University of Nevada, Reno

Assessing climate data and information needs to enhance the resiliency of water resources on reservation lands in the southwestern United States

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Hydrology

by

Helen M. Fillmore

Dr. Loretta Singletary/Thesis Advisor

May, 2019

THE GRADUATE SCHOOL

We recommend that the thesis
prepared under our supervision by

HELEN M. FILLMORE

Entitled

Assessing Climate Data And Information Needs To Enhance The Resiliency Of Water Resources On Reservation Lands In The Southwestern United States

be accepted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE

Loretta Singletary, Ph.D., Advisor

Michael Dettinger, Ph.D., Committee Member

Alexandra Lutz, Ph.D., Graduate School Representative

David W. Zeh, Ph.D., Dean, Graduate School

May 2019

Abstract

Indigenous communities are among some of the most vulnerable to climate change impacts, particularly with regards to their water resources. Planning effectively to remain resilient within existing socio-cultural, political, and economic constraints requires an assessment of the climate data and information needs most pressing in Indigenous communities. Integrating diverse Indigenous stakeholder perspectives and knowledges with western-science is fundamental in creating comprehensive climate adaptation plans for Indigenous communities. This process is also very complex due to the complex interconnections between Indigenous communities and the hydrologic systems in which they depend. This study seeks to support such integration through the use of a participatory research design that assesses data and information needs critical to enhancing climate adaptation on reservation lands in the Southwestern United States. This study outlines the development of a survey instrument implemented at the 2016 and 2017 Native Waters on Arid Lands Tribal Climate Summit and highlights the results of statistical tests using responses to the 33 Likert-type scale questions. Study participants include tribal government workers, agriculturalists, researchers, and outreach professionals interested in climate adaptation on reservation lands. Results from this regional study indicate that more than 75% of the 98 voluntary participants are Native American and 83% reside in either the Great Basin or Colorado River Basins. Participants prioritize data and information that serve to: assess climate change impacts, enhance food security, and integrate Traditional Knowledge of their communities into reservation-wide adaptation planning and action. In this data-scarce region, respondents prioritize water quality data as their highest need followed by streamflow and *temperature data. Results from this study may assist in collaborative socio-hydrologic research efforts with Indigenous communities by reducing assumptions about climate data and information needs. Furthermore, regional needs assessments with Indigenous communities related to climate impacts are rare relative to case studies due to the extensive diversity that exists among these communities. This study includes a discussion on ethical collaboration when conducting such research, with special attention to protecting the data sovereignty of Indigenous communities when sharing research information with the general public.*

Dedication

To the land, the water, and the future stewards of Wašišiw ʔItde

Acknowledgements

ʔUmwaʔaŋawi (thank you) to my advisor, Loretta Singletary, for your patience and diligence on this educational path with me. ʔUmwaʔaŋawi to my committee for your helpful recommendations. ʔUmwaʔaŋawi to my family, community, and to the Indigenous land, water, and resource managers of the Great Basin and Southwest for your dedication to managing and protecting our natural resources for future generations, and for your support and encouragement throughout the years.

This thesis research was funded by a 5-year grant from USDA National Institute of Food and Agriculture (NIFA) award number 2015-69-00723190.

Table of Contents

List of Tables

List of Figures

Assessing Climate Data and Information Needs to Enhance the Resiliency of Water Resources on Reservation Lands in the Southwestern United States

Chapter 1

1.0. Introduction

Projected climate change impacts on water resources may compound aridity issues in already water-stressed regions in the western United States (Li, Wrzesien, Durand, Adam, & Lettenmaier, 2017). Water scarcity is a defining feature of the ecological and social systems that comprise this desert region. Current water availability limits key economic industries, such as commercial agriculture, and the regional capacity to sustainably meet water needs for steady urban population growth and development (MacDonald, 2010). Increasing severity and frequency of drought and/or flooding events, decreasing annual snowpack, and earlier snowmelt impact the social, economic, and ecological health of the region (Cozzetto et al., 2013; Draut, Redsteer, & Amoroso, 2013; Fritze, Stewart, & Pebesma, 2011; Knowles, Dettinger, & Cayan, 2006; Miller & Piechota, 2011; Wine & Cadol, 2016).

While climate driven changes in water resource availability affect the human population in this region as a whole, they may affect Indigenous communities on reservation lands more severely (Gamble et al., 2018). Limited economic development opportunities, inadequate water delivery infrastructure, unresolved water rights claims, and isolated rural land bases add to the particular vulnerability of Indigenous communities to changes in water resources (Cozzetto et al., 2013). Furthermore, Indigenous communities maintain strong relationships to their natural environment including complex interconnections between social and ecological systems (Maldonado et al., 2016). In accordance with these unique socioecological systems, Indigenous cultural values not only inform natural resource management decisions, but are also shaped by local ecologic and hydrologic systems (Azar, Holmberg, & Lindgren, 1996; Maldonado et al., 2016). Ecological changes both on and adjacent to reservation lands can, therefore, result in significant losses to cultural resources and a reduction of subsistence practices which impact community health and social wellbeing (Lemelin et al., 2010). Assessing future climate impacts on reservation lands may require interdisciplinary research approaches in order to enhance local efforts to improve climate resilience (Cochran et al., 2013; Klein, 2008). This includes identifying relationships and interconnectedness among seemingly independent disciplines and/or ideas (Cochran et al., 2013; Klein, 2008; Warner, Wesselink, & Geldof, 2018).

Recognizing the inextricable feedbacks between social and hydrologic systems, the emergent field of socio-hydrologic research aims to better analyze, understand, and model these coupled human-water systems (Di Baldassarre et al., 2015; Pande & Sivapalan, 2017; Vogel et al., 2015). Integrated hydrologic models, such as those that model Prior Appropriation water right impacts on discharge and water availability, are standard predictive decision support tools (Null & Prudencio, 2016). There is also a general acceptance that changing human values are linked to water use and management, policy decisions, and the alteration of hydrologic systems (Chen, Wang, Tian, & Sivapalan, 2016; Sivapalan & Bloschl, 2015). These interactions may be particularly dynamic in water scarce environments (Gunda, Turner, & Tidwell, 2018).

While this emerging field describes and applies mechanisms to analyze coupled human-water systems, socio-hydrologic research that focuses primarily on the social factors that influence hydrologic systems remains limited (Hunter, Gironas, Bolster, & Karavitis, 2015). This thesis stands as a first step in socio-hydrologic research conducted exclusively with Indigenous communities in the southwestern United States through an assessment of Indigenous stakeholders' climate data and information needs. It does not attempt to analyze or predict water use decisions of Indigenous communities. Rather, it aims to identify climate data and information necessary to support climate adaptation on reservation lands in an arid region. The research design and methods employed, and the results reported here, may facilitate first steps in engaging with Indigenous communities to co-produce new knowledge of socio-hydrologic systems unique to reservation lands in order to enhance their climate resiliency.

Participatory action research design and methods have proven particularly successful when conducting interdisciplinary research with Indigenous communities (Datta et al., 2015; Meadow et al., 2015). Such methods engage stakeholders in co-identifying research objectives, which helps to ensure that subsequent research activities and findings are immediately applicable to local issues and can guide local decisions (Angelstam et al., 2013; Chief, Meadow, & Whyte, 2016; Klenk, Fiume, Meehan, & Gibbes, 2017; Meadow et al., 2015). Furthermore, traditional knowledge and knowledge of the unique socio-hydrologic systems that inform water resource use on reservation lands often are held at a community level, are undocumented, and are not intended for use outside these communities (Maldonado et al., 2016). In order to enhance climate resiliency on reservation lands, it is imperative to work directly with Indigenous communities to assess and integrate their diverse climate data and information needs and adaptation perspectives following research protocols acceptable to the communities engaged in the research (Klenk et al., 2017; Murphy, 2011; Robitaille, Shahi, Smith, & Luckai, 2017).

Long-established ethics systems linked to the protection of ecological services, and strong communal relationships inherent to Indigenous communities, provide a strong foundation for climate change adaptation on reservation lands (Ignatowski & Rosales, 2013; Maldonado et al., 2016). As compared to non-Native rural communities, Indigenous communities on reservations may be more likely to recognize and acknowledge evidence of climate change impacts due to human activity (Berkes, Colding, & Folke, 2000; Falloon & Betts, 2010; Fernald et al., 2015; Smith, Liu, Safi, & Chief, 2014). The coupled human and natural systems values and thinking that typify Indigenous ethics that prioritize healthy ecosystem services may make Indigenous communities more amenable to crafting public policies that aim to mitigate or adapt to climate change impacts (Fernald et al., 2015; Fillmore, 2017).

Traditional knowledge is a place-based knowledge system held by Indigenous communities and passed down generationally (Berkes et al., 2000). This knowledge system can be informed by natural ecosystem processes and the intergenerational roles of humans and their influences on these ecosystems (Berkes et al., 2000). Traditional knowledge, when used to inform integrated water management practices, has proven through time to have profound influence on ecosystem resilience (Davidson-Hunt, & Berkes, 2001). The role of traditional knowledge regarding water resources in climate adaptation planning and action, however, is potentially more complex given that many Indigenous communities are currently experiencing environmental changes that are unprecedented in the climate record (T. M. B. Bennett et al., 2014). This implies that traditional knowledge alone may be insufficient to enhance the climate resilience of Indigenous communities. The integration of traditional knowledge with the collaborative co-production of climate and hydrologic science, however, can enhance tribal communities' adaptation (Lemelin et al., 2010; Maldonado et al., 2016; Tengo et al., 2017; Williams & Hardison, 2013). This integration supports the growing call from Indigenous communities to adopt interdisciplinary approaches in investigating climate adaptation planning and action to enhance the resilience of water resources on reservation lands.

Supporting efforts to integrate local and traditional knowledge to inform climate adaptation may also help overcome adaptation barriers unique to the socio-hydrologic systems that exist among Indigenous communities on reservation lands (Maldonado et al., 2016). Increasingly, efforts are underway to include Indigenous communities in climate research while acknowledging and integrating traditional knowledge as having an important role (Murphy, 2011). While increasing numbers of academic studies argue the potential benefits of this research practice, few offer insight into how to best conduct this research (Maldonado et al., 2016; Meadow et al., 2015). Even fewer studies assess the self-identified climate data and information needs of Indigenous communities, and none offer insight into ethical research practices for conducting needs assessments at regional scales with Indigenous communities.

Continued failure to assess self-identified and/or community-identified information needs can lead to research that extracts and disseminates local and traditional knowledge for the benefit of researchers rather than research that leads to the co-production of new knowledge (Gautam, Chief, & Smith, 2013; Klenk et al., 2017).

Extraction and dissemination of traditional knowledge can be particularly harmful to Indigenous communities (Klenk et al., 2017). The misappropriation of this knowledge can lead to the desecration of important cultural sites, the over-extraction of medicinal plants, and the perseverance of dehumanizing stereotypes of Indigenous cultures (Simpson, 2004). These problems may be exacerbated further given that federal and international legal mechanisms are lacking to protect this knowledge (Brewer & Kronk Warner, 2015).

This thesis is part of a larger federally funded integrated research and outreach project to enhance the climate resilience of water resources on reservation lands in the southwestern United States. The over-arching project goal supports current Indigenous priorities on reservation lands which include assessing climate impacts on Indigenous communities (Chief et al., 2016). Because of the extensive socioeconomic and cultural diversity among tribes and because of their political sovereign status, quantifying climate impacts specific to individual Indigenous communities on a regional scale is impractical. Furthermore, such research is unethical if conducted without the consent of each tribal government involved. Instead, this thesis aims to assess the climate data and information needs and priorities of Indigenous community stakeholders living or working on reservations within this region.

A participatory action research framework is administered specifically to prevent the inadvertent extraction of sensitive cultural information, and to prevent potential threats to tribal sovereignty. Avoiding harmful assumptions and generalizations about Indigenous communities is a necessary element of participatory research best practices (Datta et al., 2015). The ethics that such best practices ensure are especially appropriate when working with Indigenous communities where research abuses have occurred in the past (Chief et al., 2016; Datta et al., 2015; Klenk et al., 2017).

A mix of stakeholders are surveyed that include farmers, ranchers, land and water managers, tribal government officials, and university faculty, staff, and students who are engaged in climate adaptation efforts surrounding water resources on reservation lands. The survey instrument is designed to assess a composite of climate data and information needs necessary to enhance the climate and hydrologic resilience of Indigenous communities on reservation lands.

Statistical analyses of primary data collected through this survey produce a hierarchy of climate data and information priorities that highlight the unique needs of survey participants. Results from this assessment can help to inform the roles and responsibilities of collaborative partners in interdisciplinary climate adaptation research, planning, and capacity-building efforts on reservation lands. These results may also help to identify readily accessible sources of climate data and information specific to Indigenous communities on reservation lands. Specifically, this thesis answers the following questions:

- What types of climate information and data are perceived as necessary to inform climate adaptation planning initiatives on reservation lands?
- What current sources of climate data and information are accessed most frequently?
- Does experiential background influence climate information and data needs prioritized and sources accessed in climate adaptation planning initiatives on reservation lands?

In particular,

- Does one's role in climate adaptation planning (either administration, analysis, or implementation of plans) influence climate information/data priorities and accessed sources?
- Do data/information priorities and accessed resources differ by location of reservation within the study region?
- Is educational attainment a factor in climate information and data need priorities and access differences?
- Is gender a factor in climate information and data need priorities and access differences?
- Is age a factor in climate information and data need priorities and access differences?

Chapter 2

2.0. Literature Review

2.1. Definition of terms. This thesis synthesizes research literature from multiple disciplines. Many of the terms presented here depict interrelated concepts. That is, some terms may have different connotations depending on usage and context. This section presents and defines key terms and clarifies how these terms are used throughout this thesis.

- Indigenous communities: This thesis focuses exclusively on "federally-recognized tribes." The status of federal recognition influences the governance structure in which tribes operate today and impacts several unique political attributes of tribes that are key to this research. Such attributes include sovereign governance and property rights institutions that involve tribal land tenure, water rights, and rights to use lands and water resources associated with traditional homelands. Reservation lands are held in trust by the federal government for federally-recognized tribes (Pevar, 2012). Political sovereignty as it relates to federally-recognized tribes is defined as the inherent ability of these communities to self-govern within the boundaries of their reservations as domestic dependent nations of the United States (Coffey & Tsosie, 2001). Tribes hold sovereign status separate from other tribes and apart from other government entities, such as states and counties (Pevar, 2012). Because of this status, sovereign tribal nations govern themselves independently from state and county laws, policies, and regulations, but remain subject to federal laws, policies, and regulations. Sovereign status has contributed to the evolution of federal and state land and water use policies unique to reservation lands (Pevar, 2012). While the primary data recruitment, collection, analysis, and outreach featured in this thesis is exclusive to federally-recognized tribes, when referring to these sovereign tribal nations, this thesis uses the term “Indigenous communities” interchangeably with the terms “tribes,” “tribal nations,” and “federally-recognized tribes.” The purpose of using Indigenous communities rather than federally-recognized tribes in various text passages acknowledges that the status of federal recognition does not influence the unique cultural attributes of tribes on reservation lands within this region. These attributes are important given the impacts on reservation resource management decisions that stem from interrelationships involving traditional knowledge, intergenerational land and water management practices, and climate adaptation planning and action. Such attributes have survived for centuries and continue to characterize Indigenous responses to changing natural resource conditions including climate impacts, regardless of federal standing (Guatam & Chief, 2016). In sections 2.5 and 2.6 that refer to key historical federal policies that continue to impact reservation lands and Indigenous communities, this thesis uses the term “Indian Nations” as some of these policies pre-date the federal-recognition policy in use today. Using the term, “Indian Nations” when referencing federal legislation and policies acknowledges the term used most commonly by the U.S. government to describe Indigenous people (Indian) while also recognizing the foundation of present-day semi-sovereign political standing of Indigenous communities (Nations) within the U.S. The terms “Indian Tribes,” and “American Indians,” are the typical terms used in legislative documents describing, outlining, and/or recognizing the rights of Indigenous communities within

U.S. boundaries, but are not used in this thesis. Aside from sections 2.5, and 2.6, the term, “Indigenous Communities” is used to describe federally-recognized tribes.

