer spatial scale is important to Navajo water managers to make decisions in allocating funds to prepare for drought and flood events. Spatial and temporal examination of historical precipitation variability and trends across the Four Corners region is also crucial to characterizing patterns of potential recharge to groundwater, a source the Navajo Nation relies upon (over 90%) for its residents, businesses, and animals (Crimmins et al. 2013).

The Navajo Nation WMBWMI Section, acknowledging the continual need to examine its water resources, has monitored and recorded hydrological and meteorological data across the Navajo Nation for decades (Navajo Nation Department of Water Resources 2003; Aggett et al. 2011; Navajo Nation Department of Water Resources 2011). The first gauges in the hydrometeorological network were precipitation gauges at Marsh Pass, Klagetoh, and Little White Cone installed from 1952 to 1962 (Garfin et al. 2007). There was no installation of new

precipitation gauges from 1962 to 1983. From 1983 to 2000, the network expanded with new precipitation gauges installed each year (Figure 1). In total, the WMBWMI has managed over 190 precipitation gauges since 1952 (Garfin et al. 2007; Aggett et al. 2011). The WMBWMI has also conducted snow surveys and stream gauging since the 1980s (Tsinnajinnie 2011; Hart and Fisk 2014).

The WMBWMI monitoring network consists of 90 rain gauges, 12 tipping buckets, 8 snow courses, and 8 stream gauges (Figure 2; 2015 water year). Though the network is spatially and temporally extensive, no comprehensive scientific analyses and interpretation of the data has been conducted. Examination of water years 2002 to 2015 was chosen because it was a time period when a relatively extensive and stable network of sites was monitored. Here, we analyze these data to identify regional patterns of precipitation variability using quantitative cluster analysis of monthly, seasonal, and annual precipitation amounts. We then correlate patterns of seasonal precipitation variation for the cluster groups with climatic modes and variables to identify how precipitation in the Four Corners region of the southwestern United States is related to larger climatic patterns. The results of this work demonstrate potential patterns of future precipitation variability in this dynamic and water-scarce region and may serve as a resource for Navajo Nation managers to use for sustainable planning for their water future.

Methods

Precipitation Monitoring

Due to the large size, relatively low population density, and limited electrical and cellular infrastructure of the Four Corners region, the Navajo Nation precipitation network is not automated. Measurements of precipitation are made manually using a U.S. Weather Bureau Type Rain and Snow Gauge 60.96 cm measuring dipstick to determine the volume of water stored in a 20.32 cm diameter rain can; the precipitation amount is calculated using the month-to-month volume difference (Aggett et al. 2011). Mineral oil is used year round to prevent evaporation; during the winter months, a mix of mineral oil

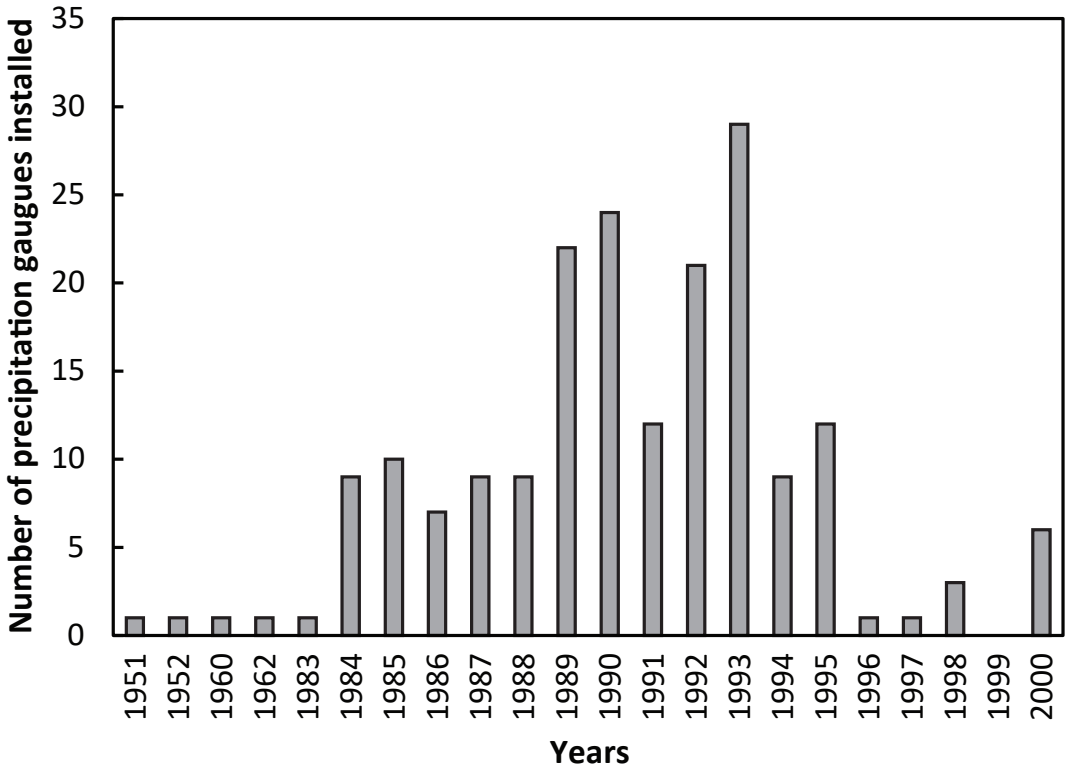

Figure 1. Number of precipitation gauges installed each year from 1951 to 2000.

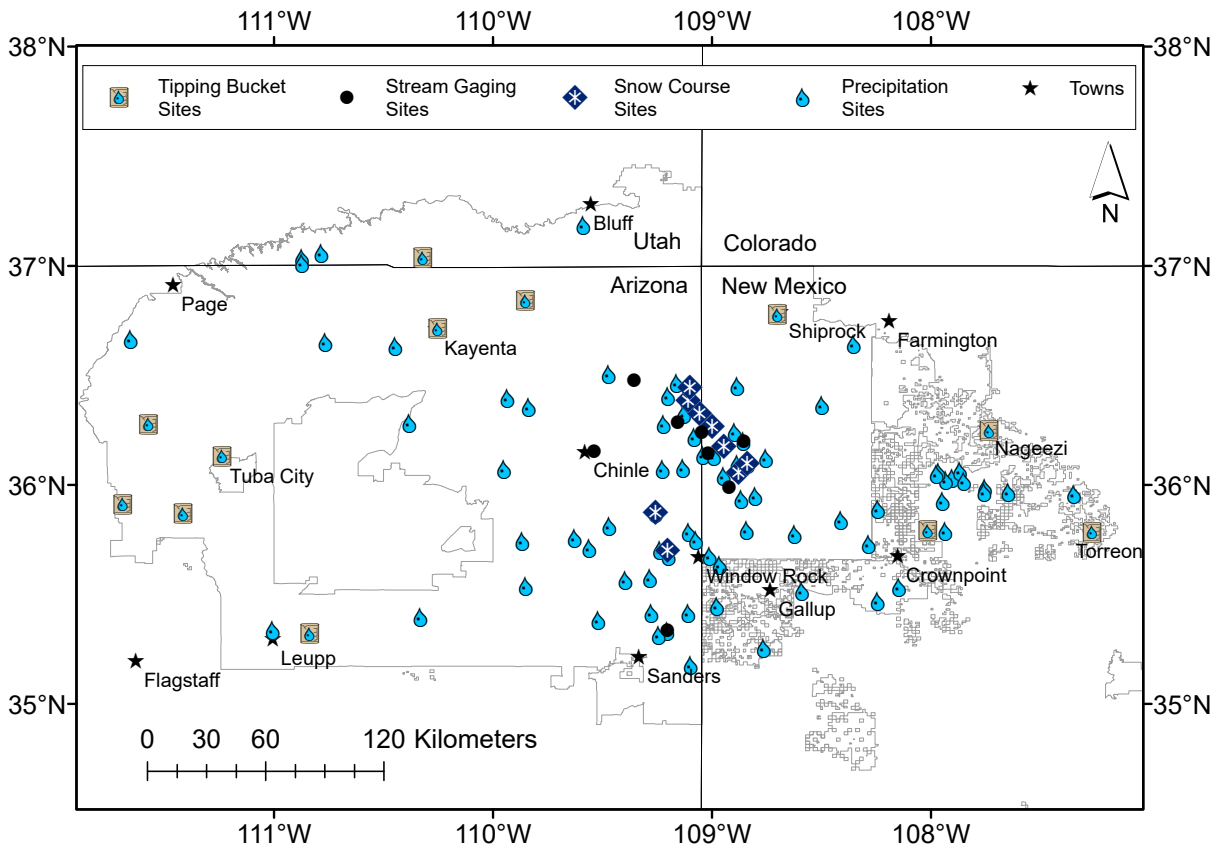

Figure 2. Navajo Nation Water Management Branch's Water Monitoring and Inventory Section hydrometeorological sites in Water Year 2015 included 90 rain gauges, 12 tipping buckets, 8 snow courses, and 8 stream gauges.

and biodegradable antifreeze is used to prevent freezing (Aggett et al. 2011). WMBWMI personnel record the date, time, air temperature, wind speed, and precipitation amount during each monthly site visit (Garfin et al. 2007; Aggett et al. 2011). Data are recorded into the Navajo Nation Precipitation Database managed by the WMBWMI.

Spatiotemporal Analysis

We used Hartigan-Wong's *k*-means clustering algorithm (Hartigan and Wong 1979; R Core Team 2013) to identify common patterns of variation in the multi-site precipitation dataset and group these sites into geographic clusters with common precipitation patterns. *K*-means clustering is a method of vector quantization that creates *k* clusters by maximizing between-group dissimilarity relative to within-group dissimilarity (Hartigan and Wong 1979). Clustering was conducted using both climatic (precipitation) and geographic (latitude, longitude, elevation) variables in order to identify spatially coherent clusters with common precipitation patterns. Data were standardized to dimensionless *z*-scores using

$$z = \frac{X - \bar{X}}{\sigma} \qquad \text{Equation 1}$$

where x is the station value and $\bar{x}$ and σ are the mean and standard deviation across the dataset, respectively.

We performed two versions of the clustering. The first used monthly averaged precipitation data across the study period (Figure 3B) to identify clusters that exhibited common patterns of intra-annual variation; the second used precipitation data summed to obtain an annual total for each year (Figure 3C) in order to identify groups with similar interannual variation. Both versions of the clustering produced similar results, and subsequent analyses used cluster groupings based on monthly

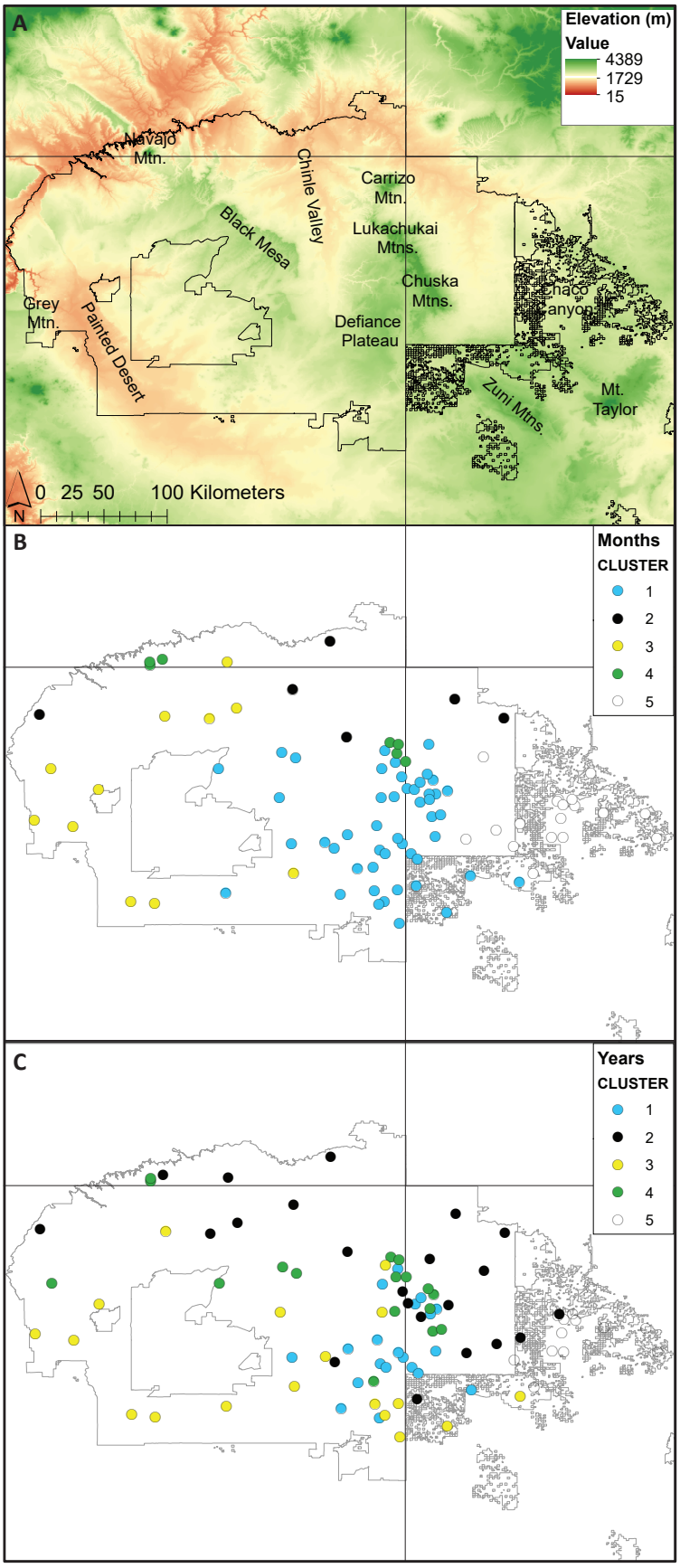

Figure 3. (A) Map of Navajo Nation geographical features; (B) cluster group assignments for precipitation sites based on latitude, longitude, elevation, and climatological average monthly precipitation amount; and (C) cluster group assignments for precipitation sites based on latitude, longitude, elevation, and total water year precipitation amount time series.

analysis grouping (Figure 3B). The number of sites in each cluster is not equally distributed, rather, they are grouped in a cluster where their individual characteristics are similar to other sites. The asymmetrical distribution of the number of sites in each group may show more precipitation variability in a smaller group than a group with more sites. We elected to use five clusters based on the sum of squares (SS) method (Hartigan and Wong 1979); the internal cohesion and external separation ratio (between SS/total SS) decreased rapidly below five clusters and slowly above five clusters. To validate the robustness of the *k*-means clustering, Principal Components Analysis (PCA) was also conducted; results from PCA exhibited similar grouping and boundaries.

Correlation Analyses

To further examine the climatology of the Navajo Nation and associations between cluster groups, we developed correlation matrices using group-average monthly precipitation values. Correlation matrices were produced for annual, winter, and summer seasons, where the seasonal analyses used the sum of precipitation amounts from November to May and June to October for each water year, respectively. The months for each season were chosen to include the beginning and end of each seasonal precipitation cycle for all the groups.

We evaluated extra-regional climate system controls on the patterns of interannual precipitation variability observed during the dominant summer and winter precipitation seasons and across the different cluster groups by creating correlation matrices. Correlation matrices were calculated between precipitation and the Pacific North American index (PNA; Leathers et al. 1991), Pacific Decadal Oscillation index (PDO; Mantua and Hare 2002), and East Central Tropical Pacific SST (Niño 3.4; Rayner et al. 2003). Correlation matrices were calculated for winter and summer separately. Climate indices data were retrieved from the National Oceanic Atmospheric and Administration Climate Prediction Center. We further investigated the dynamical associations of observed Navajo Nation precipitation patterns by mapping anomalies of 500-hPa geopotential height associated with especially wet or dry periods during the winter and summer. Geopotential height data were obtained at monthly resolution on 2.5º grids from the NCEP-DOE AMIP-II Reanalysis (R-2) (Kanamitsu et al. 2002), provided by NOAA/OAR/ESRL PSD at http://www.esrl.noaa.gov/psd. To illustrate winter patterns, the four driest and four wettest January-February periods were identified based on precipitation averaged across the five cluster groups; likewise, summer patterns were analyzed using July-August precipitation data.

Results

Navajo Nation Cluster Groups

K-means clustering using monthly precipitation data divided the dataset into five groups containing 48, 6, 11, 7, and 18 sites, respectively (Figure 3B). Group 1 included sites across the southern area of the Navajo Nation, going as far north as the Chuska Mountains and Defiance Plateau; Group 2 covered the northern part of the Navajo Nation and part of the Chinle Valley; Group 3 consisted of the Painted Desert and Grey Mountain areas in the western Navajo Nation; Group 4 primarily comprised sites in the high elevation areas of the Chuska and Lukachukai Mountains and Navajo Mountain; and Group 5 contained sites within the eastern portion of the Navajo Nation, east of the Chuska Mountains and including Chaco Canyon (Figure 3A). The areas covered by the regional groups vary in topography, land-surface characteristics, and vegetative cover, with noticeable variations in amounts for monthly, seasonal, and interannual precipitation. Clustering using annual precipitation time series yielded a similar overall pattern, with a slight expansion of the northern and western groups (2 and 3) at the expense of the southern and eastern groups (1 and 5) (Figure 3C).

Precipitation Climatology of the Four Corners Region

Precipitation totals varied substantially between years and among the cluster groups, with group-average individual month totals ranging from 0.56 cm to 6.15 cm ($\bar{x} = 2.31$ cm, $\sigma = 1.43$ cm) (Figure 4; Table 1). The highest water year total precipitation amounts were observed for the high-mountain cluster group (Group 4; $\bar{x} = 42.39$ cm), whereas the lowest totals occurred in the northern (Group 2)

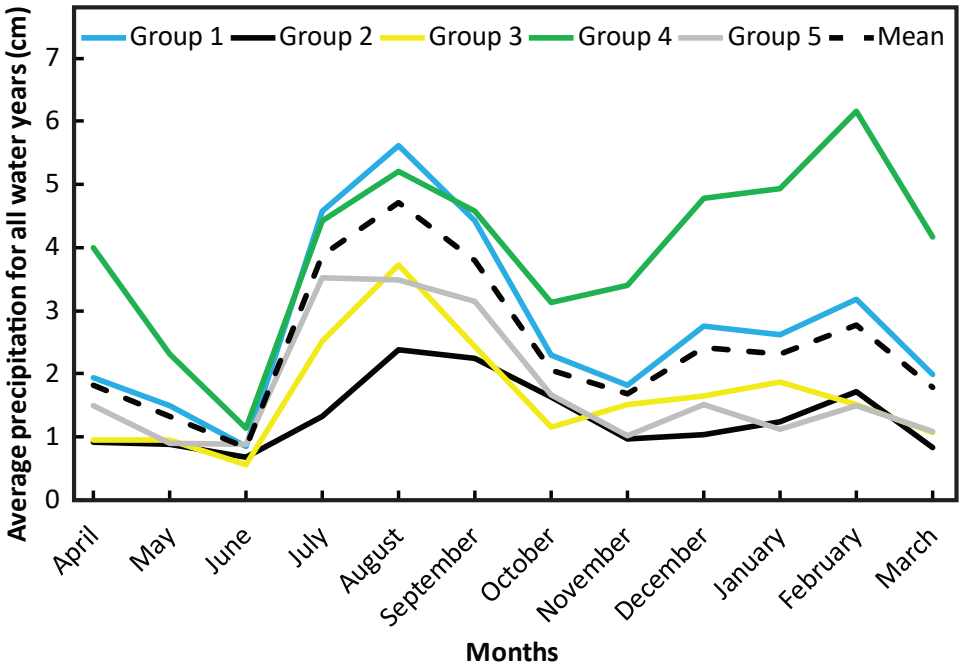

Figure 4. Annual cycle of Navajo Nation precipitation for objectively determined clusters.

Table 1. Mean and [standard deviation] of Navajo Nation precipitation for objectively determined clusters (Groups 1-5).

Months	Group 1 (south)	Group 2 (north)	Group 3 (west)	Group 4 (mountains)	Group 5 (east)
April	1.95 [0.25]	0.91 [0.11]	0.95 [0.18]	3.99 [0.49]	1.50 [0.17]
May	1.49 [0.18]	0.88 [0.09]	0.96 [0.16]	2.31 [0.26]	0.91 [0.07]
June	0.84 [0.10]	0.67 [0.05]	0.56 [0.07]	1.14 [0.13]	0.89 [0.11]
July	4.58 [0.41]	1.33 [0.09]	2.51 [0.32]	4.42 [0.55]	3.52 [0.32]
August	5.61 [0.50]	2.38 [0.07]	3.73 [0.47]	5.21 [0.71]	3.49 [0.37]
September	4.43 [0.31]	2.25 [0.10]	2.43 [0.24]	4.58 [0.54]	3.15 [0.21]
October	2.30 [0.23]	1.63 [0.10]	1.16 [0.11]	3.12 [0.32]	1.66 [0.14]
November	1.81 [0.19]	0.96 [0.08]	1.51 [0.19]	3.40 [0.32]	1.02 [0.07]
December	2.75 [0.31]	1.04 [0.05]	1.66 [0.23]	4.78 [0.52]	1.52 [0.09]
January	2.63 [0.28]	1.25 [0.05]	1.88 [0.23]	4.93 [0.40]	1.11 [0.10]
February	3.19 [0.44]	1.71 [0.09]	1.51 [0.23]	6.15 [0.53]	1.49 [0.12]
March	1.98 [0.29]	0.84 [0.05]	1.07 [0.20]	4.17 [0.53]	1.09 [0.10]

region ($\bar{x}$ = 16.87 cm). In the northern (Group 2), southern (Group 1), and western (Group 3) parts of the Navajo Nation, peak precipitation occurred in August, with amounts ranging from 2.38 cm to 5.61 cm ($\bar{x}$ = 3.91 cm, σ = 1.32 cm). For the eastern region (Group 5), summer precipitation was again dominant, but the summer peak (3.52 cm) occurred one month earlier, in July. Eastern, southern, and high-elevation groups showed a similar, abrupt onset of summer precipitation in July, with the northern and western areas showing a more gradual transition, and July precipitation totals similar to or less than 50% of the August summer maximum (Figure 4). In the western and high elevation areas the summer monsoon season ends abruptly, with a pronounced precipitation minimum in October. In contrast, the monsoon withdrawal is more gradual in the northern, southern, and eastern regions, where the fall precipitation minimum occurs in November. June is the driest month in the Navajo Nation, with rainfall ranging from 0.56 cm to 1.14 cm ($\bar{x}$ = 0.82 cm, σ = 0.20) across all groups. The high elevation mountain cluster group was the only group dominated by winter precipitation, with a peak value of 6.15 cm in February.

Temporal Precipitation Patterns

Although total annual precipitation amounts and seasonal patterns varied widely among regions, temporal trends across years were similar for all regions (Figure 5A). High annual precipitation totals were observed across most or all subregions in 2005, 2007, 2010, and 2015, with relatively low totals occurring during water years 2002, 2006, and 2008-2009. Group 2 showed the strongest interannual variability (relative σ = 0.28 cm). The least variable interannual water year precipitation totals in the Navajo Nation were found in the eastern region (relative σ = 0.20 cm).

Summer (June - October) precipitation across the Navajo Nation ranged from 3.12 cm to 26.59 cm ($\bar{x}$ = 13.53 cm, σ = 5.19 cm) (Figure 5C), and showed lower interannual variation, with relative values between 0.19 and 0.32, than winter (November - May; relative σ = 0.29 to 0.40 cm; Figure 5B). Year to year patterns of variation in summer and winter season precipitation were weakly correlated (Figures 5B and C). Both seasons contribute to the variability in annual totals (Figure 5D), with some anomalously wet years reflecting higher-than average winter precipitation (e.g., 2005) and some high summer precipitation (e.g., 2007). Similarly, dry years could be attributed to both low winter (e.g., 2006) and summer (e.g., 2008-2009) totals.