- Stakeholders: Climate change is arguably one of the most pressing global issues of modern times. Stakeholders affected by climate change impacts specific to reservation lands in the arid southwestern United States includes all community members. For the purpose of this thesis, however, stakeholders are defined as the individuals involved in climate resiliency research and outreach education on reservation lands, and/or individuals who implement climate adaptation practices on reservation lands. These include tribal government officials, employees, farmers, ranchers, and local natural resource managers. Under this consideration, the term “stakeholder” is used throughout this thesis to specifically describe survey participants.
- Interdisciplinary research: Interdisciplinary, transdisciplinary, and multidisciplinary refer to the integration of multiple academic disciplines in research studies (Angelstam et al., 2013; Klein, 2008; Kliskey et al., 2017). The “interdisciplinary” research featured here applies concepts that integrate multiple interrelated academic disciplines necessary to assess the climate data and science information needs and priorities to support climate adaptation on reservation lands. This includes assessing the role of traditional knowledge as a source of climate data and science information on reservation lands. Integrating academic disciplines supports a socio-hydrologic systems approach to assessing and enhancing climate resiliency.
- Traditional knowledge: Considering the interdisciplinary nature of this study, the term “traditional knowledge” is used to encompass several concepts that are

sometimes defined separately. These concepts include “Traditional Ecological Knowledge,” and “local knowledge,” which refer to land-use practices of Indigenous communities passed down inter-generationally, and memories of or experiences with observed patterns regarding local weather, climate and water resource availability (Berkes et al., 2000; Cheveau, Imbeau, Drapeau, & Belanger, 2008; Granderson, 2017; Klenk et al., 2017). The term traditional knowledge also encompasses “Indigenous knowledge” and “cultural knowledge,” which can refer to social concepts, such as traditional Indigenous governance systems and community values (Klenk et al., 2017; Maldonado et al., 2016; Vernooy, Sthapit, Otieno, Shrestha, & Gupta, 2017; Williams & Hardison, 2013). Therefore, traditional knowledge is defined here as any information held by Indigenous communities about socio-hydrologic systems and/or climate information specific to their traditional homelands and/or territories. It also includes any inter-generational transfer of Indigenous knowledge and/or values linked to socioecological resilience.

- Participatory research: Participatory action research, often called simply “participatory research,” is a research design intended to empower community-based decision-makers, and other pertinent stakeholders, through their direct involvement in the process of scientific inquiry (Glass et al., 2018). It encompasses a set of methodologies to ascertain the perspectives and knowledge of local participants within the study area. These methodologies are particularly helpful in ensuring that research goals and outcomes are directly applicable and thus useful to the participants (Blodgett, Schinke, Smith, Peltier, & Pheasant, 2011). Participatory research principles are central to this study to assess Indigenous stakeholders’ climate data and information needs unique to their socio-hydrologic systems. The participatory research methodologies applied in this thesis include: engaging participants as informed experts; empowering participants to co-develop research goals and objectives; and maintaining open and civil dialogue with participants throughout the entirety of the research experience which includes setting research goals, objectives, methods, results, and deliverables.

2.2. Study area. The original project, titled Native Waters on Arid Lands (NWAL) and funded (2015-2020) by the U.S. Department of Agriculture (USDA) National Institute of Food and Agriculture (NIFA), describes a loosely defined region - Great Basin Desert - as the primary study region. During the first 12 months of this project (2015-2016), however, research and outreach efforts in collaboration with project co-directors from 1994 and 1862 land grant university faculty and staff in Nevada, Arizona, and Utah, led to an expansion of the project study region to incorporate the participation of tribal colleges and universities located outside Nevada, Arizona, and Utah. This thesis, however, defines its study region boundaries using three U.S. Geologic Survey (USGS) water resource regions delineated at 2-digit hydrologic unit codes (HUCs). These are the Great Basin Region, the Upper Colorado Region, and the Lower Colorado Region. This study region as a whole is referenced throughout this thesis as the "Southwest" and spans several states including Arizona, California, Colorado, Idaho, Nevada, New Mexico, and Utah.

There exist endless possibilities to distinguish and specify a study area within this region. The primary significance of utilizing USGS water resource regions is due to the high implications of water law on water resource use and planning. Water rights are typically adjudicated at the watershed scale (Colby, Thorson, & Britton, 2005). The Colorado River basin is a relatively large watershed spanning several states. While these states oversee and manage water resources within their boundaries, total water entitlement of the Colorado River are adjudicated at the U.S. federal level. The Great Basin is composed of many smaller terminal basins. Many of the water right entitlements are adjudicated and managed at the state level. Figure 1 illustrates the boundaries of this study region.

Figure 1. Great Basin, Upper Colorado, and Lower Colorado water resource regions (scaled at USGS 2-digit HUCs).

While the broader nature of research questions that this thesis addresses allows for participation outside the study region, targeted participant recruitment occurs within the study region. Therefore, Chapter 2 of this thesis outlines issues relevant to the targeted population within the study region and describes Indigenous communities whose reservation lands are located within the study region boundaries.

The Southwest, as defined here, comprises the Great Basin region and the Colorado River region. The Great Basin boundary is delineated using USGS water resource regions at the 2-digit HUC scale. The Colorado River region boundary is determined using the combined Upper and Lower Colorado River water resource regions at the 2-digit HUC scale. These regional boundary delineations are applied in the analysis of the collected primary data to summarize and compare survey participants' responses by water resource region. While the Great Basin and the Colorado River regions share similarities related to water-stress and climate variability, unique differences concerning socio-hydrologic systems specific to Indigenous communities within the region warrant separate analyses of climate impacts. Thus, when discussions warrant the inclusion of both, this thesis references the specified study area as the Southwest. Otherwise, these two regions are referenced separately as the Great Basin region and Colorado River region.

2.3. Southwest climate. The Great Basin and Colorado River regions are among the most arid snow-fed dependent lands in the Southwest, receiving an average annual precipitation of 13 inches, average annual minimum temperatures of 38 degrees Fahrenheit, and average annual maximum temperatures of 67 degrees Fahrenheit (see

Appendix A). Orographic effects in this region lead to spatially variable precipitation patterns and contribute to the particular aridity of the Southwest (Heinselman & Schultz, 2006; Houghton, 1979; Leung, Qian, & Bian, 2003; Munroe, 2006). Mountainous topography forces much of the annual precipitation to fall as snow at higher elevations with nearly 70% of available water originating as snowpack accumulation in these regions (Li et al., 2017).

Hydrologic processes in the Southwest are highly dependent on winter precipitation falling as snow. In higher elevations of the Sierra Nevada and Rocky Mountain ranges, water is stored as snowpack (K. E. Bennett et al., 2018). As spring temperatures warm, melting snowpack releases water into the watershed eventually filling streams and riverbeds. This results in seasonal and variable water availability for large numbers of downstream ecosystem services. These include irrigated agricultural production, environmental habitat, and municipal and industrial uses.

Predominantly snow-fed river systems are demonstrating hydrologic shifts due to climate change (Fritze et al., 2011; Stewart, Cayan, & Dettinger, 2005; Tennant, Crosby, & Godsey, 2015). Stream and river discharge from snowpack run-off is peaking earlier in the spring, which leads to earlier available water (Fritze et al., 2011; Hidalgo et al., 2009; Howat & Tulaczyk, 2005; Miller & Piechota, 2011; Stewart et al., 2005; Zampieri, Scoccimarro, Gualdi, & Navarra, 2015). The shift in earlier snowmelt is projected to lead to longer, and drier summers with higher aridity during the weeks when water demands for irrigated agriculture are at their highest (Ficklin, Stewart, & Maurer, 2012; Reynolds, Shafroth, & Poff, 2015). The Southwest is also experiencing a shift in winter precipitation falling as rain rather than snow, which may influence flood patterns (Ficklin et al., 2012; Knowles et al., 2006; Tennant et al., 2015; Zampieri et al., 2015).

Climate projections do not suggest a significant decrease in overall precipitation in the Great Basin, and only a moderate decrease in annual precipitation in the southern latitudes of the Colorado River region (Dettinger, Udall, & Georgakakos, 2015). Due to rising temperatures and poleward expansion of subtropical dry zones, aridity is expected to increase throughout this region (Cayan et al., 2010; Dettinger et al., 2015; MacDonald, 2010; Seager et al., 2013).

Precipitation and evapotranspiration are the most significant factors contributing to available water in a system or watershed (Dingman, 2015). Because the rate of evapotranspiration is dependent on temperature, as atmospheric temperatures increases, the rate of evapotranspiration also increases, and thus decreases the amount of available water in a watershed (Dingman, 2015). This impact on water availability is already being observed in the Southwest as declining soil moisture; however, water managers may expect a 10% to a 45% decrease in streamflow by the turn of the 21st century (K. E. Bennett et al., 2018; Cayan et al., 2010; Rajagopal, Dominguez, Gupta, Troch, & Castro, 2014; Seager et al., 2013; Vano et al., 2014). Tools are available for managers to better understand this large range of projected outcomes (Vano et al., 2014).

Increased wildfire size, frequency, and severity is also a pressing issue related to climate change in this region (Thorne et al., 2018). This particular issue is complicated by a history of land and forest mismanagement, widespread invasive plant and insect species encroachment, and tree mortality due to insect infestations (Loehman, Flatley, Holsinger, & Thode, 2018). While wildland fire is an important disturbance regime in the

Southwest, climate change and the encroachment of invasive plant species, such as cheatgrass, have drastically altered these landscapes (Thorne et al., 2018). Shading from woody vegetation around riparian areas is an important factor influencing the ecological health of rivers and streams (Booth, Cox, Simonds, & Sant, 2012). In terms of water availability, however, wildland fire impacts have shown to increase the total amount of water available in rivers and streams by 20% as compared to watersheds with no wildland fire events (Wine & Cadol, 2016; Wine, Makhnin, & Cadol, 2018). This available water comes at the cost of vegetation removal and increased erosion in these watersheds. This suggests that the projected increase in wildland fire in the Southwest may partially mitigate the projected decrease in water availability due to climatic factors (K. W. Jones et al., 2017; Wine & Cadol, 2016).

With snowpack being the primary precipitation source of available water in the Southwest, small changes in atmospheric temperature can amplify the effects on water resource patterns, and compound the effects on people dependent on the limited resources in this arid region (Armstrong et al., 2018; Ficklin et al., 2012; Worland, Steinschneider, & Hornberger, 2018). Given that the three primary factors influencing water availability in this region are temperature, precipitation, and topography, climate change adaptation opportunities may be few. Nevertheless, Indigenous communities of the Southwest have a long history of adaptation to climate variability (Gautam et al., 2013; T. L. Jones et al., 1999).

2.3.1. Great Basin hydrology. The basin-range topography of the Great Basin contributes to several terminal basins upon which the surrounding Indigenous populations depend. This unique topography also leads to significant orographic effects contributing to the variability of precipitation and temperature from basin to basin (Houghton, 1979). Rivers in this region are nearly entirely snow-fed due to sparse summer precipitation, making them vulnerable to warming temperatures (Ficklin et al., 2012). That is, due to steep elevation changes over a limited area, there is very little upland water storage outside of snowpack, which leads to significant concerns about spring flooding events under a warming climate (Cristea, Lundquist, Loheide, Lowry, & Moore, 2014; Dickinson, 2006; Ficklin et al., 2012; Howat & Tulaczyk, 2005; Yu, Jiang, Gautam, Zhang, & Acharya, 2015). While the southern Great Basin may experience increases in aridity under current climate projections, the northern Great Basin climate is more spatially variable, and often features atmospheric effects more representative of slightly wetter latitudes in the northern U.S. such as the southern Columbia River region (Oubeidillah, Tootle, Moser, Piechota, & Lamb, 2011).

2.3.2. Colorado River region hydrology. In contrast to the terminal rivers that tend to characterize the Great Basin, the Colorado River does not terminate inland but is fed by smaller rivers and streams across the watershed until it reaches its terminus in the Gulf of California at the Sea of Cortez. While winter precipitation, stored as snow until spring melt, is the primary source of available water in this watershed, the southern Colorado River region also receives a secondary pulse of precipitation during summer months due to monsoonal rains (Hales, 1974). Precipitation from the North Atlantic Monsoon System usually occurs from June to September with a projected decrease in intensity during June and an increase in intensity in September (Heinselman & Schultz, 2006). This secondary source of precipitation provides relief during a time when the primary source of available water (snowmelt) begins to deplete. A model simulation based on data from 1971-2010 suggests that the North Atlantic monsoon system is weakening due to an increase in carbon dioxide in the atmosphere (Pascale et al., 2017). Projected climate outcomes on monsoon intensity and frequency in the Southwest, however, are partially contradictory and may have higher uncertainty due to a limited replication of studies.

2.4. Indigenous communities. Within this study area, there are 49 federally recognized tribes that inhabit reservation lands. In the Colorado River region, reservations comprise nearly 43.6 million acres. In the Great Basin, reservations comprise nearly 2.1 million acres. Figure 2 illustrates the location of reservations within the study area. Table 1 lists the Indigenous communities, per their federally-recognized tribal titles, located within the Great Basin and Colorado River region.

Table 1

Indigenous Communities in the Great Basin and Colorado River Region

Great Basin Tribes	Colorado River Region Tribes
1. Confederated Tribes of the Goshute Reservation	21. Ak Chin Indian Community of Maricopa
2. Death Valley Timbi-Sha Shoshone Tribe	22. Chemehuevi Indian Tribe
3. Duckwater Shoshone Tribe	23. Cocopah Tribe
4. Ely Shoshone Tribe	24. Colorado River Indian Tribes
5. Fort McDermitt Paiute and Shoshone Tribes	25. Fort McDowell Yavapai Nation
6. Lovelock Paiute Tribe	26. Fort Mojave Indian Tribe
7. Northwestern Band of Shoshoni Nation	27. Gila River Indian Community
8. Paiute Indian Tribe of Utah (includes Cedar, Kanosh, Koosharem, Indian Peaks, and Shivwits Bands)	28. Havasupai Tribe
9. Paiute-Shoshone Tribe of Fallon	29. Hopi Tribe
10. Pyramid Lake Paiute Tribe	30. Hualapai Indian Tribe
11. Reno-Sparks Indian Colony	31. Jicarilla Apache Nation
12. Shoshone-Paiute Tribes of Duck Valley*	32. Kaibab Band of Paiute Indians
13. Skull Valley Band of Goshute Indians	33. Las Vegas Tribe of Paiute Indians
14. Summit Lake Paiute Tribe	34. Moapa Band of Paiute Indians
15. Te-Moak Tribe of Western Shoshone Indians (Includes Battle Mountain, Elko, South Fork, and Wells Bands)	35. Navajo Nation
16. Walker River Paiute Tribe	36. Pascua Yaqui Tribe
17. Washoe Tribe	37. Quechan Tribe of Fort Yuma
18. Winnemucca Indian Colony	38. Salt River Pima-Maricopa Indian Community
19. Yerington Paiute Tribe	39. San Carlos Apache Tribe
20. Yomba Shoshone Tribe	40. San Juan Southern Paiute Tribe
	41. Southern Ute Indian Tribe
	42. Tohono O'odham Nation
	43. Tonto Apache Tribe
	44. Ute Indian Tribe of Uintah and Ouray
	45. Ute Mountain Tribe
	46. White Mountain Apache Tribe
	47. Yavapai-Apache Nation
	48. Yavapai-Prescott Indian Tribe
	49. Zuni Tribe

* Note. Although the Duck Valley Reservation is situated outside the Great Basin water resource boundary, it is included here due on its close proximity to the northern boundary of the study region and its hydrologic characteristics, which align with other reservations located within the Great Basin.