Correlation analysis reinforced the observed similarity of interannual variation among cluster groups (Figure 6). Correlations for winter season precipitation were highest, with correlation coefficients exceeding 0.9 for all comparisons except those involving group 5 (eastern region). Summer season correlations among groups were somewhat weaker, with the eastern region again exhibiting the lowest coefficients. Analysis of annual data showed strong correlations between the three groups covering the southern part of the Navajo Nation, but relatively weak correlation between the high elevation group and other regions; the high elevation group correlations were weaker for the annual average comparisons than for either of the individual seasons.

Teleconnections

Correlation results suggested much stronger teleconnections for Navajo Nation winter precipitation than for summer; teleconnections describe the persistent and recurring large-scale patterns of climate anomalies (Figure 7). Winter precipitation totals were moderately well correlated with all climate indices, but the strongest correlations (0.46 to 0.63) were observed relative to the PNA index (Figure 7A). Among the cluster groups, the PNA was most strongly correlated with winter precipitation totals for the northern and western regions (Groups 2 and 3; r = 0.63 and 0.59, respectively). Moderately strong correlations were observed between summer precipitation and PDO (positive correlation) for the northern and PNA for the western (negative correlation) regions (Figure 7B).

Analysis of geopotential heights showed that high-precipitation winters are associated with enhanced troughing over the North Pacific (Figure 8A), indicating a deepened Aleutian Low with negative Z_{500} anomalies extending into the southwestern United States (Figure 8B). Low-precipitation winters are, by contrast, associated with weakening of the trough over the North

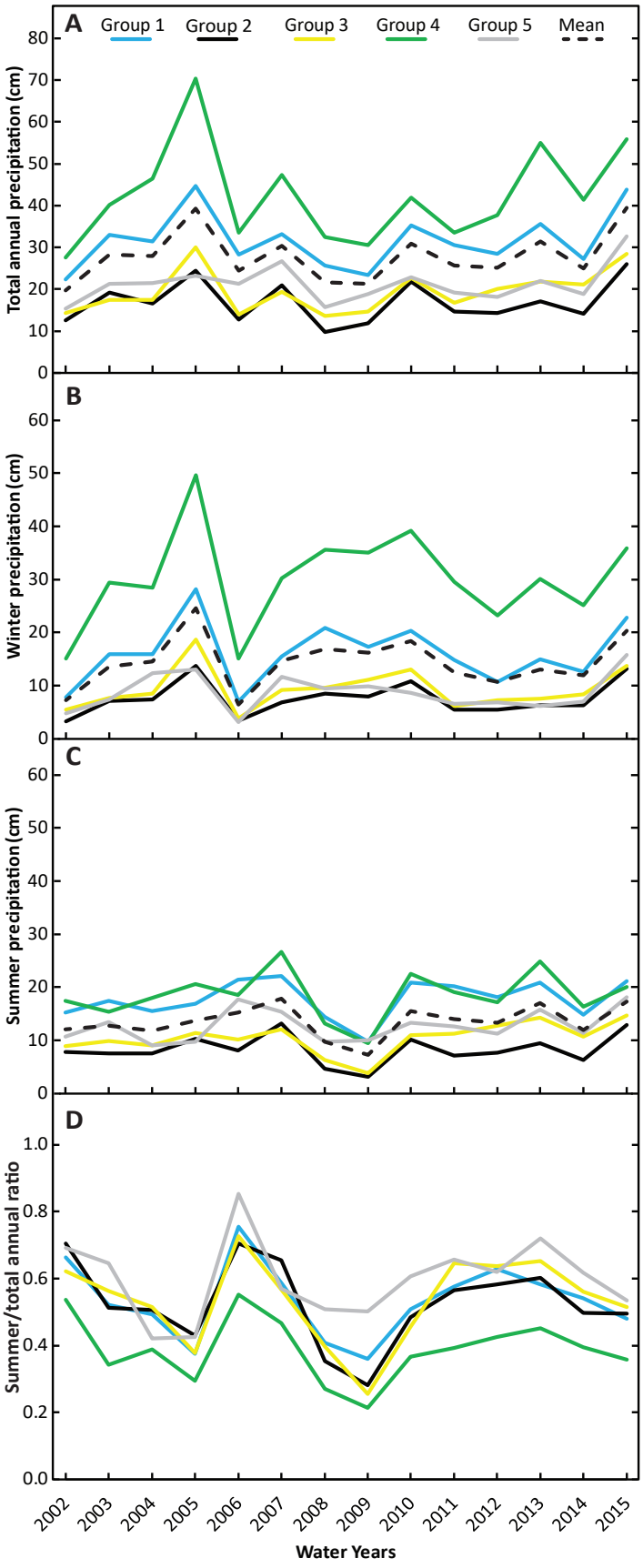

Figure 5. Precipitation time series showing cluster group averages for (A) water year, (B) winter, (C) summer, and (D) precipitation totals and the summer contribution to total water year precipitation.

Pacific (Figure 8A) and positive Z_{500} anomalies extending into the study region (Figure 8C). The finding that Four Corners winter precipitation is positively correlated with the strength of the Aleutian Low is consistent with the positive climate index correlations in Figure 7A because these indices, in their positive polarity, feature a strengthened Aleutian Low, meaning negative Z_{500} anomalies (e.g., Nigam 2003).

High-precipitation summer months are associated with poleward displacement of the mid-tropospheric subtropical ridge (STR; e.g., Carleton et al. 1990) over the southwestern United States, as illustrated by the 5900 isopleth of Z_{500} in Figure 8D. With corresponding Z_{500} anomalies being positive to the east and negative to the west (Figure 8E), poleward displacement of the STR exposes the study region to southerly geostrophic wind anomalies conducive to delivery of warm, moist air and hence convective storminess. Low-precipitation summer months are, by contrast, associated with equatorward displacement of the

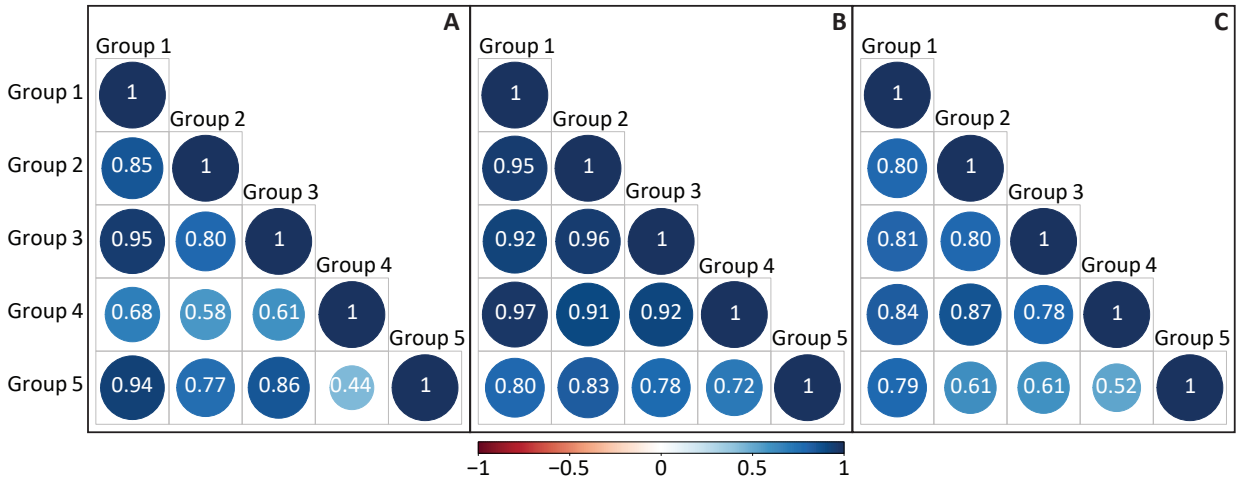

Figure 6. Correlation matrix for interannual timeseries using (A) annual; (B) winter; and (C) summer cluster group average values.

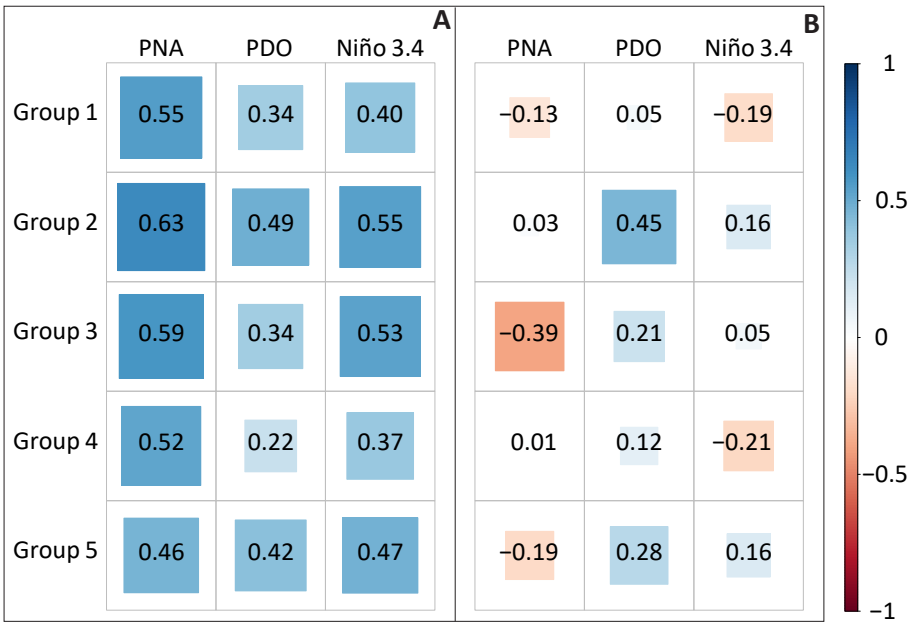

Figure 7. Interannual correlation of precipitation with climate indices for (A) winter months and (B) summer months.

STR (Figure 8E) and westerly geostrophic wind anomalies conducive to delivery of drier air. The STR is sometimes referred to as the monsoon ridge (e.g., Lahmers et al. 2016), and the anomaly patterns in Figure 8 are noted to closely resemble corresponding analysis in the review by Adams and Comrie (1997; Figure 8).

Discussion

Our cluster analysis shows several distinct and spatially-clustered modes of precipitation amount variability across the Navajo Nation, and suggests that the spatial distribution of these modes is similar for intra- and interannual precipitation variability. Differences in the seasonal precipitation cycle relate to comparing the importance of winter vs. summer precipitation in different parts of the study area, and show that although both wet seasons contribute significantly to the total precipitation received, the importance of each season varies substantially between high- and low-elevation and northern and southern sites (Figures 3 and 4). For example, high-elevation mountain areas receive peak precipitation from the winter season and low-elevation areas are dependent on summer precipitation contributions. The similarity in group membership for the cluster analyses using climatological monthly and annual average time series data (Figure 3B and C and Figure 6) suggests that the same climate system factors that control seasonal patterns of precipitation also structure variation in interannual precipitation amounts across the region.

Despite precipitation variability across the region, correlation analysis suggests that coherent patterns of interannual precipitation variability are expressed across the entire study area, particularly in the winter season. Winter precipitation is derived dominantly from cold-season synoptic-scale frontal systems arriving from the North Pacific (Cayan et al. 1998; Schwinning et al. 2008). The observed similarity in interannual variation of winter precipitation across the region, together with the strong correlations with the PNA index and PNA-like pressure patterns, is consistent in

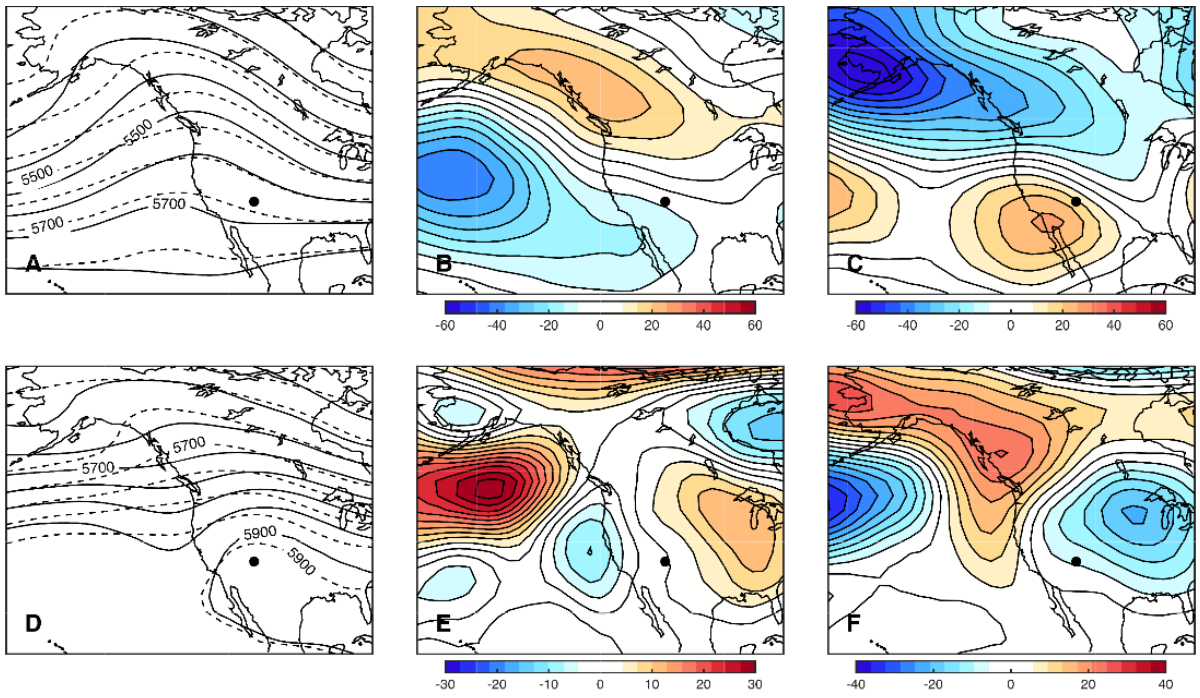

Figure 8. (A) Geopotential height of the 500-hPa isobaric surface (Z_{500}) for the wettest four (solid contours) and driest four (dashed contours January - February periods, contoured every 100 geopotential meters. Z_{500} anomalies associated with the (B) wettest and (C) driest four January - February periods. (D-F) Same as A-C but for July - August. In each panel, the filled circle is centered on the study region.

suggesting that large-scale circulation controls strongly influence winter moisture delivery to the Navajo Nation and dominate winter-season precipitation anomalies. The weakest response to these factors was observed in the eastern part of the region, which is sheltered from westerly winter systems by high topography.

Water year precipitation totals across the Navajo Nation are also strongly influenced by summer season rainfall, however, summer storms are the dominant source of precipitation in four of the five cluster group regions. Variation in warm-season precipitation totals is much less coherent across the region, consistent with the more localized, convective nature of the monsoonal precipitation arriving during the summer season (Favors and Abatzoglou 2013; Carillo et al. 2016). Although no strong teleconnections were observed for summer precipitation variability, our analysis showed that pressure patterns over the western interior correlate with summer precipitation amounts. Different subregions of the Navajo Nation also exhibited different influence of early vs. late-season summer precipitation, suggesting that the mechanisms driving summer rainfall deficit or surplus may be heterogeneous across the study area. Western and northern parts of the Navajo Nation, for example, appear likely to be less sensitive to failure of the early monsoon as they receive the majority of their summer precipitation later in the monsoon season (Figure 4).

Correlations to non-local climate indicators help identify climate drivers responsible for precipitation in the Navajo Nation, and may be useful for forecasting precipitation anomalies in support of regional water management. The PNA index is the strongest overall indicator of winter precipitation in the Four Corners region (Figure 7). PNA is known to exert strong control over winter storm tracks across North America (Wallace and Gutzler 1981). Previous work has suggested a weak association between PNA and 20th-century winter precipitation anomalies (Leathers et al. 1991) in the southwestern USA, although long-term paleoclimate data have suggested that variation in PNA is correlated with drought in the region over the past millennium (Liu et al. 2017). This correlation suggests that long-term trends in the PNA pattern, such as those suggested by paleoclimate records (Liu et al. 2014), could impact future winter precipitation and water resources in the Navajo Nation.

Connections between precipitation and dominant climate modes were weaker for summer than winter. Although summer monsoonal variations have been linked to sea surface temperatures, El Niño-Southern Oscillation (ENSO)-like variations, and possibly also different phases of the PNA pattern (e.g., Adams and Comrie 1997), the overall effect of these large-scale modes on summer circulation variability is less prominent than in winter. We did find, however, that summer precipitation was strongly correlated with a coherent pattern of large-scale pressure anomalies over the North American continent, consistent with previously observed effects of the "monsoon ridge" on summer moisture delivery to the southwestern USA (Lahmers et al. 2016).

Conclusions

We have described and examined precipitation amount variability across the Navajo Nation based on data from a spatially extensive network of monitoring stations. We identify regionalization of seasonal precipitation patterns across the area, with regions differing in terms of absolute precipitation amounts, the relative importance of summer and winter precipitation, and the timing and abruptness of summer monsoon onset and termination. Although year-to-year variations in precipitation amount are highly correlated across the study area, we also find regional structure in the interannual precipitation time series which matches that observed for the seasonal pattern. This, together with our observation that extremes in summer and winter precipitation are independent of each other, implies that future changes in water availability may be different in various parts of the Navajo Nation. Therefore, livelihoods in each region of the Navajo Nation may be differently impacted. Understanding the climate system influences driving summer and winter precipitation variability will thus be critical for accurate regional prediction of precipitation patterns. To this end, we have demonstrated that winter precipitation across the region is most sensitive to variation in the PNA pattern and winter storm-

tracks, whereas summer monsoon precipitation appears to respond only weakly to major climate modes and is sensitive to summer pressure patterns steering monsoonal flow over the western USA. This analysis has improved current knowledge by defining improved regional precipitation patterns and changes at monthly, seasonal, and annual timescales within the boundaries of the Navajo Nation. Past and future variability in these climate patterns is a likely driver of water resource variations across the Navajo Nation, and could be a target for improved understanding of water availability in this arid region.

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Navajo Nation Snowpack Variability from 1985-2014 and Implications for Water Resources Management

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Abstract: In the arid Southwest, snowpack in mountains plays an essential role in supplying surface water resources. Water managers from the Navajo Nation monitor snowpack at nine snow survey stations located in the Chuska Mountains and Defiance Plateau in northern Arizona and New Mexico. We characterize these snowpack data for the period 1985-2014 and evaluate the efficacy of snowpack data collection efforts. Peak snow water equivalent occurs in early to mid-March depending on elevation. Variability in snowpack levels correlates highly among all sites ($r > 0.64$), but higher elevation sites in the Chuska Mountains correlate more strongly with one another compared to lower elevation sites and vice versa. Northern sites also correlate well with each other. A principal component analysis is used to create a weighted average time series of year-to-year peak snowpack variability. The first principal component showed no trend in increasing or decreasing Navajo Nation snowpack. Results from this research will provide the Navajo Nation Department of Water Resources information to help determine if any snow survey sites in the Chuska Mountains are redundant and can be discontinued to save time and money, while still providing snowpack information needed by the Navajo Nation. This summary of snowpack patterns, variability, and trends in the Chuska Mountains and Defiance Plateau will help the Navajo Nation to understand how snowpack and water resources respond to climate change and climate variability.

Keywords: *mountain hydrology, climate, Southwest*

In the Southwest region of the United States, snowpack is an important indicator of water resource availability. Snowpack annually stores large amounts of water in mountainous regions in the Southwest. Snowpack feeds perennial and ephemeral streams in mountainous watersheds. Snowmelt runoff in headwaters contributes to streamflow in large river basins, such as the San Juan River, Colorado River, and Rio Grande. Thus, monitoring snowpack can be used for the interpretation and prediction of climate and hydrologic conditions in the region. Snow water equivalent (SWE) data manually collected from snow courses and/or automated data from SNOTEL (SNOpack TELemetry) stations are commonly used to study the relationships between snowpack variability and climate. Previous research shows the importance of snowpack data in helping to characterize and further understand regional climate and sensitivity to climate variability. Gutzler (2000) found an inverse relationship between spring snowpack and summer rainfall in the Southwest. Other studies show that snowpack is sensitive to temperature and precipitation variability (Cayan 1996; Scalzitti et al. 2016) and to warming trends (Mote 2006). Observed decreasing trends of snowpack (Kalra et al. 2008) and projections of large snowpack losses (Fyfe et al. 2017) have created a sense of urgency for additional studies and understanding of relationships between climate, snowpack, and streamflow.

Recent studies have focused on the influence of warming and climate variability on streamflow generated from snowmelt runoff. Several tools and methods have been developed to assess impacts of

warming climate on streamflow driven by snowmelt (Day 2009). Declines in peak snowpack and sensitivity of snowpack to temperature variability have led to shifts towards earlier snowmelt and snowmelt timing (Clow 2010) for much of the western U.S. With increasing discussion and evidence of climate change, more climate and water resources researchers and professionals are looking for improvements of snowpack data collection and analysis to make these forecasts.

Collecting and storing snowpack data are very crucial for water resources agencies and departments to characterize water resources for the year. The Navajo Nation Department of Water Resources (NNDWR) is responsible for monitoring snowpack and streamflow within the boundaries of the Navajo Nation. The NNDWR collects snowpack data from the Chuska Mountains and Defiance Plateau, which are located primarily in northeastern Arizona and partially in northwestern New Mexico on the Colorado Plateau (Figure 1). The Chuska Mountains are the major mountain range within the boundaries of the Navajo Nation and are the only location of perennial snowfed