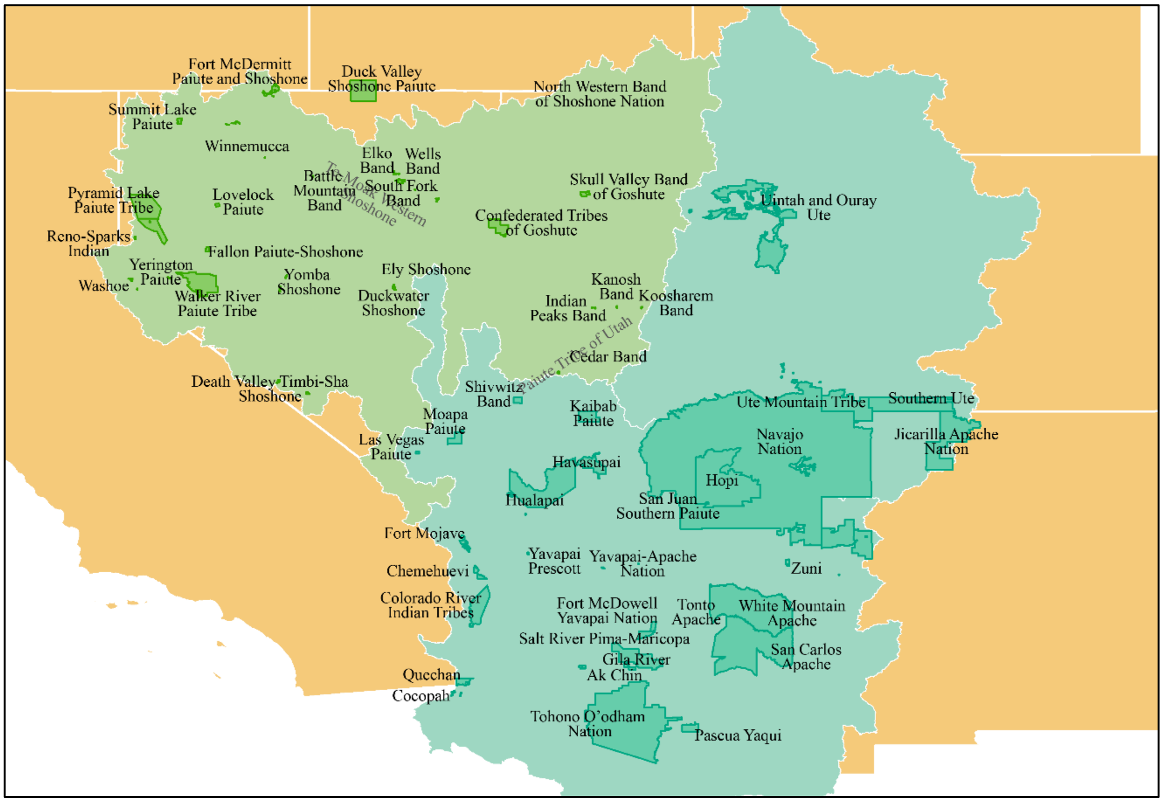


Figure 2. Federally-recognized tribal reservations in the Great Basin (light green) and Colorado River region (forest green), United States. All spatial layers are sourced from USGS geographic information systems (GIS) spatial layers for the following: government unit boundaries (including Native American Area and State or Territory) and watershed boundary dataset. These were accessed online in 2015 from an online portal that is no longer available. These layers are still available online via The National Map, a USGS interagency project (https://viewer.nationalmap.gov/advanced-viewer/). These layers were projected in ArcMAP 10 to create this figure and edited to include the names of the federally-recognized tribes whose lands are located within the Great Basin and Colorado River region.

A preliminary analysis was conducted prior to development of this thesis using secondary data from 29 of the 48 Indigenous communities located within the study region boundaries.[1] Similar to a pilot study, the purpose of this preliminary analysis was to

[1] This data analysis launched the project using the original study area boundaries of the Great Basin Desert region and featured 29 federally-recognized tribes with prominent agricultural operations. The tribes not included in this preliminary analysis either do not have significant agricultural operations, secondary data was not available for their water or agricultural operations, or were located too far away from the undefined Great Basin Desert region originally described for the larger NIFA project.

develop a land, water, and agricultural profile of the reservation communities located within the Southwest to facilitate additional and more detailed research. Secondary data collected and analyzed for each reservation land base include total reservation acreage, land acreage in agriculture, annual water rights entitlements in acre-feet per acre, and existence of pre-European agricultural practices. Appendix B provides a summary of the secondary data findings. This analysis also served to identify relationships between agriculture and the Indigenous communities situated on these reservation lands.

Twenty-four of the 29 Indigenous communities (83%) dedicate at least half of their total reservation landholdings to commercial agriculture and/or range cattle production. Of these 29 Indigenous communities, roughly a third practice traditional agriculture (see Appendix B). Traditional agriculture is defined here as any agricultural practice that pre-dates European contact in the region.

Several Indigenous communities in the region maintain important social, cultural, and spiritual relationships with their traditional agricultural practices, including the Hopi Nation's dryland farming of corn, for example (Sundjordet, 2017). These traditional agricultural practices no longer provide the sole mainstay food source for the Hopi people, but still dictate many spiritual practices that are key to the Hopi's long-established social and cultural systems. Additionally, the Hopi people's longstanding traditional corn cultivation practices have led to the identification of some of the most bio-diverse corn varieties in the world while demonstrating dryland farming techniques under scarce and variable water availability (Sundjordet, 2017). The persistence of traditional agricultural practices such as these demonstrate the ongoing influence of traditional knowledge and have contributed to significant and well-established Indigenous socio-hydrologic systems unique to reservation land bases.

At least 27 of these 29 Indigenous communities (93%) have quantified their water right entitlements, a process of negotiating a legal right to a specific annual or seasonal allocation of water. The remaining two have not yet quantified their water entitlements, and therefore do not receive an annual allotment of water regardless of availability. The uncertainty for Indigenous communities in the arid Southwest surrounding the quantification and adjudication of water right entitlements is likely to impact their capacity to adapt to future climate impacts (Colby & Orr, 2005; Cosens & Chaffin, 2016). The opportunity costs and time involved with quantifying and securing access to water rights entitlements stymies economic self-determination on reservation lands (Deol & Colby, 2018).

The Great Basin, as it is defined in this study, is home to 20 Indigenous communities (see Table 1 and Figure 2). The Great Basin is comprised of four distinct Indigenous cultures: Goshute, Paiute, Shoshone, and Washoe. Indigenous communities within these cultural groupings may share similar cultural practices, values, languages, and beliefs. This may create opportunities to facilitate the integration of traditional knowledge into climate adaptation plans that can be replicated, or expanded upon on reservations elsewhere.

Evidence of human inhabitance in the Great Basin region dates back 10,000 years (T. L. Jones et al., 1999). Considering the environmental variability that these ancient societies would have faced over this period of time suggests that resilience is inherent to the culture of these Indigenous communities (T. L. Jones et al., 1999). Due to the effects from more than a century of European colonization, however, these Indigenous communities may not have the same options for climate adaptation as in the past. Traditionally semi-nomadic hunting and gathering peoples, presently these communities are confined to reservation lands that are a fraction of the size of their original homelands.

There are 28 Indigenous communities located in the Colorado River region with the majority of them (all but four) located in the Lower Colorado River region (see Table 1 and Figure 2). In contrast to the Great Basin, Colorado River reservation land bases are larger in size with greater ecosystem diversity. The Indigenous communities are more numerous and culturally more distinct. The diversity of ecosystems and cultures in the Colorado River region make it challenging to summarize the impacts of climate change on these communities at the regional level. Indigenous communities depend on healthy ecosystems not only for sustenance purposes and their cultural relevance and value, but also for economic enterprises key to their survival and quality of life (Tiller, 2015).

2.5. Key federal Indian land policies. In the formation and ratification of the U.S. Constitution (1787), the U.S. government explicitly acknowledges that it has a responsibility to engage with tribes as independent Indian Nations (art. I, § 8). The U.S. government used this written right to acquire Indigenous traditional homelands through war and/or the creation of treaties with Indian Nations.

These early interactions between the U.S. government and Indian Nations demonstrated government-to-government relations. The sovereign status of Indian Nations shifted, however, following three pivotal U.S. Supreme Court decisions known as the “Marshall Trilogy,” after U.S. Supreme Court Chief Justice John Marshall. The

Marshall Trilogy maintains that only the U.S. government has the right to purchase lands from Indian Nations (Johnson v. M'Intosh, 1823); that Indian Nations are indeed sovereign entities (Worcestor v. Virginia, 1832); but that while sovereign entities, Indian Nations remain domestic dependents of the U.S. government (Cherokee Nation v. Virginia, 1831). These court decisions collectively set a precedent for all federal policies regarding Indian Nations that followed.

The Indian Removal Act of 1830, in combination with the Indian Appropriation Act of 1851, were enacted to set aside, or reserve, unsettled lands west of the Mississippi River for Indian Nations to occupy. This led to the reservation lands system still in place today. These legislative acts were ratified prior to the U.S. government's knowledge of the monetary value of the mineral resources that lie underneath much of these reserved lands.

In 1887, the U.S. government (i.e., federal government) enacted the General Allotment Act, also known as the Dawes Severalty Act for its author Senator Henry Dawes of Massachusetts. This legislation sought to assimilate Indigenous people into European culture by breaking up communal land holding systems and requiring that reservation lands, held in trust by the federal government, be owned and farmed by individual Indigenous heads of household. The General Allotment Act maintained that every head of household be allotted a 160-acre parcel. However, in reality, the size of land allotments varied by reservation, ranging from as small as 10 to 20 acres on smaller land bases to as large as 320 acres on larger land bases (Banner, 2005). Once reservation lands were allotted to individuals who had voluntarily registered with the U.S. Indian Census, also known as the Dawes Rolls, the federal government auctioned the remaining lands to non-Native settlers (Prucha, 1984; Pevar, 2012; Singletary et al., 2014). Allotted land parcels remained in trust status for 25 years; afterwards, much of these lands were converted to fee-simple status and ultimately taxed, sold, and in some cases stolen (Banner, 2005; Singletary et al., 2014).

The General Allotment Act proved disastrous for Indian Nations. The ultimate effect of the General Allotment Act was a dramatic reduction in Indian land holdings. In 1881, Indian nations held nearly 156 million acres. By 1900, Indian nations held half that amount, or only 78 million, with 5.4 million of those acres allotted (Prucha, 1984). Others maintain that of the 138 million acres of reservation lands that existed at the beginning of the allotment period, only one third, or 48 million acres, of these trust lands remained available to Indigenous communities by the end of the allotment period (Indian Land Tenure Foundation, 2006).

The majority of Indigenous communities living on trust and/or allotted reservation lands across the United States were forced into highly impoverished living conditions. Dramatic increases in rates of disease, starvation, and death in these communities led to the passage of the Indian Reorganization Act in 1934. The purpose of this legislation, enacted during the New Deal era, was to rectify some of the negative impacts resulting from previous federal Indian policies. The Indian Reorganization Act served to ratify Indian Nations as “federally-recognized tribes.” To receive federal recognition Indian Nations were required to organize a procedure for tribal governance and to develop and ratify constitutions to guide tribal governance. The legislation also established a procedure for which tribes could place any acquired lands into trust status with the federal government (Indian Reorganization Act, 1934).

These key federal Indian policies, have resulted in highly fractionated land bases and a lack of clear property rights institutions that continue to impact land and water use on reservation and traditional homelands today (Singletary et al., 2016). While tribal governments have the authority to manage their reservation land base, the complexities of overlapping federal, state, and county jurisdictions and traditional land-use customs can delay crucial resource management decisions. For this reason, tribally owned lands held in federal trust status may present greater obstacles to achieving sustainable resource management and can potentially derail the sustainable practices on remaining individual Indian trust allotments, land assignments, or land leases (Singletary et al, 2014; Russ & Stratmann, 2016; Anderson & Parker, 2008).

2.6. Key policies affecting reservation water resources. Due to the semi-sovereign status of Indian Nations, tribal governments and their legislative decisions are generally exempt from state legislative oversight. However, the federal government authorizes state legislatures to define and administer state water law and to oversee the management of water resources within state jurisdictional boundaries. This significantly affects Indigenous communities' access to and management of water resources for reservation lands. For example, while Prior Appropriation water entitlements may be adjudicated in federal courts, quantifying water entitlements generally occurs in state courts, and annual allocations are managed at the state level (Greetham, 2018).

In the arid Southwest, both surface water and groundwater rights entitlements impact nearly all aspects of rural economies (Chief et al., 2016; Cozzetto et al., 2013). Water access as well as hydrologic and adjudicated water availability often limit both Indigenous traditional practices and emergent economic development needs such as agriculture to ensure food security (MacDonald, 2010). Planning for the future of Indigenous communities on reservations in the context of climate change, therefore, also requires a thorough understanding of state water law. Jurisdictional reservation boundaries and state boundaries, in addition to watershed boundaries each merit important considerations in assessing climate impacts on water resources in the Southwest.

When the first water policies were drafted in the western United States, it was thought that local evaporation drove local precipitation, so legislation was put into place with the belief that placing farmers on the landscape was enough to permanently eradicate aridity and change the climate for the better (Limerick, 2001; Reisner, 1986; Thompson, 1999). Lack of knowledge about the climate of this region led to the establishment of static water management regimes still in place today.

The foundational principle in western water law is Prior Appropriation Doctrine, which prioritizes water allocation based on the year a claim to the resource was established (Thompson 1999). Prior Appropriation Doctrine was established initially to support beneficial usage of water resources, which in those times were primarily mining followed by irrigated agriculture (Walston, 1989). Water rights were allocated based on "first in time, first in right" (Drozdoff et al., 2015; Pisani, 1992). Beneficial use is key to this allocation mechanism and is based on the amount of water needed for a particular applied use, rather than the amount of water present in a system (Tarlock, 2001). Thus, Prior Appropriation Doctrine allocated to individuals the right to divert a set maximum amount of water (water duty) based upon their agricultural irrigation needs. A key feature of Prior Appropriation Doctrine is the principle of "use it or lose it," which encourages water rights holders to use fully and consistently their water right entitlement on an annual basis rather than risk losing their water entitlement due to non-use (Tarlock, 2001).

Water scarcity in the Southwest has led to significant water right litigation over time. For Indigenous communities, a 1908 U.S. Supreme Court decision (Winters v. United States, 1908), resulting in the Winters Doctrine, has been key to adjudicating and quantifying water rights entitlements specific to reservation lands. The Winters Doctrine maintains that when lands were set aside for reservations, and under the General Allotment Act, irrigable acreage inherently requires and maintains water rights to those lands (Winters v. United States, 1908; Pevar, 2012). Key to the Winters Doctrine is that the priority date of water right entitlement for reservation lands is the year in which the reservation was established by treaty or executive order (Winters v. United States, 1908; Pevar, 2012). For some river basins in the Southwest, Winters Doctrine entitles reservation lands to some of the earliest water right priority dates established. Yet, while the Winters Doctrine provides for the establishment of water rights on reservation lands, to date few Indigenous communities have reached settlement agreements in order to quantify and receive their full water entitlements (Greetham, 2018).

2.7. Traditional knowledge. Increasingly, scientists have expressed interest in better understanding the role of traditional knowledge in informing landscape management decisions, both on and off reservation lands. Traditional knowledge may become paramount in understanding historical ecological health and the interactions between traditional land-use practices and species development (Von Heland & Folke, 2014). The role of traditional knowledge in climate change adaption may be limited, however, because such knowledge is constrained to observations of prior weather and climate patterns (Gilles, Thomas, Valdivia, & Yucra, 2013; Granderson, 2017; Okumura, 2018). That is, traditional knowledge is typically considered a place-based accumulation of individual and collective experiences over generations (Berkes et al., 2000). Given that climate projections are unprecedented in human experiences, the ability to apply traditional knowledge in adapting to future climate scenarios may be limited (Okumura, 2018).

To overcome these limitations, many Indigenous communities have found success in merging traditional knowledge with western climate science, per the European science tradition, to enhance climate adaptation efforts (Fernald et al., 2015; Granderson, 2017; Ignatowski & Rosales, 2013; Pacheco-Cobos, Rosetti, Esquivel, & Hudson, 2015; Robitaille et al., 2017; Tendeng, Asselin, & Imbeau, 2016; Vernooy et al., 2017). Furthermore, the integration of traditional knowledge may be a valuable method for overcoming limitations of coarse climate data and challenges associated with applying scientific methodologies that contrast the cultural values of Indigenous communities (Cozzetto et al., 2013; Fillmore, 2017; Smith et al., 2014; Tengo et al., 2017). While Indigenous communities and outside researchers may assume that traditional knowledge is in direct conflict with western science, some studies suggest that traditional knowledge can uphold and reaffirm western climate science findings (Mason et al., 2012; Ranco et al., 2012). Because of the outcomes of these studies, researchers and natural resource managers are looking to engage Indigenous traditional knowledge-holders to provide local-scale climate information to better identify potential adaptations that cannot be captured by coarse-scale climate models (Fernald et al., 2015; Granderson, 2017; Maldonado et al., 2016).

Weaving traditional knowledge into climate adaptation planning processes on reservation lands ensures community accepted and culturally appropriate results that can be implemented more readily (McGregor, 2012). Traditional knowledge can also inform practical community adaptation options and community-based monitoring of future climate change impacts (Riedlinger & Berkes, 2001). Both strategies are necessary to climate adaptation planning efforts in general. Considering the ongoing politicization of and resistance to credible scientific studies that indicate humans have a role in contributing to climate processes, it is important to find meaningful ways to engage the public. On reservation lands, engaging community members to incorporate traditional knowledge and to co-produce hydrologic and climate science information can enhance public acceptance while also help to validate model projections (Fillmore, 2017).

The types of traditional knowledge that have particular applications beneficial to climate adaptation planning on reservation lands are: (a) traditional Indigenous land-use practices that contribute to or sustain ecological health; (b) individual and collective experience with past climate events and adaptation practices that contribute to the continued resilience of Indigenous people over time; and (c) cultural relationships that demonstrate awareness of and responsibility for the inter-dependence between natural and human systems to promote adaptation (Granderson, 2017; Ignatowski & Rosales, 2013; Klenk et al., 2017; Lemelin et al., 2010; Maldonado et al., 2016; Murphy, 2011; Vernooy et al., 2017; Williams & Hardison, 2013). Some traditional knowledge requires special protections and cannot be shared outside Indigenous communities. This includes the sharing of sensitive knowledge with either researchers or the general public. In investigating the role of traditional knowledge in climate adaptation, researchers must work diligently to protect sensitive information, which warrants prior and informed consent from research participants (Klenk et al., 2017; Savaresi, 2018; Williams & Hardison, 2013).

The impact of climate change on Indigenous communities in the Southwest is an understudied topic, but interdisciplinary and participatory research involving local decision-makers may help overcome barriers associated with a lack of foundational studies (Meadow et al., 2015). Incomplete continuous baseline data at applicable spatial and temporal scales may be a significant factor considering the limited dispersal of climate monitoring equipment across rural areas of this region. Appendix C shows the location of USGS hydrologic monitoring equipment stations within the study region. The lack of monitoring equipment in rural areas can be partially attributed to low population density. Much of the climate monitoring equipment that exist are concentrated in urban areas where the larger populations are located (see Appendix C). Reservations within this region, however, are located primarily in rural counties, with only a few located in urban counties.

Efforts are underway to expand climate monitoring equipment regionally. For example, the Nevada Climate-Ecohydrology Assessment Network (NevCAN), established in 2008, has installed two transecting stations to provide a permanent monitoring system in the Great Basin (Mensing et al., 2013). While improved regional climate data monitoring can reduce uncertainty when quantifying climatic change and associated impacts, another set of metrics unique to this rural region that may be employed involves local knowledge (Cozzetto et al., 2013). Individuals living within a specific area over a significant period of time have the capacity to identify local weather and climate patterns, which can inform climate data, baseline benchmarks, and trends, and can contribute to climate adaptation planning and action (Berkes et al., 2000; Cozzetto et al., 2013; Granderson, 2017; Ignatowski & Rosales, 2013; Lemelin et al., 2010).

Chapter 3

3.0. Methods

3.1. Research design. This study employs a participatory action research design. This research design, often referred to simply as participatory research, embodies a set of methodologies intended to engage research participants as research collaborators in meaningful ways. Such methodologies aim to collect information directly from participants, and may typically include face-to-face semi-structured interviews, in-person structured surveys, and focus groups. The methodologies and the participatory research design aim to empower research participants to act locally through their direct involvement in scientific inquiry that harnesses their perspectives and knowledge (Datta et al., 2015). Their participation ensures that research outcomes are directly applicable and useful to the participants in informing community-based decisions (Blodgett et al., 2011).

Indigenous communities are expert witnesses to the challenges and opportunities related to climate adaptation on reservation lands. In this context, participatory research is designed to engage Indigenous community stakeholders in an environment of reciprocity to ensure the co-production of new knowledge. This requires that these stakeholders inform the research agenda, questions, and methodologies, and that research findings are shared with participants regularly and in a format that emphasizes transparency, respects local culture and knowledge, and improves research accountability (Benham & Daniell, 2016; Datta et al., 2015; Glass et al., 2018). When participatory research principles and practices are followed consistently, it can enhance the capacity of scientific inquiry to meet the needs of community stakeholders in pursuit of climate adaptation (Singletary & Sterle, 2017; Singletary & Sterle, 2018; Campos et al., 2016).

Assessing the climate data and information needs of Indigenous communities requires that primary data be collected from individuals interested and/or involved in climate adaptation planning and efforts on reservation lands. These individuals are key research participants considering they are not only familiar with the types of climate data and information that is already accessible, but are also familiar with the challenges impacting adaptation efforts. The perspectives of broader community members can help to elucidate climate change processes and impacts on reservation lands while identifying adaptation opportunities and barriers (Chief et al., 2016; Maldonado et al., 2016). These insights are crucial when assessing climate impacts, and adaptation opportunities for communities. This research specifically assesses the data and information needs of key research participants as self-identified through their participation in annual tribal climate summits.

3.2. Survey instrument. The challenge associated with primary data collection in the context of participatory research is to identify a set of questions that effectively capture the information sought. To implement the principles and practices of participatory research, the question items developed for this survey were based in part on informal observations of information exchange during facilitated small group discussions held at the first (2015) Native Waters on Arid Lands Tribal Leadership Summit held in Las Vegas, Nevada. Sponsored and organized by the USDA-NIFA grant funded research and outreach team for this project, the summit was attended by approximately 85 individuals in the first year. The majority of attendees represented natural resource management and leadership of federally-recognized tribes across the Southwest; therefore, they reasonably represent the key research participants necessary to achieve research goals.

The topics that summit attendees cited most frequently as information or knowledge gaps were noted and used to begin formulating question items related to general climate data and information needs. This approach supported the development of a first draft of survey question items intended to be meaningful and relevant to the targeted sample population for this study.

Additional information topics were determined from a literary analysis of climate adaption planning frameworks adopted on reservation lands.[2] This included information particular to the climate vulnerability assessment guidelines, available through the U.S. Climate Resilience program's Tribal Climate Change Adaptation Planning Toolkit. Developed by the Institute for Tribal Environmental Professionals, the toolkit was developed to provide tribes with resources to assist in the climate change adaptation planning process, and resources are available online through Northern Arizona University.

Survey question items developed were then cross-referenced with existing research literature related to climate adaptation planning, and climate impacts on water resources specific to Indigenous communities on reservation lands (Chief et al., 2016;

[2] The majority of tribal climate adaptation plans follow prescribed guidance as outlined in the Tribal Climate Change Guide (University of Oregon, 2015). Tribal adaptation plans are funded through competitive grants provided by the U.S. Bureau of Indian Affairs Climate Change Program. Adaptation plans and vulnerability assessments completed to date are accessible online at: https://tribalclimateguide.uoregon.edu/adaptation-plans.

Maldonado et al., 2016; T. M. B. Bennett et al., 2014; Chief, Daigle, Lynn, & Whyte, 2014; Cochran et al., 2013; Cozzetto et al., 2013; Gautam et al., 2013). Survey question items were also cross-referenced with information related to climate change impacts as reported in the Third National Climate Assessment (see Chapters 2, 3 and 10) and impacts specific to Indigenous peoples (see Chapter 12) (T. M. B. Bennett et al., 2014).

An interdisciplinary panel of four faculty members with expertise in hydrologic science, climate science, agricultural and applied economics, and survey design, reviewed drafts of the survey instrument. In addition to academic expertise, this panel of faculty also included decades of outreach experience working with tribal governments and communities to address various issues pertaining to water use and management on reservation lands. The purpose of these reviews was to improve the readability and clarity of question items and to identify any missing question item content. Question items were revised based on the feedback received from these reviews.

The final survey instrument was tested with a random sample of five Indigenous community representatives who were familiar with the study objectives. These individuals were eliminated from the survey sample. The test indicated that the survey instrument performed effectively in that all questions were completed, no indication of survey error was noted, and no further revisions to the instrument were necessary.

Appendix E features a detailed explanation of rationale for each question item. Survey question items are intended to assess needs pertaining to climate and water management information, weather and hydrologic data types, and additional sources of information potentially useful to climate adaptation planning initiatives specific to reservation lands. These include items pertaining to climate and environmental data types and information resources primarily used by land and water managers in daily and longer term observations of patterns related to weather, climate, and water availability on reservation lands. Such information is important to routine resource management decisions.

While specific data types for water, climate, and environmental data and information may vary by individual use, the items featured in the survey instrument are verified as publicly available, and are key for conducting climate assessments and informing adaptation initiatives. For example, a key data type for water managers is streamflow, which may be accessible online from the USGS. Additional data sources include tribal governmental resources and potentially non-profit, private and/or corporate resources.

3.2.1. Part I. Part I of the survey includes 23 questions (see Appendix D). Survey questions 1-20 are intended to identify and prioritize information necessary for tribal communities to adapt to and plan for climate uncertainty. Each question provides an equal-weighted Likert-type rating scale of “1” indicating “very low priority,” “2” indicating “low priority,” “3” indicating “neutral” priority, “4” indicating “high priority,” and a “5” indicating “very high priority.” For twenty closed-ended question items, the question stem is: “To adapt to and plan for climate uncertainty, tribal communities need information about…”

Survey questions 1-12 identify and prioritize information needs, and/or topics that can support climate adaptation on reservation lands (Chief et al., 2016; Maldonado et al., 2016; T. M. B. Bennett et al., 2014; Chief et al., 2014; Cochran et al., 2013; Cozzetto et al., 2013; Gautam et al., 2013). The twelve question endings are: (1) how to conduct a climate resiliency assessment; (2) climate change impacts on tribal lands, water, and economies; (3) enhancing tribal food security and sovereignty; (4) adaption strategies unique to tribal lands; (5) incorporating traditional knowledge in adaptation planning for tribal lands; (6) how to protect traditional knowledge used in adaptation; (7) examples of other tribes' climate adaptation plans; (8) how to finance implementation of climate adaptation plans; (9) meaning of future climate projections for individual reservations; (10) selecting equipment to monitor/collect data to inform tribal climate adaptation; (11) how to finance monitoring/data collection on tribal lands; and (12) training tribal employees to ensure consistent data monitoring and collection on tribal lands.

Because this is a regional analysis spanning multiple states, these topics were intentionally developed without specific climate impact indicators. That is, topics referencing specific climate impacts such as "drought" or "flood" or "precipitation" were omitted from this survey. This regional assessment was not developed to bypass tribal governmental approval or meaningful engagement with Indigenous communities. Rather, it was developed to help inform and enhance those efforts by assessing stakeholder needs. Results allow both outside researchers and Indigenous partners to have a better understanding of each other's prioritized climate data and information needs.

Survey questions 13 – 18 are to identify and prioritize specific types of climate data necessary to support adaptation and land-use management. These data are considered standard components of analyses to determine regional climate characteristics and hydrological systems at local and regional scales. The question stem is the same as the set of questions discussed above, and the question endings are: (13) precipitation data; (14) temperature data; (15) streamflow data; (16) soil moisture data; (17) snowpack data;

and (18) water quality data. Each question specifies preferred frequency of data collection/observation (e.g., daily, weekly, monthly) for each data type. Data types featured include: precipitation, temperature, streamflow, soil moisture, snowpack, and water quality.

Survey questions 19 and 20 are designed to assess data accessibility by gaging preference for raw data (19) as compared to generalized reports and/or summaries of data (20). That is, for example, the USGS provides public access to a variety of raw streamflow data. Individuals who wish to utilize these data must possess the capacity to interpret and analyze these data to inform decisions in the field. Such publicly available data remains “inaccessible” when training and experience are required to use the data effectively. When compared side by side, these questions help provide insight into more effective distribution of limited resources. That is, if a particular demographic of stakeholders is more likely to prioritize climate summaries over raw data, it might be more advantageous to direct limited resources towards analyzing and summarizing raw climate data rather than towards installing and maintaining climate and weather monitoring equipment.

Survey question 21 is intended to measure “willingness to pay” for climate adaptation as indicated by a percentage of employer annual operating budget allocation. This question also measures respondents’ perceptions of how “climate adaptation” fits into their individual job priorities. Survey questions 22-23 are intended to assess the occupational role of research participants in climate adaptation efforts on reservation lands. Data from these demographic questions are used in cross-correlative analyses.

3.2.2. Part II. Survey questions 24-36 in Part II of the survey ask participants to rate the frequency, using an equal-weighted Likert-type scale, in which they access sources of information in climate adaptation planning information from the sources listed. Each closed-ended question provides a Likert-type scale rating of "1" which indicates this resource is "never accessed," "2" indicates "rarely accessed, "3" indicates "occasionally accessed," "4" indicates "often accessed," and a "5" indicates "very often accessed." The stem for these 13 question items is, "In climate adaptation planning, we are currently using information provided by…" Question endings are: (24) tribal farmers and ranchers; (25) tribal oral histories; (26) traditional knowledge holders; (27) tribal natural resource/water/land departments; (28) tribally owned and operated monitoring equipment; (29) tribal colleges and universities; (30) other colleges and universities; (31) the Weather channel, Weather.com, or local news and radio; (32) National Oceanic Atmospheric Administration (NOAA); National Weather Service; SRCS Snotel; (33) USDA Climate Hubs; (34) USGS stream gages; (35) Bureau of Indian Affairs climate planning programs; and (36) Native Waters on Arid Lands annual tribal summits. Survey question 37 asks respondents to provide other information not included in this list. This question is included to ensure that other sources of climate information not identified for this survey could also be identified.