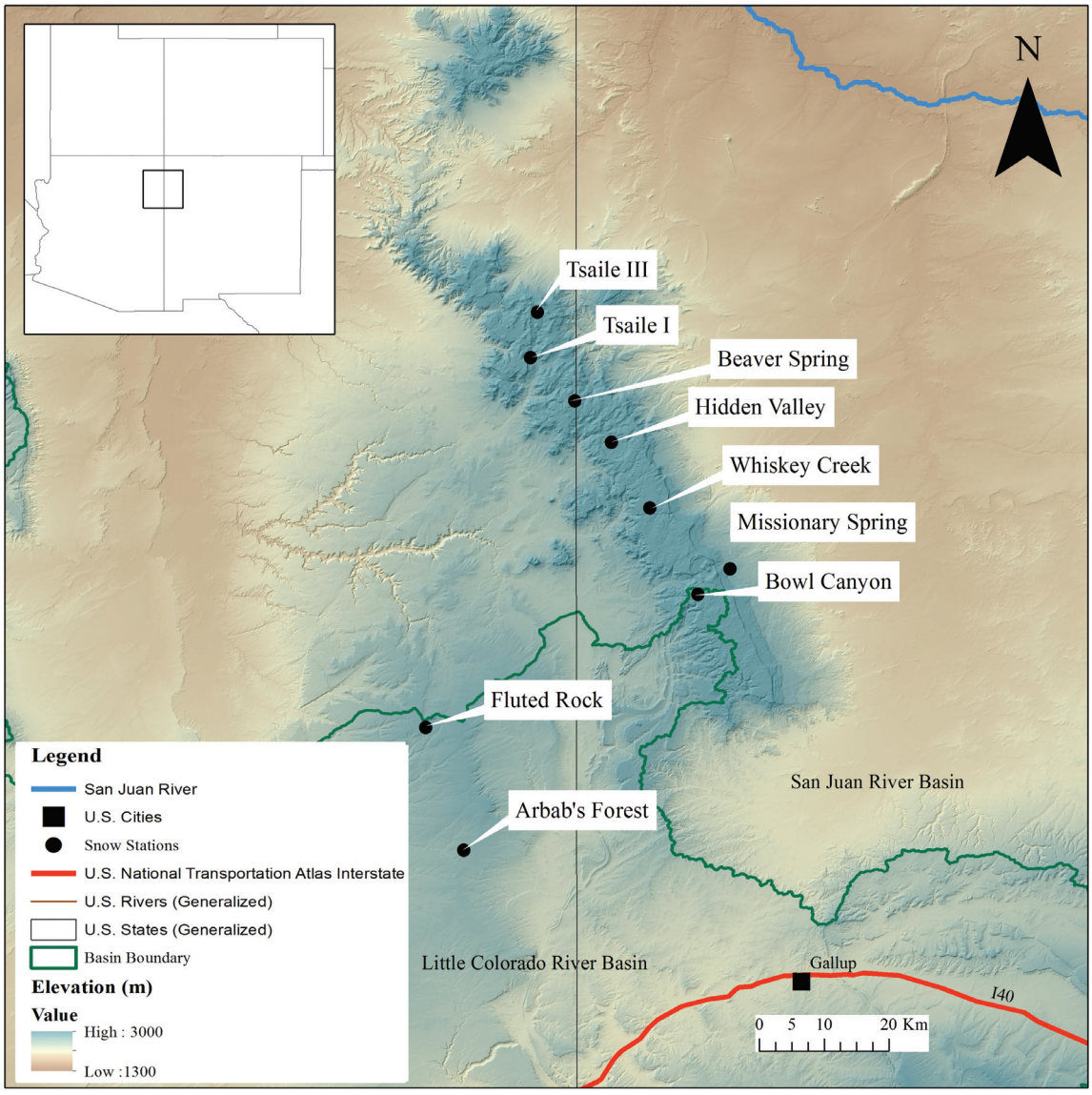

Figure 1. Location map of Navajo Nation snow survey sites. Map colors denote elevation. Black line represents the drainage divide between San Juan and Little Colorado Rivers.

streams completely sourced within Navajo Nation boundaries. Six of the nine stream gages monitored by the NNDWR are in the Chuska Mountains-Defiance Plateau landscape.

Every winter, between December and April, the NNDWR conducts manual snow surveys twice monthly. Collection of snowpack data is an important component of monitoring and managing water resources for the Navajo Nation, but snow surveys are time-consuming and costly. In a time of changing climate and uncertainties about water supply in the arid Southwest, more ways of efficiently collecting and interpreting snowpack data that would help in the forecast of water supplies are needed. A better understanding of data captured by snow survey sites on the Navajo Nation will help the NNDWR make management decisions about snow survey sites that may save time and money for future collection of snowpack data.

We intend to address the need for additional analysis and characterization of snowpack on the Navajo Nation. The overall research question addressed in this paper is "How well is snowpack in the Navajo Nation represented, based on data from individual snow survey sites in the Chuska Mountains and Defiance Plateau?" This question is determined through three sub-questions:

- What is the climatology of snowpack on the Navajo Nation?
- How do snowpack data from the nine survey sites in the Navajo Nation compare with one another?
- Could snowpack data collection efforts be refined with fewer sites and still maintain a quality data standard?

This research may help the Navajo Nation make better predictions of its water supply, as well as provide additional information about the local and regional climate and hydrology.

Background

The Navajo Nation is one of the largest recognized tribes in the United States and has the largest Indian reservation in the country. The Navajo reservation is located in the Four Corners area of the southwestern U.S. and spans parts of Utah, Arizona, and New Mexico with an area of approximately 71,000 km^2. The Navajo Nation has a population of approximately 330,000, over 150,000 of whom live on the reservation (Navajo Epidemiology Center 2013). The primary source of municipal water on the reservation is groundwater (NNDWR 2000). The Coconino, Navajo, Dakota, and San Juan Unit aquifers are the four major aquifers of the Navajo Nation and total about 700 million acre-feet of storage (NNDWR 2000). Surface water sources on the reservation include the Colorado River, Little Colorado River, San Juan River, tributary washes, and other river systems (NNDWR 2000). However, many residents do not have access to a safe source of potable drinking water. In 2009, U.S. legislation was signed to settle Navajo Nation water rights claims to the San Juan River, including authorization for the Navajo-Gallup Water Supply Project that will pump water from the San Juan River to communities on the reservation.

As a sovereign entity, the Navajo Nation manages its own natural resources through the Navajo Nation Division of Natural Resources and the Navajo Nation Environmental Protection Agency (NNDWR 2000). The NNDWR is institutionally within the Navajo Nation Division of Natural Resources. Its Water Management Branch monitors Navajo Nation water resources with networks of monitoring wells, stream gages, weather stations, and snow courses (NNDWR 2000). Data collected by the Water Management Branch play a crucial role in assessing and forecasting water resources for the Navajo Nation. In 2007, a study was conducted to assess the Navajo Nation hydroclimate network, analyzing the accuracy and efficiency of data collected at NNDWR stream gage and weather stations (Garfin et al. 2007). Some of the weather and streamflow data were inconsistent, irregular, or compromised by site conditions because of a shortage of resources to efficiently manage all the data collection stations in the hydroclimate network.

Snowpack data collected by the Navajo Nation are not fully integrated with U.S. national snowpack data collection. The U.S. Natural Resource Conservation Service (NRCS) manages a national network of SNOTEL sites throughout the United States. Two of the NNDWR snow survey sites in the Chuska Mountains are also SNOTEL sites. Besides climate monitoring, the NRCS also

uses data collected in the SNOTEL system for water supply forecasting. Simulation models have been developed, or are in the process of being developed, using SNOTEL data to predict water supplies. However, statistical-regression relations based on historical snowpack data have been the more common method of discerning climate trends and forecasting water supplies.

Recent studies have focused on snowpack variability in the Chuska Mountains and nearby regional mountains. Novak (2007) analyzed snowfall in the Chuska Mountains using unpublished NNDWR data for the period 1985-2006 for seven of the nine snow survey sites analyzed here. Novak (2007) created aggregated time series of SWE in the Chuska Mountains for high elevation sites and for low elevation sites. Correlations of SWE with temperature and precipitation were also computed as part of the snowfall analysis of Novak (2007). Comparisons of year-to-year SWE results from the present study with results from Novak (2007) are presented in the Summary and Discussion section below. Jones (2007) analyzed snowpack in the San Juan Mountains and its relationship with streamflow, finding that snowpack in southern, lower elevation basins had earlier snow melt and March 1 SWE values are better to use when correlating snowpack with streamflow for the northwest New Mexico area.

Although land in the Chuska Mountains is managed by the Navajo Forestry Department, many families have homesteads in the Chuska Mountains and Defiance Plateau and rely on land and water resources for ranching and agriculture. If not connected to utility water supply, residents in these local communities rely on water from domestic wells, developed springs, or hauled water from other sources. Navajo Nation chapters (local government subdivisions) that lie within the Chuska Mountains and Defiance Plateau include Crystal, Red Lake, Mexican Springs, Tohatchi, Tsaile/Wheatfields, and Lukachukai. Communities with relatively high populations within these chapters include Tsaile, AZ, Lukachukai, AZ, and Crystal, NM. Window Rock, AZ, the Navajo Nation capital, is approximately 20 miles south of the Chuska Mountains and is within 10 miles east of the Defiance Plateau.

Data and Methods

The NNDWR has nine active snow survey sites in the Chuska Mountains and Defiance Plateau (Figure 1) that range in elevation between 2338-2813 m (Table 1). Six sites (Tsaile III, Tsaile I

Table 1. Navajo Nation snow survey site information.

Site Name	Established	Elevation (m)	Basin	# Years Missing	Station Type/s
Arbab's Forest	1/31/00	2338	Little Colorado	0	snow course
Beaver Spring	9/1/85	2813	San Juan River	8	snow course, SNOTEL
Bowl Canyon	10/3/85	2731	Little Colorado	1	snow course
Fluted Rock	10/20/84	2429	Little Colorado	0	snow course
Hidden Valley	9/11/85	2473	San Juan River	2	snow course
Missionary Spring	10/17/90	2393	San Juan River	6	snow course
Tsaile I	11/29/84	2496	San Juan River	2	snow course
Tsaile III	10/17/90	2758	San Juan River	3	snow course
Whiskey Creek	10/31/84	2761	San Juan River	0	snow course, SNOTEL

Beaver Springs, Hidden Valley, Whiskey Creek, and Missionary Springs) are located within the San Juan River Basin. Three sites (Bowl Canyon, Fluted Rock, and Arbab's Forest) are in the Little Colorado River drainage. Fluted Rock and Arbab's Forest are on the Defiance Plateau and the rest of the sites are in the Chuska Mountains. The Whiskey Creek and Beaver Springs snow survey sites include snow courses and active SNOTEL sites. Snow survey samples are collected by NNDWR hydrologic technicians according to NRCS sampling techniques. Snow survey sampling is typically conducted twice per month between late December and early April. Data provided by the NNDWR for this research include snow depth, SWE, and snow density from the nine sites over the 30-year period 1985-2014, as well as basic snow course information.

SWE, the amount of water contained in the snowpack, is the parameter used to characterize for snowpack in this study. It is listed as "water content" in NNDWR snow survey sampling field notes. SWE used for this analysis is measured from snow courses at the snow survey sites established by the NNDWR because these have a longer history than the two active SNOTEL sites. Snow depth and snow density are measured at aerial markers that form an established transect for each snow course. SWE is calculated from the snow depth and snow density at each marker and an average SWE from each marker is used as the representative SWE for the snow course.

Climatology of snowpack on the Navajo Nation is characterized by seasonal cycle, time of maximum SWE, and year-to-year variability. Comparison of snowpack data from Navajo Nation snow survey sites is made using principal component analysis. The minimums, maximums, quartiles, medians, and means of each sample date (January 1, January 15, February 1, February 15, March 1, March 15, and April 1) for the 1985-2014 period of record were calculated for each snow survey site to characterize the climatological seasonal cycle of snowpack in the Chuska Mountains. Two March SWE measurements (March 1 and March 15) for every year were averaged for each site, and are used to represent maximum seasonal snowpack accumulation at the sites. If one of the March sample date measurements was missing, an average for that year was not calculated and was left blank. A year-to-year correlation table (Table 2) for March SWE was created using the correlation function in Microsoft Excel. Missing data were filled from average normalized anomalies. Normalized anomalies of real data were calculated by:

$$anomaly_{x,t} = \frac{y_{x,t} - \mu_x}{\sigma_x} \qquad \text{(Equation 1)}$$

where $anomaly_{x,t}$ is the normalized anomaly for a snow survey site x, at year t; $y_{x,t}$ is the March SWE from x at year t; μ_x is the mean March SWE for all years at x; and σ_x is the standard deviation of March SWE for all years at x. The normalized anomalies for missing data were calculated by taking the average normalized anomalies of all sites with non-missing data for the year with missing data. Missing SWE values were then estimated and filled by:

$$y^*_{x,t} = anomaly_{x,t} * \sigma_x + \mu_x \qquad \text{(Equation 2)}$$

where $y^*_{x,t}$ is the estimated SWE for year t with a missing sample at site x (Table 2).

A year-to-year correlation table (Table 3) for a complete time series of March average SWE (1985-2014) measurements between snow survey sites in the Chuska Mountains and Defiance Plateau was created using the estimated March SWE data in Table 2. The correlation coefficients generated in the year-to-year correlation table were used to assess the relationships between each of the snow survey sites.

A two-tailed t-test was used to determine whether the year-to-year correlation coefficients are large enough to be statistically different from zero at 1% and 5% levels based on 30 years of snowpack data, assuming 1 degree of freedom per year. For alpha = 5%, correlation coefficients of 0.36 or above are needed for the relationship of the snow survey sites to be statistically significant relative to a null hypothesis of zero correlation. For alpha = 1%, correlation coefficients of 0.46 or above are needed for statistical significance.