Responses to these questions can help identify ways in which tribes may target the improvement of access to these information sources to support increased the use of focused climate data and information for adaptation. For example, tribal farmers and ranchers can be a strategic source of local climate information. For tribes who practice traditional agriculture, these individuals may also hold traditional knowledge that may inform and/or support climate adaptation. Successful agricultural and ranching operations depend on knowledge of local climate trends as well as seasonal and annual variability. Some producers may also have private weather monitoring equipment to help inform their individual practices, and thus have monitoring data not available to the public.

Similarly, tribal oral histories, which include local knowledge, can inform and/or support adaption. Individuals informally transfer this information, usually in oral form, and it is relatively easy to obtain by Indigenous community members. Many cite conversations over morning coffee as opportunities for learning and sharing. While such information may not be formally documented, it remains readily used. The usefulness of this knowledge to inform decision-making processes, however, varies among Indigenous communities. It is imperative that adaptation efforts recognize local protocols for integrating traditional knowledge within adaptation frameworks.

Traditional knowledge remains an important component of climate adaptation planning on reservation lands (Berkes et al., 2000; Granderson, 2017; Ignatowski & Rosales, 2013; Pacheco-Cobos et al., 2015; Robitaille et al., 2017; Vernooy et al., 2017). The use of the term, “traditional knowledge holders,” rather than “elders,” acknowledges that in Indigenous communities there are and have always been multiple generations of individuals who hold and transfer traditional knowledge. Knowledge held by such individuals, although valued, may not always be shared with others. Established protocol governs how traditional knowledge can be shared and used at the individual, community, and societal level. This may make this particular source of information inaccessible to the majority of individuals involved with climate adaptation on reservation lands. For this source of information to be included in adaptation planning initiatives, careful attention must be given to protecting such sensitive information to prevent misappropriation (Savaresi, 2018).

Survey questions 27-30 assess the use of information sourced from institutions and include tribal governmental departments, tribal monitoring equipment, tribal colleges and universities, and other colleges and universities. Survey questions 31-34 are information sources that may be used in adaptation planning by both Indigenous and non-Indigenous populations.

In contrast, survey questions 35 and 36 are information sources that target Indigenous populations at the national scale. The U.S. Bureau of Indian Affairs climate program (35), for example, offers funding to tribes to support tribal resiliency efforts and planning projects. Such awards can provide a significant source of support for tribal climate adaptation planning efforts. Furthermore, because Indigenous communities have a direct connection to the Bureau of Indian Affairs relative to other federal agencies, these programs may be tailored to assist with the diverse adaptation and resiliency needs of reservation communities. Survey question 36 assesses the value of the Native Waters on Arid Lands Tribal Leadership Summits. In retrospect, expanding this question to include, "or similar conferences/summits" would offer more useful information.

Survey question 38 identifies respondents' use of climate information/data in their work. An individual's interest in climate resiliency on tribal lands may or may not be related to their professional background. Members of Indigenous communities often serve their communities in a multitude of capacities. For example, while someone may work for their tribal government, they may also farm; however, their priorities for climate change resiliency might focus on empowering youth on their reservation to have the tools to consider and develop community solutions to climate impacts. Survey question 39 assesses the most convenient and effective method of data and information dissemination for the various stakeholders represented by the target population. The items listed encompass primary means of public information consumption. “Other” is included in both of these questions as an option to allow participants to identify responses items that may have been overlooked.

Survey question 40 provides an open-ended question to invite respondents to identify “what is needed most to support climate adaptation on tribal lands.” Including this question ensures respondents have an opportunity to provide information that may have been overlooked in the development of the survey. Responses to this question will be grouped into a specific number of categories and cross-analyzed with demographic/background questions.

Survey question 41 assesses the perceived level of risk that climate uncertainty poses to tribal resources and communities, using an equal-weighted Likert-type scale. A rating of “1” indicates “no risk,” “2” indicates “minor risk,” “3” indicates “neutral,” “4” indicates “major risk,” and a “5” indicates “extreme risk.” This question asks specifically about “climate uncertainty” rather than “climate change impacts,” as this study is focused on assessing gaps in climate data and information needs (See Appendix D).

Similarly, survey question 42 asks participants to consider the issue of climate uncertainty by asking them about which resource concerns them most. The choices provided stem from literature related to climate resiliency planning on tribal lands (Cozzetto et al., 2013). Although related, water quantity and water quality are listed as separate items because their values to stakeholders may be different. Aquatic and terrestrial ecosystems are also listed separately because they may also hold separate value. For example, some tribes may relate their personal and cultural resiliency to the resiliency of their aquatic habitats while terrestrial habitats may be considered differently. Tribal agriculture is included because of its significant relationship to climate, and because of the emphasis on ensuring food security and/or food sovereignty on reservation lands (Fernald et al., 2015). While Human survival on tribal lands may not seem like an impact that people are concerned about in relation to climate change to the general public, Indigenous communities consider future generations when they discuss their values and decision-making processes. Furthermore, many, if not all, of these reservations are already located in extreme climates where basic resources – such as access to potable water – are scarce. These reasonable issues warrant including human survival as being potentially impacted by climate uncertainty.

3.2.3. Part III. Part III of the survey instrument includes questions about demographic information and pertinent attributes unique to reservation lands that are related to climate adaptation. Survey questions 43-44 identify state and reservation of residence and/or employment. Survey questions 45 identifies numbers of years lived or working on reservation lands and survey question 46 asks respondents to describe their reservation's primary land tenure types (e.g., assigned trust; allotted trust/fee simple; assigned/allotted trust; fee simple; allotted trust; public domain allotted trust; and other). Survey questions 49 and 50 ask respondents to indicate their gender and highest level of education completed, respectively. These question items will be used test for relationships between demographic characteristics and responses to survey question items. Many of these questions will be grouped and coded for cross-correlation analyses, which will be discussed in more detail in the Results section of this thesis.

3.3. Target population. To inform land and water management decisions, Indigenous communities access multiple and diverse forms of local and traditional knowledge as well as western science (T. M. B. Bennett et al., 2014; Chief et al., 2014; Cochran et al., 2013). Community members who hold this knowledge may include but are not limited to elders, traditional knowledge holders, local knowledge holders, local and tribal land and water management professionals, tribal governmental leaders/official, federal land and water management agencies, tribal colleges and universities, state universities, and private environmental consultants (Cozzetto et al., 2013; Gautam et al., 2013; Kalafatis et al., 2015: Lacey, Howde, Cvitanovic, & Dowd, 2015).

While it is important to consider the entire population of Indigenous communities in assessing climate impacts, this study necessitates a purposeful sampling strategy that targets individuals who demonstrate an interest or professional role in climate adaptation on reservation lands (Gautam et al., 2013; Fowler, 2014). A purposeful sample is necessary to assess data and information needs specific to Indigenous communities. This is particularly appropriate for this analysis given the unique land tenure and water right challenges related to federally-recognized reservation lands as compared to non-tribal lands.

The purposeful sample population in this case is comprised entirely of individuals who self-selected to attend annual tribal summits to learn more about climate projections and adaptation strategies on reservation lands. These individuals are, for the most part, already engaged or interested in becoming engaged in adaptation initiatives on reservation lands. Thus, the survey respondents already possess some awareness and rudimentary understanding of the complexities of climate adaptation on reservation lands and insight into specific data and information needs that are lacking in current initiatives. If our target sample population were extracted from the general population living on reservation lands, the survey questions would need to be revised accordingly.

3.3.1. Survey sample. Accessing the target research participant population for this study is extremely challenging. If the intent behind this study were to conduct a more in-depth analysis of data and information needs for individual reservation communities as a whole, it would warrant contacting each tribal government to request permission to develop and conduct a survey with the communities located within reservation land boundaries. Instead, this study seeks to assess the data and information needs of individual land and water managers, agriculturalists, scientists, and other pertinent stakeholders engaged in climate adaptation planning and action on reservation lands. This limits to some extent the causational relationships and conclusions that can be infered from data analyses by limiting relationships to individual respondent attributes rather than inferences to causation by a tribal entity. This process and limitation will be addressed in greater detail in the Results section.

Because our target research participant population comprises individuals directly engaged or interested in being engaged in climate adaptation on reservation lands, and because these individuals are difficult to identify, locate, and recruit for participation, the survey was implemented during the second (2016) and third (2017) Native Waters on Arid Lands (NWAL) Tribal Leadership Summit. These summits are organized by land-grant university extension outreach professionals with decades of experience working with Indigenous communities in the Great Basin and southwestern U.S. This pragmatic expertise ensures that Indigenous communities within the study area were recruited to participate in the summit. Furthermore, the summits attract participants who are in some way engaged or interested in climate adaptation on reservation lands. The annual summits feature experts on climate adaptation who are invited to address diverse topics and issues that indigenous communities face due to climate change. The summit format ensures that summit attendees, and thus recruited survey participants, have some knowledge of the topics included in the survey. This is paramount to the success of this assessment given the specific questions asked.

3.3.2. Survey recruitment and administration. This survey was administered over a period of two consecutive years (2016-2017) during plenary summit sessions that included attendees of the Native Waters Annual Tribal Climate Leadership Summit. To recruit survey participants, and to ensure prior and informed consent for participation, summit attendees received a brief overview of the study during plenary summit sessions. An oral presentation was delivered, using Power Point, that included a review and explanation of the purpose for the data and information assessment, question item content, and an explanation of questions that featured a Likert-type scale and a definition of scores provided (e.g. 1 = Very Low Priority and 5 = Very High Priority). Participants were also encouraged to contribute additional comments in writing as prompted and in space provided on the survey instrument.

The presentation was designed to clarify the purpose of the survey and to mitigate the potential for survey error due to participants' misinterpretation of written instructions. Participants were instructed to omit from the questionnaire any personal identifying information. Survey administrators were available during this time to answer any clarifying questions.

To ensure confidentiality, survey administrators collected the completed questionnaires and immediately placed the documents in an envelope and sealed the envelope. This administrative protocol was reviewed and approved by the University of Nevada, Reno Office of Research Integrity and Internal Review Board.

Chapter 4

4.0. Results and Discussion

The purpose of this thesis is to analyze the climate data and information needs of Indigenous communities on reservation lands in the Southwest. The survey designed to assess this information, as described and administered in Chapter 3, yields data that require multi-step analyses in order to obtain meaningful results useful to adaptation initiatives. This chapter presents an overview of these analyses and summarizes and discusses the results from each analytical step.

4.1. Analytical tools and survey instrumentation. Collected survey data were analyzed using IBM Statistical Package for Social Sciences (SPSS) Version 24.0, Microsoft Excel Version 14.7.3, and ArcMap version 10. Appendix F presents a summary of the frequency count for responses to each survey question item.

Cronbach's coefficient alpha (CCA) was used to estimate internal consistency of the 33 Likert-type scale question items developed to assess climate information and data needs and access. The CCA score was high for each of the three sections (totaling 33 question items). For survey questions 1-12 (climate information needs), $r = 0.897$; for survey questions 13-20 (climate data types), $r = 0.921$, and for survey questions 24-36 (climate information sources), $r = 0.86$. These scores indicate high internal consistency, or reliability, among the question items (Carmines & Zeller, 1979).

4.2. Survey respondents. A total of 98 completed survey questionnaires serve as the data sources for the study. Given the noted difficulty in survey sampling and recruitment with our target research participant population - individuals involved in climate adaptation efforts on reservation lands - the purposeful sampling strategy, as employed here, appears effective (Sandefur, Rindfuss, & Cohen, 1996). Additionally, contemporary climate adaptation initiatives on reservation lands often involve multiple agencies, institutions, departments, and stakeholders, and these initiatives are very recent. This makes it nearly impossible to estimate the total population, or the percentage of total individuals that belong to each stakeholder group involved in these initiatives. Estimating a response rate of our survey population in relation to our target population is not possible for this study. The surveyed population, however, is reasonably representative of the target population given that it includes professionals from multiple universities, federal agencies, and tribes within our study area (Dillman, 1978; Fowler, 2014). Limitations related to this study are discussed in Chapter 5 (see pages 122-123) of this thesis.

The majority of survey respondents (n=85) lives and/or works in the Great Basin (45%) and Colorado River region (39%) region study area, with 16% of respondents representing other locations. Also, the majority of respondents (84%, n = 85) represent the watersheds that comprise the study area (e.g., Great Basin (45%), Lower Colorado, (21%), Upper Colorado (18%)). Approximately 8% of respondents represent watersheds also in arid lands that include Missouri (6%), Pacific Northwest (3%), and Rio Grande (2%).

A majority of respondents live/work in Nevada and in Arizona, states which largely fall within the study area boundaries. The remaining respondents mainly reside/work in states adjacent to and partly located within the study area boundaries and include 6% in New Mexico, 4% in Utah, 3% in Idaho, and 2% in California.

Approximately 7% live/work in Montana and 1% in Washington, both states include significant arid reservation lands. Only 6% of the survey respondents represent states outside the study area (Wisconsin, Ohio, and Georgia) but are involved in work on reservation lands.

To summarize, the majority of respondents are engaged in climate adaptation within the designated study area. This outcome ensures that the overall results reported here are representative of the larger population of individuals engaged in climate adaptation on reservation lands in the study area.

Additional respondent attributes are characterized by a majority of respondents self-reporting as: Native American (72%, n = 71); male (70%, n = 69); 45 years of age or older (61%, n = 60); having post-secondary education (83%, n = 81), and; 55% specifically holding bachelor or graduate degrees (n = 54). Approximately 87% of respondents live on reservations (n = 85), with 23% having lived on reservations for 30 years or less (n = 23) and 52% (n = 51) for more than 31 years. Approximately 61% of respondents (n = 60) use climate science information/data in tribal agriculture, natural resource management, tribal college/university education, tribal government, or to teach tribal youth. Nearly half (43%, n = 42) of respondents self-reported as working for tribal governments.

Finally, when asked to rate the level of risk that climate uncertainty poses to tribal natural resources and communities, using a Likert-type scale where 1 = none, 2 = minor, 3 = neutral, 4 = major, and 5 = extreme risk, the majority of respondents indicated that climate uncertainty poses either major (56%, n = 53) or extreme (29%, n = 28) risks. Of the 75 respondents who answered the survey question, “what are the most challenging issues that climate uncertainty poses to tribal resources and communities," 36 indicated water resources in general on tribal lands, followed more specifically by tribal agriculture (11), human survival (9), tribal economic well-being (5), wildlife habitat (5), water quality impairment (3), and tribal fisheries (3).

4.3. Climate information and data priorities. Basic descriptive statistics are used to analyze and prioritize respondents' climate data and information needs. Specifically, the following analysis answers the research question: What types of climate information and data are perceived as necessary to survey respondents to inform climate adaptation planning initiatives on reservation lands? Figure 3 presents a flowchart depicting an overview of the methods used to obtain this prioritization.

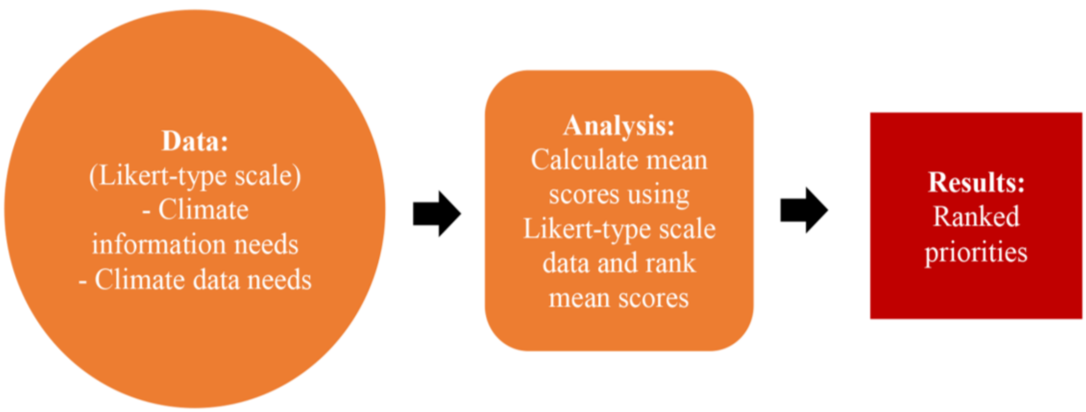


Figure 3. Methodological overview of analysis to obtain a prioritization list of perceived climate data and information needs on reservation lands in the Southwest.

In order to identify and prioritize survey participants' data and information needs, question items featured equally-weighted Likert-type scale choice ratings, from one to five. A score of 1 indicates an information topic is of a "very low priority," 2 indicates "low priority," 3 indicates "neutral" priority, 4 indicates "high priority," and a score of 5 indicates this topic is of "very high priority."

Mean scores for each climate information and data need item (survey questions 1-20) were calculated using Likert-type scale survey response data and items were ranked from highest to lowest priority. A ranking of mean scores reveals respondents' prioritized climate data and information needs relative to others. That is, the lowest ranked climate information item does not necessarily indicate an overall "very low priority" rating for that item, but rather indicates its priority standing relative to other climate information and data items identified for this assessment.

Table 2 displays the calculated priority ranking for climate information needs to support adaptation on reservation lands. These topics relate to the interdisciplinary nature of community climate resilience, such as the "Role of traditional knowledge in climate adaptation on tribal lands," as well as, "How to finance implementation of climate adaptation plans." The top prioritized information item (m = 4.33, n = 97) is, "Climate change impacts on tribal lands, water, and economies." This result is not surprising considering that tribal leaders on reservation lands across the U.S. have voiced consistently the need for impact assessments as a critical first step to adaptation planning (Jantarasami et al., 2018). This result also confirms recent community and environmental health investigations related to climate impacts conducted with Indigenous communities (Chief et al., 2016; Cozzetto et al., 2013; Fillmore, Singletary, & Phillips, 2018; Gautam et al., 2013; Smith et al., 2014).

Table 2

Prioritized Climate Information Needs

Rank	Need	N	Mean	Std. Dev.
1	Climate change impacts on tribal lands, water, and economies	97	4.33	0.86
2	Enhancing tribal food security and sovereignty	96	4.18	0.94
3	Role of traditional knowledge in climate adaptation on tribal lands	97	4.16	0.76
4	How to protect traditional knowledge that tribes incorporate into their adaptation strategies	97	4.16	0.91
5	How to finance implementation of climate adaptation plans	96	4.08	0.91
6	Training tribal employees to ensure consistent data monitoring and collection on tribal lands	97	4.06	0.93
7	Adaptation strategies that address issues unique to tribal land tenure and water rights	95	4.05	0.88
8	How to conduct a climate vulnerability assessment	97	3.96	0.85
9	How to finance monitoring/data collection on tribal lands	97	3.89	0.92
10	Meaning of future climate projections for individual reservations	97	3.88	1.00
11	Selecting equipment to monitor/collect data to inform tribal climate adaptation planning and implementation	97	3.87	0.94
12	Examples of other tribes' climate adaptation plans	97	3.71	0.88

Note. Topics are ranked first by highest mean score (5=Very High Priority) to lowest mean score (1=Very Low Priority), and then by lowest standard deviation (i.e., mean value with lowest associated distribution/error).

The second ranked information need (m = 4.28; n = 96), "Enhancing tribal food security and sovereignty," reaffirms results from a recent national climate adaptation needs assessment with tribal college and university administrators, faculty, and students. In this example, food sovereignty and adaptive agriculture on reservation lands were topics frequently identified by respondents as necessary to enhance tribal climate resilience (Fillmore et al., 2018).

While the third and fourth ranked information needs have equivalent mean scores (m = 4.16; n = 97 respectively), the item with a smaller standard deviation (0.76 as compared with 0.91) is ranked higher. These information needs include the "Role of traditional knowledge in climate adaptation on tribal lands" and "How to protect traditional knowledge that tribes incorporate into their adaptation strategies." The high priority ratings assigned to these topics indicate the highly valued nature of traditional knowledge in Indigenous communities and may demonstrate a need for internal collaboration among Indigenous communities to apply this knowledge in climate adaptation planning.

That is, integrating traditional knowledge into climate adaptation processes must be undertaken by Indigenous communities. Traditional knowledge is specific to each Indigenous community and exists at the community level. Appropriately applying this type of information to climate adaptation efforts requires engagement of community members who are both familiar with the knowledge itself, its level of sensitivity to outside exposure, and its relationship to climate adaptation (Klenk et al., 2017; Kovach, 2010). This includes seeking permission first in order to integrate Indigenous traditional knowledge in adaptation planning.

If individuals outside these communities are involved in shared knowledge, it must be with the understanding that an outsider is unable to add to or embellish upon traditional knowledge particular to an Indigenous community (Kovach, 2010). This is not to say, however, that outside information may not be useful to supporting Indigenous community efforts to revitalize practices based on traditional knowledge. Rather it suggests that if the integration of traditional knowledge into climate adaptation processes is important, then collaboration is required with local traditional knowledge holders based in a particular community (Klenk et al., 2017).

Table 3 displays the ranked mean scores for climate data needs, utilizing the same Likert-type scale responses with “1” being “very low priority” and “5” being “very high priority.” These topics include the types of numerical data used to inform land and water use management decisions, to develop and inform climate projections and scenarios, and to explain hydrological processes and changes (Dingman, 2015).

Table 3

Prioritized Climate Data Needs

Rank	Need	N	Mean	Std. Dev.
1	Water quality data	93	4.22	0.81
2	Streamflow data	92	4.07	0.81
3	Temperature data	92	4.05	0.80
4	Precipitation data	94	4.03	0.87
5	Snowpack data	91	4.03	0.91
6	Soil moisture data	94	3.93	0.88

Note. Topics are ranked first by highest mean score (5=Very High Priority) to lowest mean score (1=Very Low Priority), and then by lowest standard deviation (i.e., mean value with lowest associated distribution/error).

Of the types of climate data identified in this survey, respondents rated water quality data needs as their highest priority (m = 4.22; n = 93) with a 0.15-point difference in mean score between this top-rated need and the second ranked need, streamflow data (m = 4.07; n = 92). Compared to the other data types featured in this assessment, water quality data are the least readily available through the USGS online data portal for the

Southwest. The U.S. Environmental Protection Agency (EPA) is tasked with enforcing provisions of the Clean Water Act, to monitor point source pollutants and non-point source pollutants, and is charged with overseeing water quality monitoring, assessment, and reporting (Federal Water Pollution Control Act Amendments, 1972). This water quality data, however, are limited in its scope to inform management decisions.

Furthermore, quantifying climate impacts on water quality at a regional scale is a complex process, as no single accepted method exists to measure the effects of climate change on the quality of water bodies (Senhorst & Zwolsman, 2005). That is, water quality is defined differently for different bodies of water, and is dependent on the location, purpose, use, and or accessibility of the water (Xia, Wu, Mou, & Lai, 2015). From this survey, it is uncertain if stakeholders are primarily concerned with assessing the extent to which climate impacts influence EPA baseline water quality standards, drinking water quality, water quality for agriculture, and/or riparian water quality to support ecosystem services. A more in-depth analysis would be required to better understand stakeholder priorities related to this question. Increasingly, Indigenous communities are calling specifically for research specific to the effects of climate change on water quality (Jantarasami et al., 2018).

For the remaining data types featured here, temperature ranked third (m = 4.05; n = 92), followed by precipitation ranked as fourth (m = 4.03; s.d. = 0.87; n = 94), snowpack data as fifth (m = 4.03; s.d. = 0.91; n = 91), and soil moisture data ranked last comparatively (m = 3.93; n = 94). A surprising finding from this analysis (see Table 3) is that respondents ranked snowpack data fifth in priority. For the snow-fed basins that comprise our study area, planning effectively for summer water availability requires earlier and accurate predictions of water equivalent stored in winter snowpack (Knowles et al., 2006; Oubeidillah et al., 2011). A comparatively lower ranking for this item may indicate a need for education and capacity-building in the use of snowpack data to predict summer water availability. In contrast, it may also suggest the recognition of the decline in this resource, or recognition of limited snow-based forecasting system availability.

Another informative finding here is that survey respondents revealed a clear preference for “Generalized reports of summaries on water resources and climate information data” (m = 4.02, n = 93) as compared to “Raw data collected from monitoring instruments” (m = 3.84, n = 94) as evidenced by 0.18-point difference in mean scores between the two items (see Table 4). This preference may be interpreted to indicate limited knowledge of respondents’ skills and/or confidence to use raw data as compared with generalized summaries. Alternatively, it may indicate lack of time and/or additional human resources (staff) necessary to collect and process raw data in a timely and consistent manner so as to be useful to adaptation planning and implementation.

Table 4

Prioritized Climate Data Format

Rank	Need	N	Mean	Std. Dev.
n/a	Generalized reports of summaries on water resources and climate information data	93	4.02	0.82
n/a	Raw data collected from monitoring instruments	94	3.84	0.92

Note. Data needs are ranked by highest mean score (5=Very High Priority) to lowest mean score (1=Very Low Priority).

4.4. Climate data/information sources. This section responds to the second of the three thesis research questions: “What current sources of climate data and information are accessed most frequently?” Responses to this question have implications for data and information accessibility improvements necessary to enhance climate adaptation on reservation lands. Figure 4 presents a flowchart depicting an overview of the methods used to obtain this information:

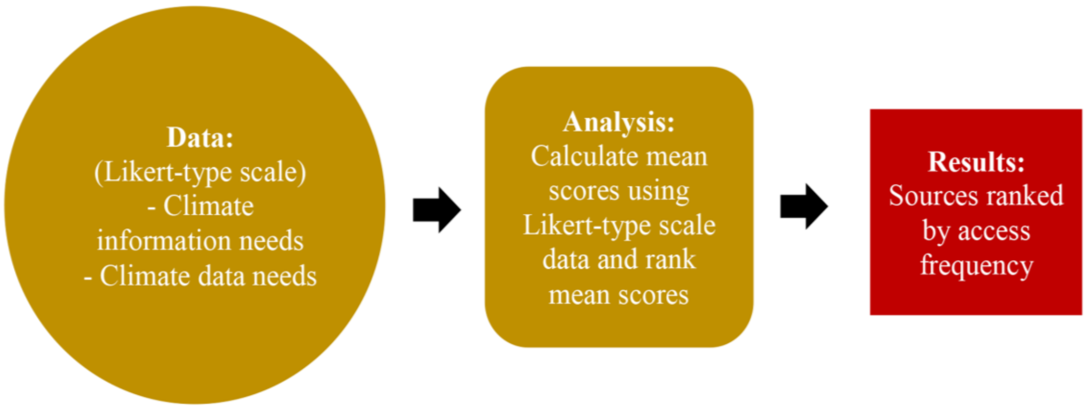


Figure 4**.** Methodological overview of analysis to obtain a prioritization list of climate data and information sources on reservation lands in the Southwest.

Table 5 shows mean scores for access frequency, on a scale of “1” being “never accessed” to “5” being “very often accessed,” for 13 climate data and information source options to support climate adaptation on reservation lands. Using mean scores, data and information sources are ranked from most frequently accessed to least frequently accessed. For mean scores that are the same, the smaller standard deviation, or variance from the mean, determines the higher ranked item.

Table 5

Most Frequently Accessed Climate Data and Information Resources

Rank	Source	N	Mean	Std. Dev.
1	Tribal natural resource/water/land departments	90	3.74	1.10
2	USGS Stream Gauges	91	3.41	1.16
3	National Oceanic Atmospheric Administration (NOAA); National Weather Service; NRCS Snotel	91	3.36	1.13
4	Tribal oral histories	91	3.30	0.99
5	Traditional knowledge holders	90	3.29	1.03
6	Tribal farmers and ranchers	92	3.20	1.14
7	Colleges and universities	90	3.19	1.16
8	Tribally owned and operated monitoring equipment	88	3.18	1.25
9	Native Waters on Arid Lands tribal summits	89	3.12	1.19
10	USDA Climate Hubs	91	2.99	1.13
11	The Weather Channel; Weather.com; local news and radio	91	2.96	1.17
12	Bureau of Indian Affairs climate planning program	90	2.90	1.18
13	Tribal colleges and universities	90	2.64	1.26

Note. Topics are ranked by highest mean score (5=Very Often Accessed) to lowest mean score (1=Never Accessed).

"Tribal natural resource/water/land departments" is the most frequently accessed data and information resource (m = 3.74; n = 90). A score of 3.74 indicates that respondents access this climate data and information source "occasionally" (3) to "often" (4). The second ranked source currently accessed is "USGS stream gauges" (m = 3.41; n = 91). This result supports previous findings reported for climate data needs (see Table 3) where the second most prioritized item is streamflow data. The next information source ranked closely together is: NOAA/NWS/NRCS (m = 3.36; n =91). This source includes critical climate weather and temperature data that can be used in stakeholder decision-making processes.

By descending order of mean scores, the next cluster of sources accessed “often” include: tribal oral histories (m = 3.30, n =91); and traditional knowledge holders (m = 3.29, n = 90); tribal farmers and ranchers (m = 3.20; n = 92); colleges and universities (m = 3.19; n = 90); tribally owned and operated monitoring equipment (m = 3.18, n = 88); and Native Water on Arid Lands Annual Tribal Summits (m = 3.12; n = 89). These six sources uphold key values of collaborative initiatives for enhancing climate resiliency. That is, survey respondents indicate that they are often in communication with Indigenous stakeholders and traditional knowledge holders. They also access sources that are intended to help build local capacity to understand, analyze, and plan more effectively for climate resilience.

The least frequently accessed climate data and information sources are the USDA Climate Hubs (m = 2.99; n = 91); Weather Channel and local news (m = 2.96; n = 91); Bureau of Indian Affairs climate planning program (m = 2.90; n = 90), and tribal colleges and universities (m =2.64; n = 90). The mean scores calculated for these sources indicates respondents only “rarely” to “occasionally” access these sources for climate data and information.

This lowest ranking for tribal colleges and universities contrasts with results from a recent (2017) national-study conducted with tribal colleges and university administrators, faculty members, and students. That study maintains that tribal colleges and universities may have a key role in assisting local tribes with climate adaptation (Fillmore et al., 2018). This contrast is likely due to the relatively small (three) number of tribal colleges and universities located within the study area. These include the Dine College (northeastern Arizona), Navajo Technical University (northwestern New Mexico), and Tohono O'odham Community College (southern Arizona) (American Indian College Fund, 2017).

Additionally, a chronic lack of funding of tribal colleges and universities may also contribute to a comparatively low rating for tribal colleges and universities. While the national study indicates tribal colleges and universities can play a significant role in enhancing the climate resiliency of Indigenous communities, public funding for these institutions has remained nearly the same since 1994, when federal legislation was enacted to increase access to higher education on reservation lands (Fillmore et al., 2018). Finally, a low rating by a group engaged in climate adaptation as compared with a group of individuals affiliated with tribal colleges and universities might signal that these institutions must work harder to promote what they can offer to support adaptation planning.

4.5. Demographic correlation analysis. In order to conduct a meaningful analysis of respondents' climate data and information needs and sources accessed, it is imperative to test for variation in response frequency based on respondents' demographic characteristics. Figure 5 provides a general overview of the steps taken to test for demographic associations to climate data and information needs in this thesis.