The correlation matrix of March SWE for the nine NNDWR sites (Table 3) was passed as input into MATLAB to perform an eigenanalysis (Von Storch and Zwiers 2002). Eigenanalysis is used to analyze the similarities and differences between snowpack variations at the Chuska Mountain sites.

Table 2. March snow water equivalent (SWE) and principal component time series for snow survey sites (filled data in bold).

AF	BS	BC	FR	HV	MS	T I	T III	WC	PC1	PC2
0.066	**0.296**	0.258	0.095	**0.228**	**0.121**	0.197	**0.266**	0.279	0.119	0.017
0.005	**0.168**	0.131	0.010	**0.107**	**0.027**	0.117	0.203	0.157	-0.176	-0.010
0.020	**0.212**	0.213	0.027	0.133	**0.053**	0.131	0.174	0.218	-0.090	0.008
0.061	0.291	0.269	0.121	0.204	**0.129**	0.225	0.296	0.271	0.139	0.013
0.013	0.258	0.169	0.046	0.175	**0.068**	0.141	0.208	0.265	-0.035	0.027
0.048	0.116	0.161	0.081	0.113	**0.034**	0.065	0.149	0.133	-0.189	-0.101
0.036	0.281	0.260	0.122	0.239	0.076	0.204	0.246	0.304	0.108	0.043
0.058	0.255	0.217	0.119	0.230	0.114	0.201	0.262	0.226	0.077	-0.020
0.069	0.420	0.377	0.150	0.342	0.193	0.269	0.386	0.396	0.390	0.109
0.019	0.215	0.236	0.038	0.151	0.061	0.157	0.225	0.222	-0.042	0.027
0	0.339	0.304	0.043	0.292	0.043	0.260	0.325	0.314	0.165	0.175
0.005	0.132	0.099	0.010	0.023	0.010	0.022	0.154	0.136	-0.292	-0.063
0.079	0.340	0.326	0.135	0.271	0.268	0.239	0.290	0.358	0.285	-0.002
0.130	0.320	0.293	0.196	0.310	0.171	**0.263**	**0.336**	0.307	0.292	-0.023
0	**0.088**	**0.095**	0.000	0.013	0.000	0.022	0.062	0.027	-0.388	-0.118
0	0.146	0.157	0.000	0.090	0.003	0.067	0.182	0.164	-0.216	-0.004
0.086	**0.302**	0.246	0.132	0.197	0.152	0.193	0.246	0.245	0.114	-0.045
0.010	**0.119**	0.103	0.015	0.066	0.014	0.047	0.086	0.072	-0.311	-0.097
0.013	0.182	0.189	0.055	0.171	0.083	0.137	0.240	0.224	-0.053	0.001
0.036	0.197	0.171	0.089	0.145	0.104	0.154	0.220	0.216	-0.042	-0.047
0.015	0.331	0.329	0.050	0.253	0.047	0.192	0.300	0.340	0.142	0.151
0.023	0.057	0.046	0.020	0.032	0.028	0.032	0.047	0.053	-0.380	-0.163
0.037	0.169	0.165	0.071	0.130	0.047	0.123	0.180	0.216	-0.107	-0.041
0.097	0.372	0.338	0.178	0.321	0.194	0.206	0.295	0.370	0.308	0.016
0.018	**0.250**	0.251	0.056	0.220	0.052	**0.159**	**0.228**	0.310	0.034	0.071
0.187	0.470	0.405	0.211	0.403	0.253	0.387	0.434	0.443	0.584	0.057
0.014	**0.210**	0.199	0.027	0.157	0.023	0.165	0.231	0.212	-0.069	0.042
0.008	0.170	0.175	0.005	0.131	0.010	0.099	0.183	0.194	-0.159	0.015
0.043	0.239	0.211	0.077	0.206	0.064	0.234	0.295	0.240	0.054	0.036
0	0.084	0.076	0.003	0.011	0	0.028	0.119	0.094	-0.351	-0.090

Table 3. Year-to-year March snow water equivalent (SWE) correlation matrix with filled data. Rows and columns labeled as principal components or PCs are derived from eigenvector analysis of the site time series (see text and Table 4).

	AF	BS	BC	FR	HV	MS	T I	T III	WC	PC1	PC2
Arbab's Forest	1.00	0.71	0.67	0.93	0.73	0.87	0.74	0.67	0.64	0.78	0.16
Beaver Spring	0.71	1.00	0.97	0.80	0.97	0.82	0.94	0.94	0.96	0.98	0.70
Bowl Canyon	0.67	0.97	1.00	0.77	0.96	0.78	0.91	0.93	0.96	0.96	0.72
Fluted Rock	0.93	0.80	0.77	1.00	0.83	0.91	0.81	0.76	0.75	0.87	0.29
Hidden Valley	0.73	0.97	0.96	0.83	1.00	0.80	0.95	0.94	0.95	0.98	0.70
Missionary Spring	0.87	0.82	0.78	0.91	0.80	1.00	0.79	0.75	0.77	0.86	0.30
Tsaile I	0.74	0.94	0.91	0.81	0.95	0.79	1.00	0.96	0.91	0.96	0.66
Tsaile III	0.67	0.94	0.93	0.76	0.94	0.75	0.96	1.00	0.93	0.95	0.69
Whiskey Creek	0.64	0.96	0.96	0.75	0.95	0.77	0.91	0.93	1.00	0.96	0.72
Principal Comp 1	0.78	0.98	0.96	0.87	0.98	0.86	0.96	0.95	0.96	1.00	0.64
Principal Comp 2	0.16	0.70	0.72	0.29	0.70	0.30	0.66	0.69	0.72	0.64	1.00

Eigenvectors were created to show the optimum combination of snow survey sites that accounts for the most total year-to-year variance of March SWE in the Chuska Mountains and Defiance Plateau. Corresponding eigenvalues show the fraction of total year-to-year variance accounted for by each eigenvector. The first and second eigenvectors, which account for most of the year-to-year variance within the network as a whole, were projected into principal component time series that show the year-to-year variations in strength of the eigenvector patterns in each year's March SWE map.

Results

Mean SWE peaks in March for most NNDWR snow survey sites. Mean SWE for each sample date of each site for all years on record was calculated to show the seasonal cycles of snowpack (Figure 2). Arbab's Forest generally has the least snowpack, while Beaver Spring has the most snowpack. Mean SWE at Arbab's Forest peaks in mid-February (at least two weeks earlier than other sites) at 0.058 m. Mean SWE at Beaver Spring peaks in mid-March at 0.25 m. The other seven sites have peak SWE between early and mid-March. The higher peak snowpack values occur mostly in the higher elevation (Figure 3) and northern (Figure 4) sites (Tsaile I, Tsaile III, Beaver Springs, Hidden Valley, Whiskey Creek, and Bowl Canyon) where SWE measurements range from 0.156-0.25 m. Lower peak snowpack measurements occur in the more southern and lower elevation sites (Missionary Springs, Fluted Rock, and Arbab's Forest) where SWE measurements range from 0.058-0.099 m.

The year-to-year correlation matrix (Table 3) shows that the March SWE fluctuations among the sites are all positively and significantly correlated. Two pairs of sites that have the strongest correlations are Beaver Spring and Bowl Canyon and Beaver Spring and Hidden Valley, both pairs with $r^2 = 0.94$. Sites with the weakest correlations include Arbab's Forest and Whiskey Creek ($r^2 = 0.41$), Arbab's Forest and Bowl Canyon ($r^2 = 0.45$), and Arbab's Forest and Tsaile III ($r^2 = 0.45$).

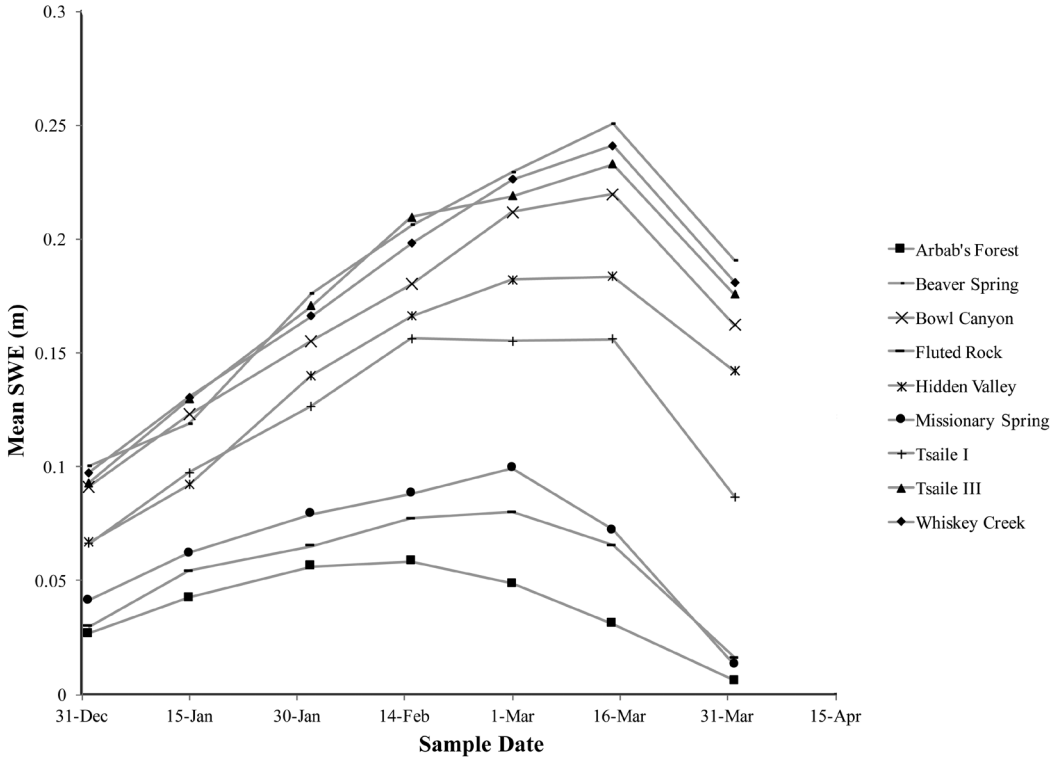

Figure 2. Climatological mean snow water equivalent (SWE) at each site, illustrating the seasonal cycle of snowpack for Navajo Nation snow survey sites.

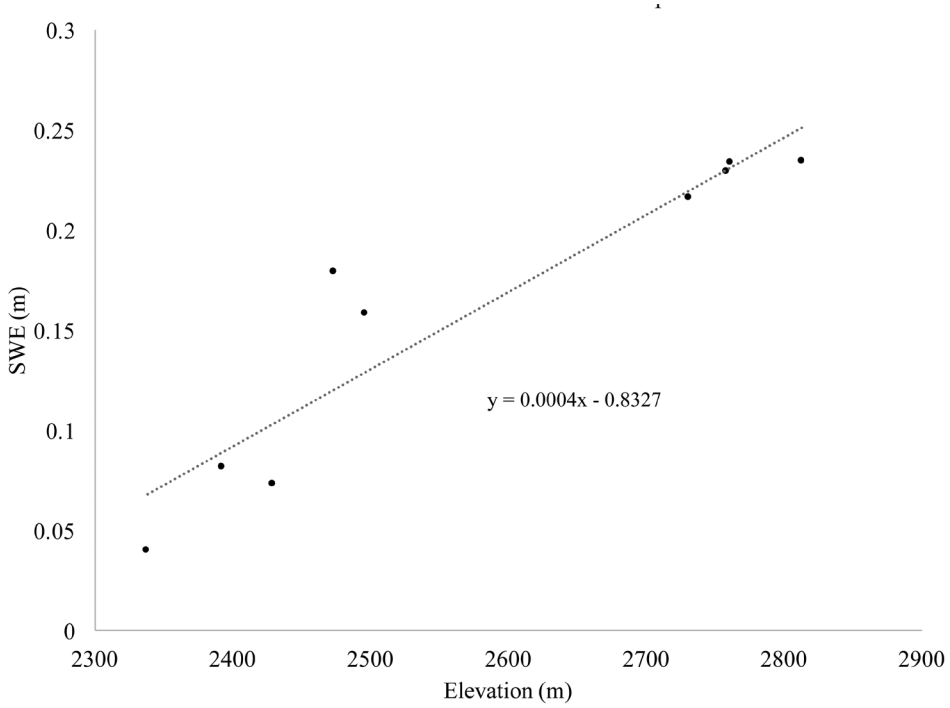

Figure 3. Navajo Nation March snow water equivalent (SWE) as a function of snow station elevation. Linear regression indicates that March SWE increases by 4 cm per 100 m in elevation.

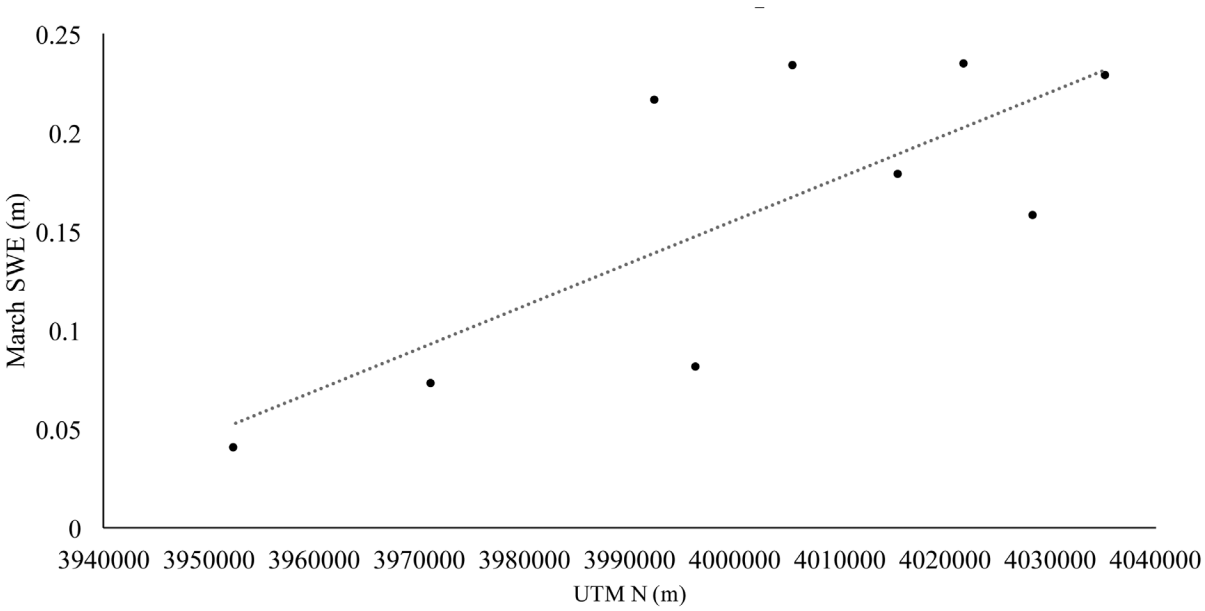

Figure 4. Plot of Navajo Nation snow survey site UTM northing coordinates and March snow water equivalent (SWE).

High elevation sites correlate well. Northern sites (Tsaile III, Tsaile I, Beaver Spring, Hidden Valley, and Whiskey Creek), which are all high elevation sites and nearby to one another, correlate well. Southern sites (Missionary Spring, Bowl Canyon, Fluted Rock, and Arbab's Forest) do not correlate as well with each other as do the northern sites, likely due to the southern sites being further away from one another and having more variation in altitude.

A corresponding set of eigenvectors and eigenvalues was created for the nine Chuska Mountain sites based on the matrix of March SWE year-to-year correlations. The principal component analysis reduced the dimensionality (found patterns that optimally described the year-to-year variability in less than nine individual time series) of the nine Chuska Mountains and Defiance Plateau snow survey sites. Nine eigenvectors of the correlation matrix were created that completely account for the total year-to-year variability at all sites. The first eigenvector, associated with the first eigenvalue, is a pattern that explains the most year-to-year variance of the nine snow survey sites. The second eigenvector, associated with the second eigenvalue, is orthogonal to the first eigenvector and explains the most remaining year-to-year variance of the snow survey network sites. The first two eigenvectors in this analysis together account for 95% of the total year-to-year variance. Subsequent eigenvectors, together accounting for just 5% of the variance, were not considered. Table 4 shows the first and second eigenvectors and their associated vector weights and eigenvalues.

The first eigenvalue accounts for 86% of the total year-to-year variance of March SWE in the Chuska Mountains and Defiance Plateau. Thus, the pattern of the first eigenvector signifies the optimized or "primary" mode of year-to-year variability. In this first eigenvector, all sites have positive coefficients, representing positive correlations between year-to-year March SWE fluctuations at each pair of sites. The coefficients of the first eigenvector are relatively evenly weighted, ranging from 0.2927 for Arbab's Forest to 0.3503 for Hidden Valley. Therefore, the eigenanalysis suggests that, to a first approximation, March SWE rises and fall together at all nine sites.

The second eigenvector accounts for 9% of the total March SWE variance in the Chuska Mountains. By construction, this eigenvector must be spatially orthogonal to the first eigenvector, so the out-of-phase structure of this vector, with three sites exhibiting large negative coefficients

Table 4. First and second eigenvectors, eigenvalues, and associated percent variances.

Site	Vector Weight	
	1	2
Arbab's Forest	0.2927	-0.5883
Beaver Spring	0.3477	0.2261
Bowl Canyon	0.3417	0.2408
Fluted Rock	0.3212	-0.4384
Hidden Valley	0.3503	0.1523
Missionary Spring	0.3167	-0.4107
Tsaile I	0.3439	0.1369
Tsaile III	0.3393	0.2655
Whiskey Creek	0.3424	0.2676
Eigenvalue	7.7537	0.8322
Percent Variance	86.1522	9.2467

and the other six sites exhibiting modest positive coefficients, is built into the analysis. The three sites with the large negative coefficients are all located near the southern end of the network of sites, and are the three lowest-elevation sites (less than 8000 feet, as documented in Table 1). Additionally, the snowpack fluctuations at these three sites are more strongly correlated with each other than with the higher elevation sites to the north (Table 3). We interpret the second eigenvector as mostly representing variability of SWE at the southern end of the Chuska Mountains and not correlated with the snowpack in the rest of the range.

The first and second eigenvectors were projected back onto the year-to-year variability time series of March snowpack anomalies to compute the corresponding principal-component time series. Missing March average SWE values were filled in using average normalized anomalies of all the NNDWR sites with actual data for March of that year. Figure 5 shows the first principal component (PC1) time series for March SWE. This time series shows times of high and low snowpack accumulation in the entire Chuska Mountains and Defiance Plateau region. Each PC1 point in the time series can be interpreted as an optimally weighted average of March SWE over the entire network of sites. The second principal component (PC2) time series, projected from the second eigenvector (Figure 5), shows a different aspect of year-to-year March SWE variability associated with the low-elevation southern sites that project strongly onto the second eigenvector.

The principal component analysis reduces the amount of uncorrelated "noise" associated with the compilation of every site's time series of March snowpack year-to-year variability. The set of nine time series, representing year-to-year variability of the nine NNDWR sites, is reduced to two representative time series. The PC1 time series illustrates the first or "primary" mode of year-to-year variability of March snowpack in the Chuska Mountains and Defiance Plateau, showing the years of high snowpack in 1993, 1997, 1998, 2008, and 2010, and years of low snowpack in 1996, 1999, 2002, 2006, and 2014. The PC2 time series shows the second mode of year-to-year variability of March snowpack in the Chuska Mountains and Defiance Plateau, representing most of the residual year-to-year variance.

The PC1 time series was correlated with the nine NNDWR snow survey sites and the five regional SNOTEL sites to compare the weighted composite average with the individual sites. The correlation map of the PC1 time series for March SWE (Figure 6) shows that the principal component analysis effectively synthesizes the correlations of individual NNDWR sites. The PC1 correlation map shows very strong correlation with all of the snow survey sites, especially with those in the higher elevations of the Chuska Mountains, where snowpack is most variable.

Summary and Discussion

Climatological means for each snow survey site in the Chuska Mountains and Defiance Plateau were calculated for the years 1985-2014. Snow survey sites in lower elevations showed peak snowpack accumulation in early March (snow measurements conducted from February 26 to March 1). Snow survey sites in higher elevations showed peak snowpack accumulation in mid-March. Therefore, a March index was developed based on the average of both yearly March observation dates. March

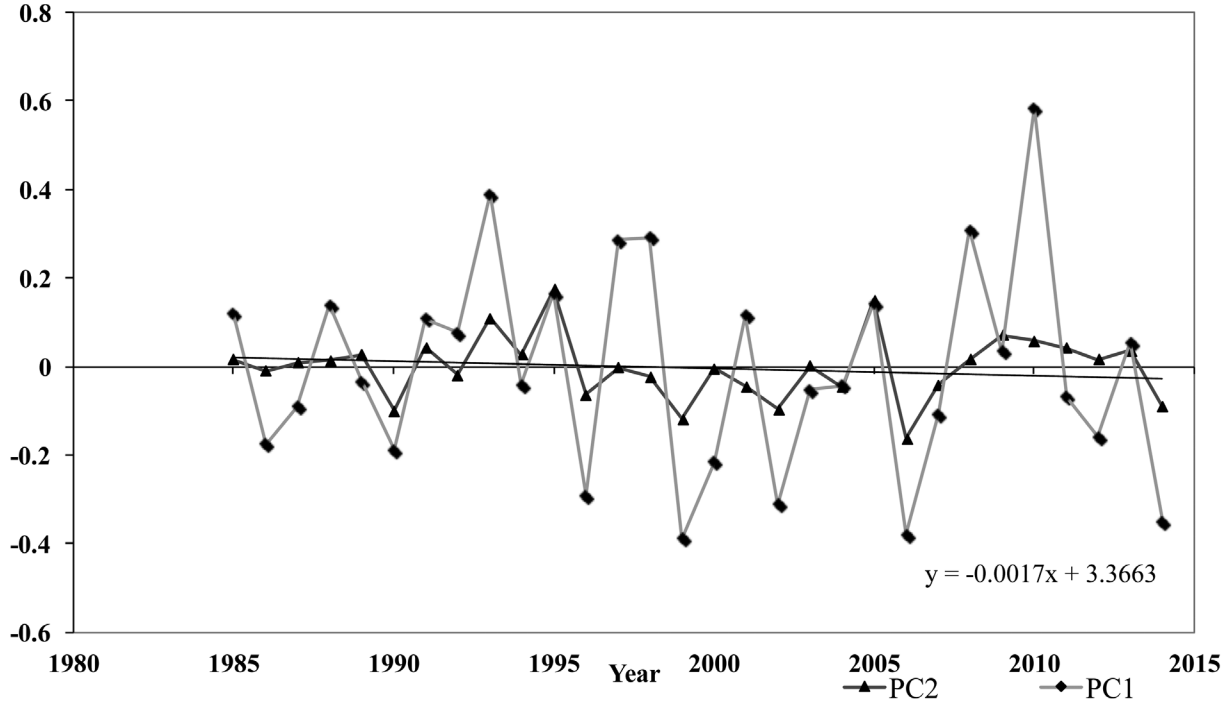

Figure 5. Weighted March Index (1985-2014). Time series of PC1 and PC2 of March SWE in the Chuska Mountains and Defiance Plateau. Dashed line and regression equation in lower right describe a linear trend fit to the PC1 time series.