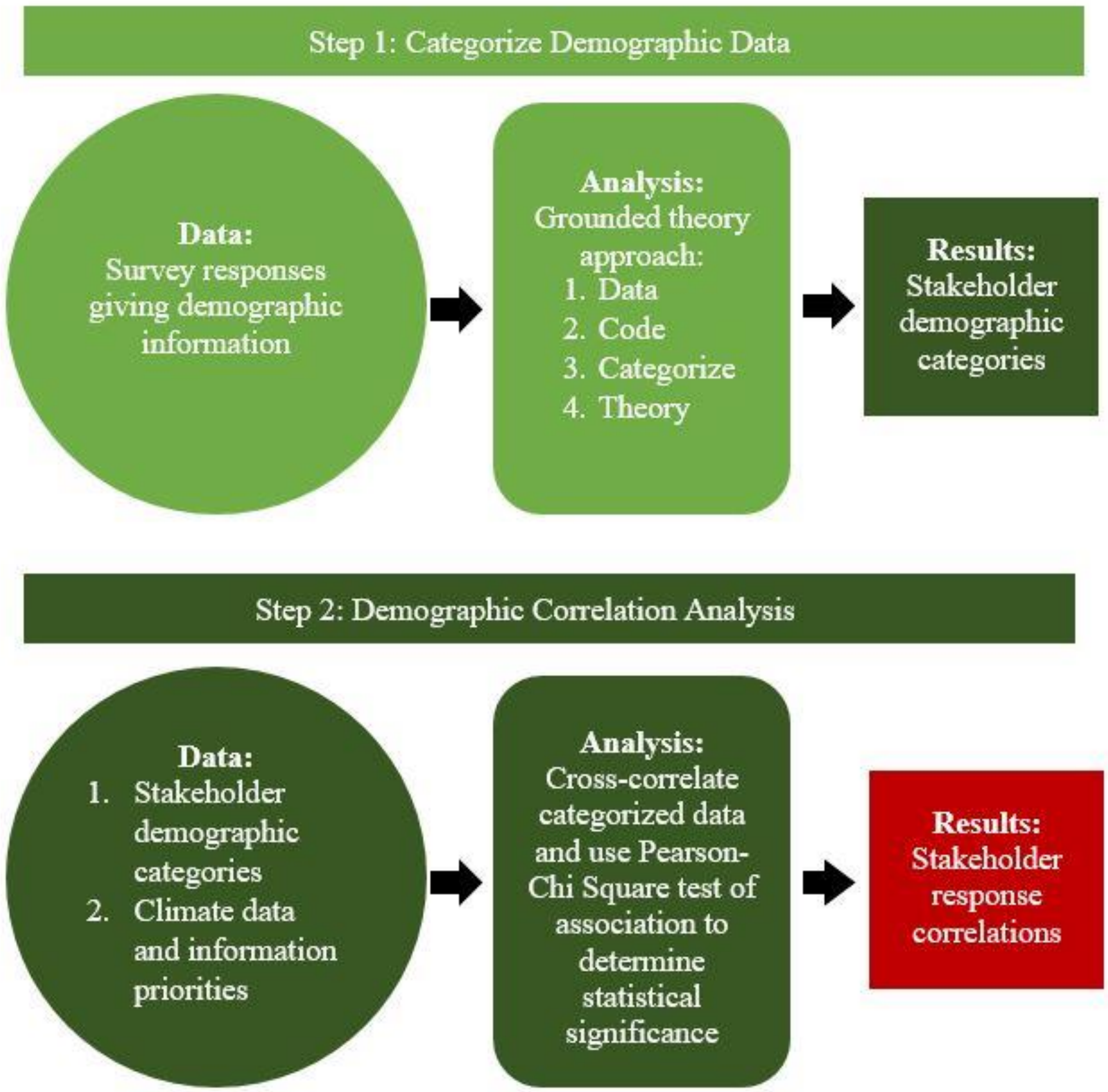


Figure 5. Flow-chart depicting a two-step process for analyzing the cross-correlation of demographic response frequency to climate data and information priorities.

Specifically, this section responds to the third research question this thesis poses, which asks, "Does experiential background influence climate information and data needs prioritized and sources accessed in climate adaptation planning initiatives on reservation lands?" To answer this question, the responses to demographic questions were categorized into five independent variables using a grounded theory approach: (1) respondents' role in climate adaptation planning on reservation lands; (2) geographic location; (3) educational attainment level; (4) gender; and (5) age group. By testing for statistical significance of association between each of these demographic attributes and each of the climate data and information priorities, the following section addresses the research questions:

1. Does one's role in climate adaptation planning (either administration, analysis, or implementation of plans) influence climate information/data priorities and accessed sources?
2. Do data/information priorities and accessed resources differ by location of reservation within the study region?
3. Is educational attainment a factor in climate information and data need priorities and access differences?
4. Is gender a factor in climate information and data need priorities and access differences?
5. Is age a factor in climate information and data need priorities and access differences?

Grounded theory is a foundational social science methodology used to derive theory from either qualitative or quantitative social science data (Glaser & Strauss, 1967). This method of inductive reasoning generally follows four steps: (1) collection of data; (2) coding of similar concepts; (3) grouping concepts into categories; and (4) development of theory (Bernard, 2013). The purpose of using a grounded theory approach to group data into categories, rather than a dimensional analysis strategy, or a content analysis strategy is that grounded theory produces categories that represent the basic social processes that contribute to the demographic variables (Kools, McCarthy, Durham, & Robrecht, 1996). The essential grounded theory approach to analyze social data is depicted in Figure 6. Demographic survey data are grouped into codes based on similar concepts. Coded data are grouped into categories, which are grouped into variables. The resulting categorical variables are cross-correlated to analyze data for association.

Figure 6. Grounded theory approach to social data analysis.

In this study, using a grounded theory approach, responses to demographic question items are coded based on similarities, and then the data further reduced to create five demographic variables that are used in the correlative analysis. These five demographic variables are cross-analyzed with participant responses to each question item concerning climate data and information needs and resources. Because these resulting demographic variables comprise categorical data, the most appropriate tool to test for statistical significance of association is the Pearson Chi-Square test (Bernard, 2013). The following sections describe the specific approaches, and supporting theory, used to categorize survey responses, conduct the cross-correlative analysis, and report the final results.

4.5.1. Priorities based on stakeholder role in climate adaptation planning. Stakeholder role in this analysis is determined by occupational information provided by survey respondents. There are several reasons to test for the statistical significance of association between potential roles of stakeholders in climate adaptation planning on reservation lands and their climate data and information priorities. As stated previously, comprehensive climate adaptation planning on reservation lands requires collaborative efforts that include a variety of research interests, and expertise (Meadow et al., 2015). Identifying differences with regards to respondents' prioritization needs, based on their roles in climate planning initiatives, can inform how to more effectively disseminate data and information resources. Analyzing response differences in frequently accessed climate information and data sources may help identify the expertise necessary to better support adaptation planning initiatives on tribal lands. For example, specific climate adaptation planning initiatives may require information on traditional knowledge-based land use, and/or resilience strategies unique to a particular area. Thus, identifying stakeholder groups that may frequently access "traditional knowledge holders" for climate data and information can facilitate the integration of this information in planning processes.

Survey question 22, "I work in_____" (see Appendix D), asks respondents to identify their employment, and to specify a department if they work in tribal government. Of the survey questions asked, this item most closely relates to stakeholder roles in climate adaptation initiatives. This is particularly the case under the assumption that annual summit attendance is based on professional and/or occupational interests. These occupational responses are used to determine stakeholder role groups through a grounded theory approach yielding a "stakeholder role in climate adaptation initiatives" variable. This new variable will be described as "stakeholder role" in this analysis rather than "respondents' occupational sectors" in order to specify the difference between the variable resulting from the analysis and the original survey respondent data.

Nearly half (42.9%; N=42) of the respondents indicate that they work for a tribal government and the specific department, as requested in the survey question (see Figure 7). In addition to tribal councils, these departments include environmental protection and natural resource management, range management, cultural resource, and education departments.

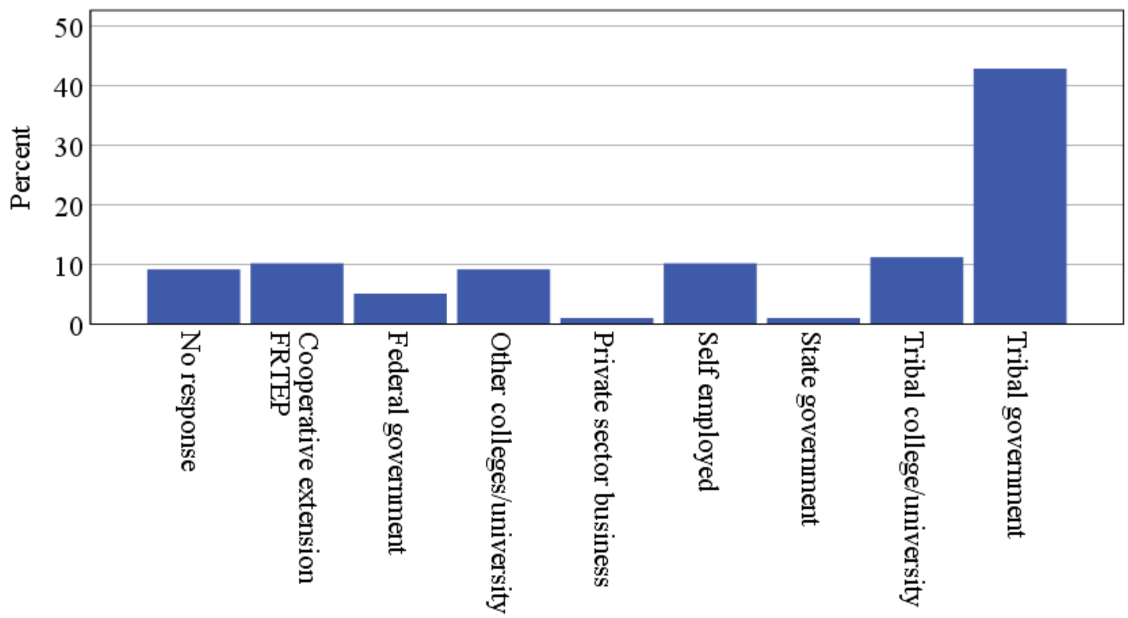


Figure 7. Distribution of responses to survey question 22: "I work in ____."

Because responses referencing tribal departments are indicative of respondents' application of climate data and information, when compared to tribal government, these written responses were aggregated to create a new variable. A multi-step analysis using a grounded theory approach is employed to reduce data from multiple codes to three primary role categories that stakeholders may assume in climate adaptation efforts. This type of analysis ensures that results capture the broad representation of experiential backgrounds of survey respondents.

The first step in the process is to identify trends among the 42 written responses describing respondents' tribal government department, and to code these responses based on similar occupational sectors (Bernard, 2013). Because the 42 written responses are brief, typically one or two words, identifying and coding similar responses was simple and straightforward. For example, responses that ranged from "natural resources," "environmental protection," and "environmental" were all coded as "Tribal Department: Environmental." Tribal environmental and natural resource departments are similarly tasked with overseeing the direct management of land and natural resources on reservation lands.

This process resulted in six different codes representing tribal departments with various functions, which are shown in Figure 8. These tribal department codes include: (1) agriculture; (2) environmental; (3) water resources; (4) cultural resources; (5) tribal government; and (6) education. These six codes reasonably encompass all tribal departments represented by the survey data for these written responses. For example, "tribal council" is clearly related to "tribal government." "Range management," is most similarly related to "agriculture," and is thus coded under the "Tribal Department: Agriculture" variable (see Figure 8). These six codes resulted in no outlier responses, and were chosen because they are similarly as broad as the rest of the sectors of employment offered as potential answers to the question, "I work in ____."

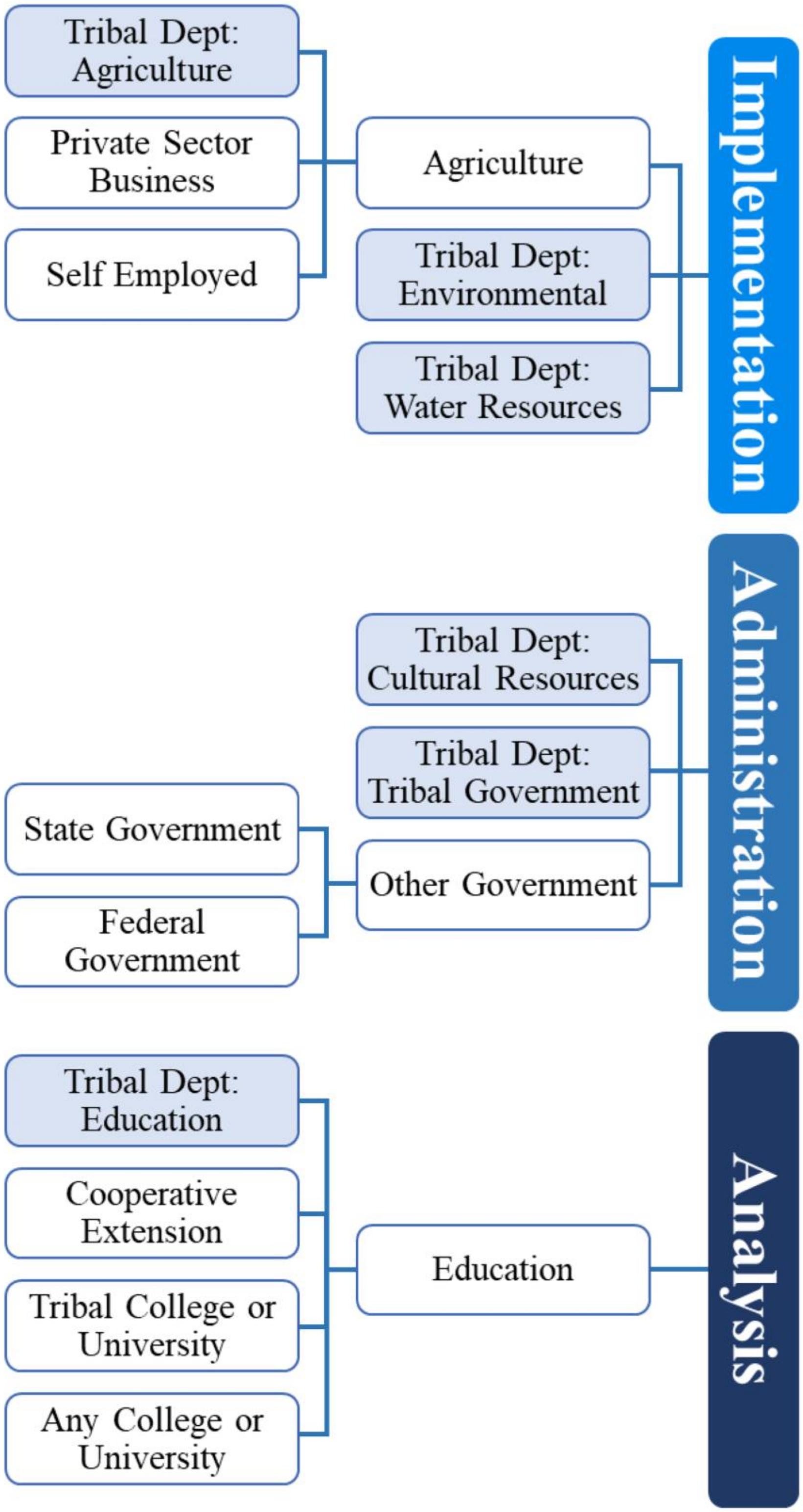


Figure 8. Flow chart depicting grounded theory analysis of responses to survey question 22, "I work in____," to determine stakeholder role.

The additional seven response items listed as options for question item 22, “I work in______” (see Figure 7) were also coded into similar occupational sectors. An analysis of these response items based on similarities resulted in three codes: (1) agriculture; (2) non-tribal government; and (3) education (see Figure 8). These three occupational sector codes and the six tribal department codes are together referenced as occupational sector codes, and are reasonably representative of the potential climate adaptation planning role of each survey respondent.