SWE increases with both elevation and latitude for snow survey sites in the Chuska Mountains, as seen in Figures 3 and 4. Generally, most mountains in the western U.S. have peak snowpack accumulation somewhat later, in early April (Bohr and Aguado 2001). The earlier peak snow accumulation in the Chuska Mountains and Defiance Plateau is likely due to the warmer temperatures associated with the more southern latitude snow survey stations. Though altitudes of the NNDWR snow survey sites are generally at higher elevations than other snow survey stations in the western U.S., Harpold et al. (2012) and Ralph et al. (2014) found timing of peak snowpack to vary by region and latitude in western mountains. Within the NNDWR network, earlier peak snow accumulation dates are associated with sites being at lower elevations.

Year-to-year snowpack anomalies in the Chuska Mountains and Defiance Plateau are generally highly correlated among all snow survey sites; each of the snow survey sites correlated positively with every other site with R values of 0.6 or greater. Snow water equivalencies at sites in lower elevations and sites in higher elevations vary somewhat more from each other. Of the higher elevation sites, Hidden Valley explains the most year-to-year variance of the overall snowpack time series and Whiskey Creek carries the least weight in the eigenvector that describes coherent year-to-year variability throughout the nine-site network. A second mode of variability was primarily associated with lower elevation snowpack sites at the southern end of the Chuska Mountains, accounting for nearly 10% of total SWE variability that is uncorrelated with the principal range-wide, year-to-year fluctuations.

The PC1 time series is also used as a weighted composite average of SWE representing the Chuska Mountains and Defiance Plateau. This series (Figure 5) shows multi-year trends. A linear fit to the PC1 time series shows a slight decline of March snowpack from 1985 to 2014 that cannot be confirmed because the decreasing trend is statistically insignificant. Novak (2007) also found trends of declining SWE in both aggregated SWE time series of five high elevation (>2440m) and two low elevation (<2440m) Chuska Mountain snow survey sites for the 1985-2006 period. The 2006 snow year, the final year in the time series available to Novak (2007), was one of the lowest

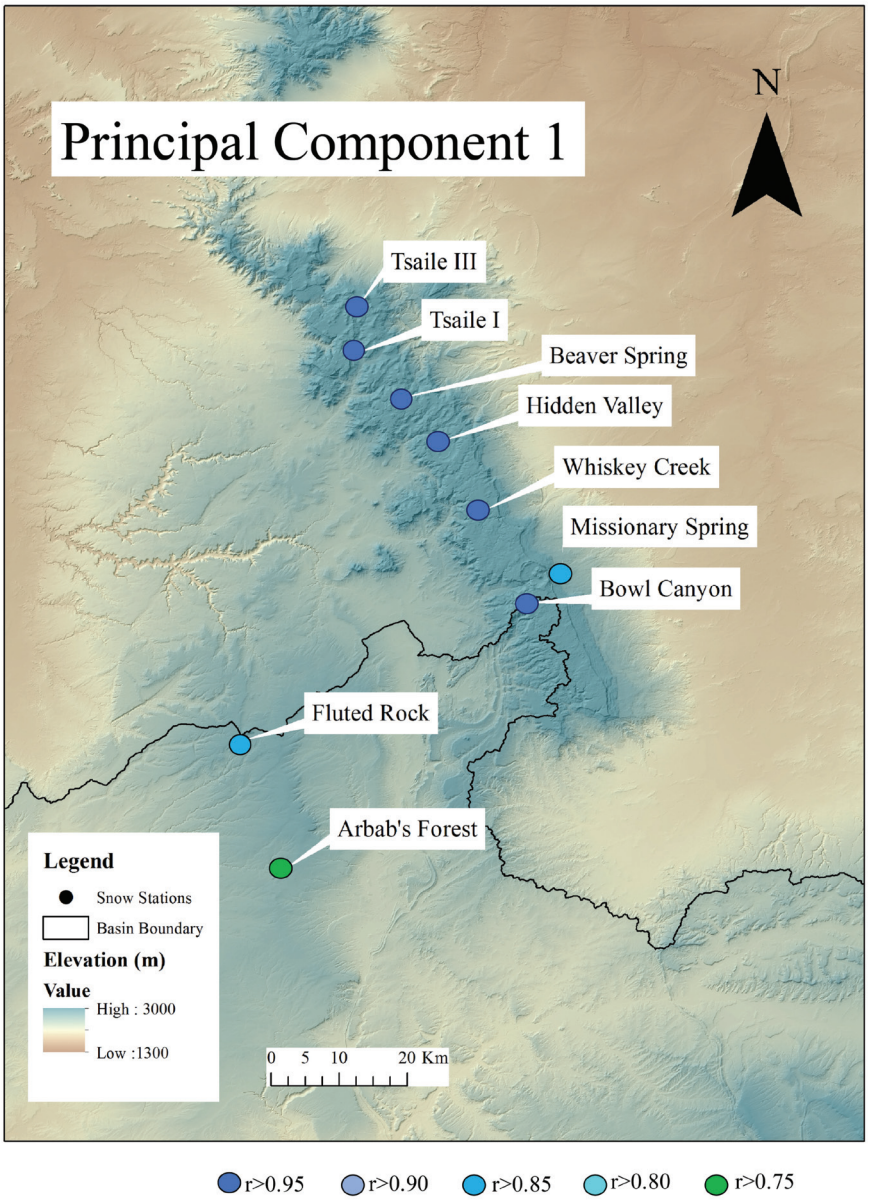

Figure 6. Year-to-year correlation map of March SWE for Principal Component 1.

years on record for SWE in the Chuska Mountains. Years of relatively high snowpack following the 2006 snow year changed the overall snowpack trend based on snow survey record between 2006 and 2014. Because of the length of the NNDWR snowpack record, multiple years of relatively high or relatively low snowpack within a short time span (~5 years) could still greatly influence the snowpack trend. The snowpack record length for the Chuska Mountains studied for this research is thirty years (1985-2014) but still ends on an unusually dry year. Thirty years is the standard length of time required to calculate a climate "normal" that can be used to describe climate in a particular area based on a climatic element such as temperature or SWE. An average over a thirty-year period of record is typically long enough to accurately represent climate because it spans several episodes of short term weather variations and anomalies. However, the year-to-year variability and short term fluctuations of SWE observed in the Chuska Mountains (likely

due to natural short term weather patterns such as the El Niño/Southern Oscillation cycle) can influence trend estimation. Thus, the linear trend fitted for the 1985-2014 record may not entirely reflect the actual long term trend in climate in the Chuska Mountains. If a longer period of record of snowpack were available, short term weather variations and long term climate trends could be more easily differentiated from one another.

The NNDWR faces challenges of collecting snow survey data with minimal funding and staff. If the NNDWR needs to eliminate any of its snow survey sites in the Chuska Mountains or Defiance Plateau, removing a snow survey site from pairs of stations that are very strongly correlated with one another is most likely to maintain the most accurate representation of snowpack in the Chuska Mountains and Defiance Plateau. The NNDWR should initially consider discontinuing sites from pairs with highest correlation ($r = 0.97$) seen in Table 4. In particularly dire conditions, high elevation and low elevation sites from each of the two different watersheds and sites that represent the two different modes of year-to-year variability need to be kept. The recommended sites to keep (at a minimum) include: Bowl Canyon as a high elevation site in the Little Colorado River watershed; Fluted Rock or Arbab's Forest as a low elevation site in the Little Colorado River watershed and as a site from the second mode of variability; Missionary Spring as a low elevation site in the San Juan River watershed; and at least one of the remaining five sites (Tsaile III, Tsaile I, Beaver Spring, Hidden Valley, and Whiskey Creek). From the eigenvector analysis, the Hidden Valley site carries the most weight from the first mode of year-to-year variability out of all the Chuska Mountain sites. It is recommended that Hidden Valley be kept in the NNDWR snow course network as a high elevation site in the San Juan River watershed that represents the first mode of year-to-year variability in the eigenvector analysis. The Whiskey Creek snow course is also recommended to be continued because it has one of the longest, most continuous snow data records of all the NNDWR sites. Additionally, continuing the Whiskey Creek snow course is important for comparing and validating snowpack data collected by the SNOTEL station.

Eliminating any of the snow courses from the NNDWR network would result in a loss of resolution of the snowpack data. Loss of a data collection site is a loss of data. Correlations based on historical data may unexpectedly change in a time of uncertain climate change and reducing sites could still lead to a loss of coverage of snowpack variability. Further studies may show different types of importance any of the sites have that is not yet known, due to limited research on responses of surface water and groundwater to snowpack variability, or due to climate uncertainty. For example, if further research is completed on the relationship between snowpack and snowmelt runoff in the Chuska Mountains, results may reveal high correlation between certain snow survey sites and stream gages. Also, the thirty-year period of record may be too short to show any sensitivity of snowpack to long-term climate trends. Different areas of the Chuska Mountains and Defiance Plateau may show a variation of responses to climate variability that is not shown in this study, so any truncation of snow data collection would result in some loss of sensitivity in future climatic analyses.

The NNDWR can use the information provided in this study as a basis for future studies, projects, and decisions on their snow course network. This study provided a basic characterization of snowpack in the Navajo Nation. Further understanding of the seasonal cycle and variability of snowpack can help the NNDWR in forecasting snowmelt runoff and surface water resources for the Navajo Nation through additional studies involving correlation of snowpack and stream discharge in the Chuska Mountains. The correlation and "weighting" of NNDWR snow survey sites with one another may help the NNDWR prioritize snow survey sites and determine which, if any, snow courses can be discontinued. However, it is advisable that the NNDWR retain the current snow survey and SNOTEL sites to maintain resolution of data. Also, merging of NNDWR snow survey data with national networks of data, such as the NRCS SNOTEL network, may provide a better understanding of snowpack patterns from a larger regional perspective.

Amid growing concern over climate change, it is important for the Navajo Nation and other tribes

to continue to monitor and collect meteorological, climatic, and hydrologic data to better understand how climate change and climate variability influence their water resources. In the Chuska Mountains and the Defiance Plateau, snowpack provides runoff to streams and recharge to groundwater and springs which are all economically, culturally, ecologically, and hydrologically important. Local communities rely on springs and groundwater as one of their sources of drinking water. Streams in the Chuska Mountains provide water for agriculture and ecosystems. Snowmelt provides water for ponds and lakes used for recreation and livestock. Snowmelt is also important for providing soil moisture for vegetation. Results will help the NNDWR relay information to communities that rely on snowpack and water resources in the Chuska Mountains. The NNDWR has built a solid foundation in the collection of data in their streamflow, precipitation, and snowpack records. Further and continued analyses of hydroclimatic data will help the Navajo Nation and local communities in the Chuska Mountains and Defiance Plateau to better plan and manage for any changes in water resources in the near or distant future.

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Contents

Emerging Voices of Tribal Perspectives in Water Resources
Karletta Chief 1

Native Water Protection Flows Through Self- Determination: Understanding Tribal Water Quality Standards and "Treatment as a State"
Sibyl Diver 6

Disparities in Water Quality in Indian Country
Otakuye Conroy-Ben and Rain Richard 31

Tribal Economies: Water Settlements, Agriculture, and Gaming in the Western U.S.
Suhina Deol and Bonnie Colby 45

Assessing Tribal College Priorities for Enhancing Climate Adaptation on Reservation Lands
Helen M. Fillmore, Loretta Singletary, and John Phillips 64

Climate Change in the Lumbee River Watershed and Potential Impacts on the Lumbee Tribe of North Carolina
Ryan E. Emanuel 79

Perspectives on Water Resources among Anishinaabe and Non-Native Residents of the Great Lakes Region
Andrew T. Kozich, Kathleen E. Halvorsen, and Alex S. Mayer 94

Navajo Nation, USA, Precipitation Variability from 2002 to 2015
Crystal L. Tulley-Cordova, Courtenay Strong, Irving P. Brady, Jerome Bekis, and Gabriel J. Bowen 109

Navajo Nation Snowpack Variability from 1985-2014 and Implications for Water Resources Management
Lani M. Tsinnajinnie, David S. Gutzler, and Jason John 124



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