The next step of the grounded theory approach used in this analysis is to establish the categorical relationships among occupational sector codes to determine stakeholder role categories in climate adaptation on reservation lands. This is an important step in determining the baseline social processes from which these codes stem. The overall coding and categorizing process is summarized in Figure 8. This process analyzes all of the occupational sector codes together. The first analysis results in seven occupational sector codes (see Figure 9): (1) agriculture; (2) environmental; (3) water resources; (4) cultural resources; (5) tribal government; (6) other government; and (7) education. A second analysis to reduce the number of codes further results in three primary categories representing stakeholder role in climate adaptation on reservation lands (see Figure 10): (1) implementation; (2) administration; and (3) analysis.

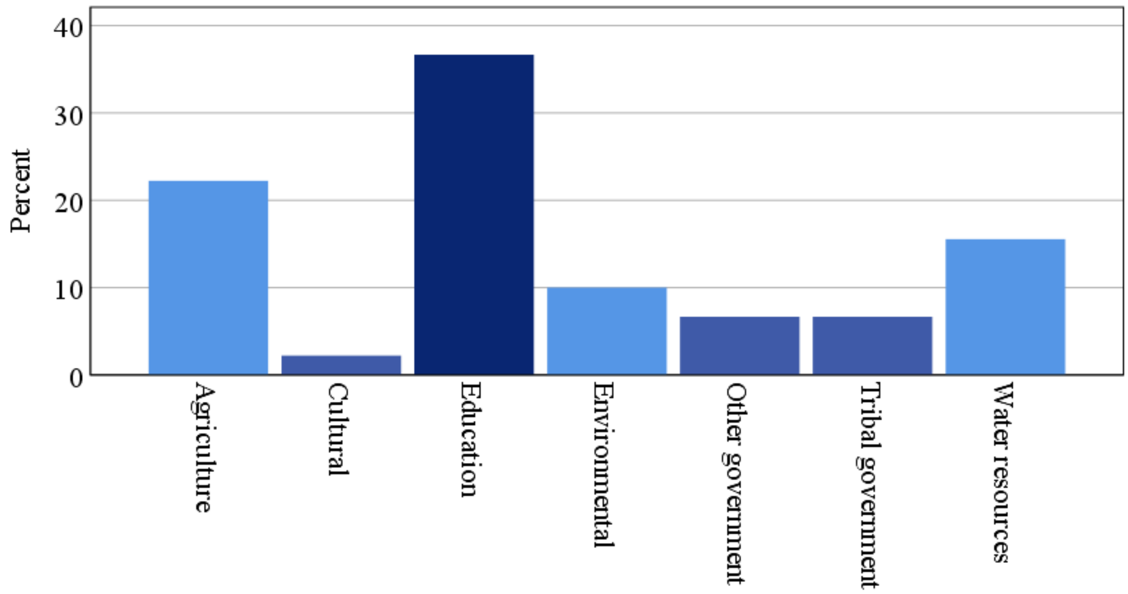


Figure 9. Percentage of survey respondents per occupational sector code.

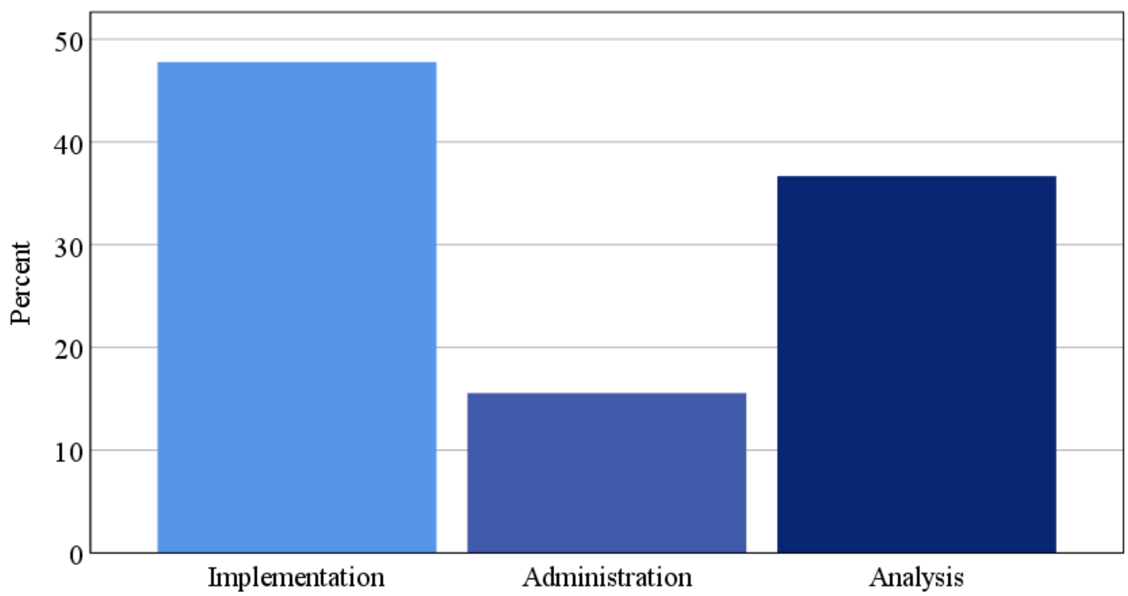


Figure 10. Distribution of responses grouped into final categories representing **stakeholder role** in climate adaptation initiatives.

Survey respondents grouped under the “implementation” stakeholder role category are those who primarily use data and information to inform decisions that are implemented on the landscape at local and/or regional levels. These include land-managers, agriculturalists, ranchers, and/or individuals whose livelihood is directly dependent on environmental services. Respondents grouped under the “administration” stakeholder role category are those who primarily use data and information to inform policy, advocacy, planning, and funding allocations for example. These include government officials and cultural resource departmental staff, as these departments typically serve the socio-cultural and public policy interests of Indigenous communities. Respondents grouped under the “analysis” stakeholder role category primarily use climate data and information to conduct research, or to inform educational outreach, and thus include the respondents who work in educational sectors.

These final three stakeholder-role categories, implementation, administration, and analysis, comprise a single variable describing stakeholder role in climate adaptation on reservation lands. A cross-correlation analysis was conducted using this variable and responses to each of the climate data and information needs assessment question items (survey questions 1-20) and climate information and data source questions (survey questions 24 – 36). To determine the significance of cross-correlated responses, a Pearson Chi-square test for association is employed for each pair. Because each analysis involves two categorical variables, a Pearson Chi-square test for association is the most appropriate to test for association (Bernard, 2013). Each variable being tested for association is cross-tabulated to display the distribution of association. Only the cross-correlated data with statistically significant associations are discussed in this study.

Cross-correlated data without statistically significant association demonstrates a congruent response frequency to question items regardless of demographic background. This indicates that respondents agreed in overall ranked mean results for those question items.

While the conventional threshold for statistical significance is a 95% confidence interval ($p < 0.05$), for this study a 90% confidence interval is used ($p < 0.10$) to determine statistical significance (Hawkes & Marsh, 2004). A 90% confidence interval is an acceptable threshold considering that this study is exploratory in nature, and the results reported do not have life-threatening implications. Furthermore, this helps mitigate issues related to correlations that may not meet standards for statistical significance, but may be substantively significant in nature (Vogt, 1993). Table 6 displays statistically significant results from this test for association between stakeholder role in climate adaptation initiatives and responses to data and information priorities and frequently accessed sources of information. A complete report of p-value results from the Pearson Chi-square test for correlation can be found in Appendix G.

Table 6

Needs Correlating to Stakeholder Role in Climate Adaptation on Reservation Lands

Overall Rank:	Information needs:	p-value
1	Climate change impacts on tribal lands, water, and economies	0.071
10	Meaning of future climate projections for individual reservation	0.011
Overall Rank:	Data and information sources:	p-value
6	Tribal farmers and ranchers	0.018
7	Colleges and universities	0.007
9	Native Waters on Arid Lands Tribal Summits	0.045

Note. Overall rank refers to the prioritized need rankings reported in tables 2 through 5. Statistically significant association determined using a 90% confidence interval ($p < 0.10$) calculated using a Pearson's Chi-square test.

The two climate information topics with statistically significant associations listed in Table 6 are similar in scope. Both identify the need for a better understanding of climate impacts on reservation lands. They differ in that one is an interdisciplinary analysis of climate impacts, and the other refers to a meaningful interpretation of climate projects at local scales (see Appendix E). The Pearson Chi Square test is used to test the statistical significance of association. Figures 11-13 graphically report the distribution of cross-tabulated data for the statistically significant associations listed in Table 6.

The Chi-square test of association p-value is statistically significant ($p = 0.071$) between stakeholder role, and the ranked priority variable, "Climate change impacts on tribal lands, water, and economies." This means the uneven response distribution to priority value based on stakeholder role is significant (see Figure 11). Cross-tabulated results indicate that respondents grouped into the "analysis" stakeholder role had an expected count of 16.7 responses marking this variable as a "very high priority," but with an actual count of 23 (see Appendix G). Survey respondents grouped into the "administration" and "implementation" roles both had higher actual counts than expected rating this need as "neutral" and a "high priority," and lower actual counts than expected counts rating this need as a "very high priority" (see Appendix G). This demonstrates that respondents assigned to the "analysis" stakeholder role category were significantly more likely to value this need relative to respondents in administration and implementation roles.

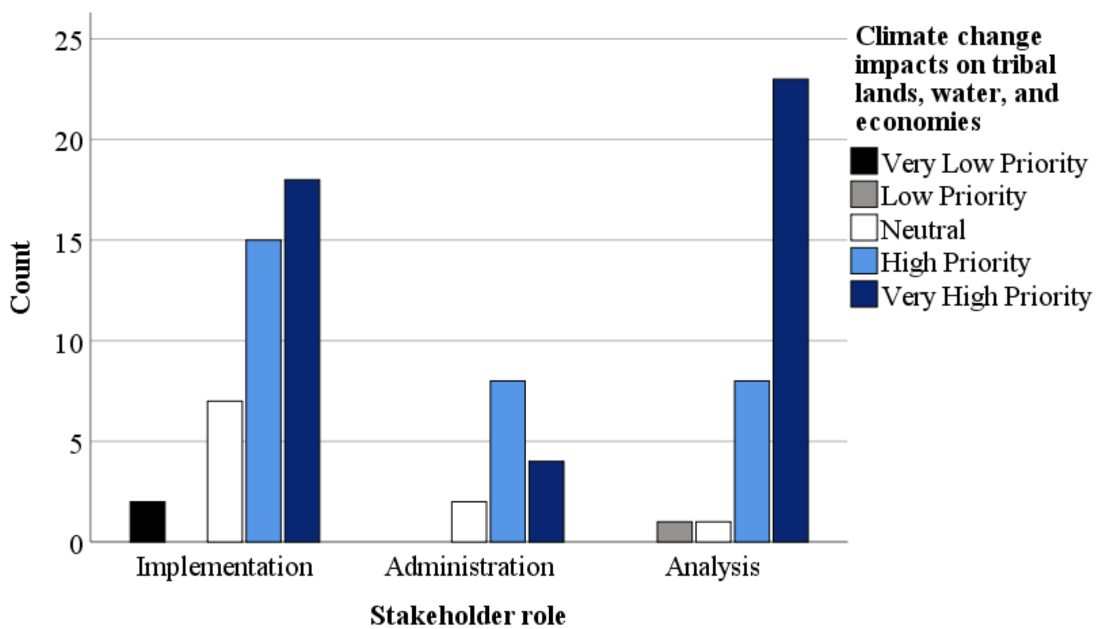


Figure 11. Cross-tabulation counts from a statistically significant association between **stakeholder role** and **climate information** need, "Climate change impacts on tribal lands, water, and economies."

The cross-tabulated results between the stakeholder role variable and the climate information variable, "Meaning of future climate projections for individual reservations" has a statistically significant association (see Table 6). The actual count compared to the expected count distributions for respondents grouped in the “implementation” and “administration” stakeholder role categories were similar to the cross-tabulated results from the previous association (see Appendix G). These categories had lower actual counts rating this variable as a “very high priority,” and higher actual counts rating this variable as “neutral” and a “high priority” (see Figure 12). This indicates that respondents did not prioritize this variable as high as was expected. Respondents grouped in the “analysis” stakeholder role category, however, had higher actual counts than expected counts in both the “low priority” rating category and the “very high priority” rating category (see Figure 12). This indicates respondents grouped in this category rated this variable higher than expected, but also lower than expected relative to respondents in implementation and administration stakeholder roles. This suggests that, within the analysis category, there is a division in priorities when it comes to the question item, “Meaning of future climate projections for individual reservations.”

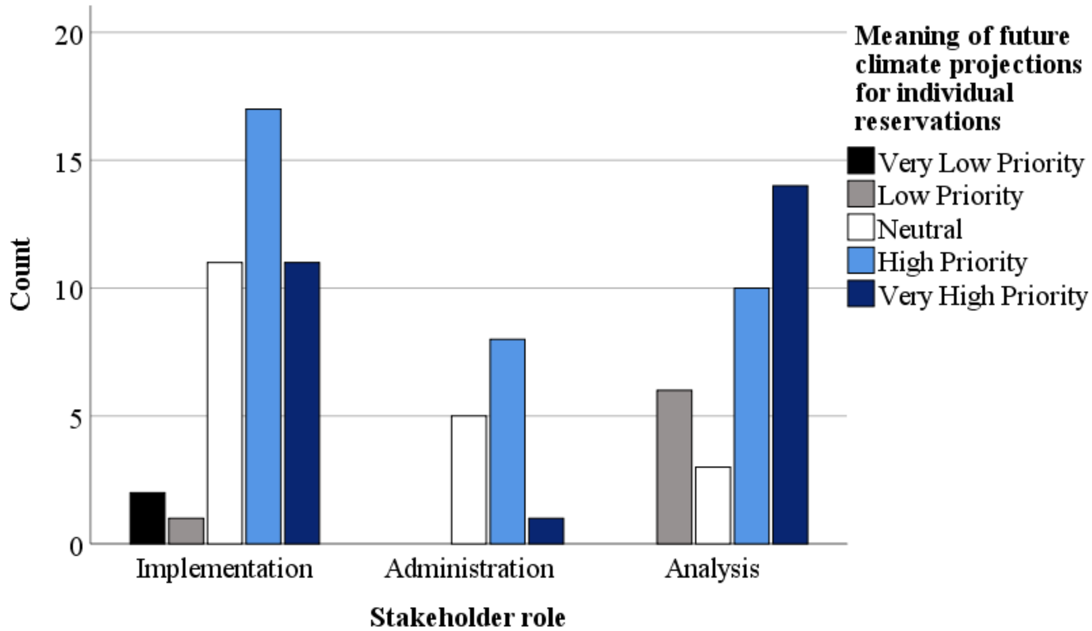


Figure 12. Cross-tabulation counts from statistically significant association between **stakeholder role** and **climate information** need, "Meaning of future climate projections for individual reservations."

Evident from the results as displayed in Figure 13, the statistical significance of the uneven distribution of responses depends on stakeholder role. Stakeholders in implementation roles more frequently access tribal farmers and ranchers as sources for climate data and information compared to those in analysis roles who rarely access this source. The opposite is true for accessing climate data and information from colleges and universities. Respondents in implementation roles access this source less frequently. There is a split among those in analysis roles in terms of their access of climate data and information through the annual, "Native Waters on Arid Lands Tribal Leadership Summits." The majority indicated that they often access this source for information while a lesser but relatively large percentage indicate that they access this source rarely. This split appears contradictory, but may be evidence of distinct sub-groups within the analysis category. Further analysis of respondent priorities and demographic information within the analysis category is required in order to better understand this division in access.

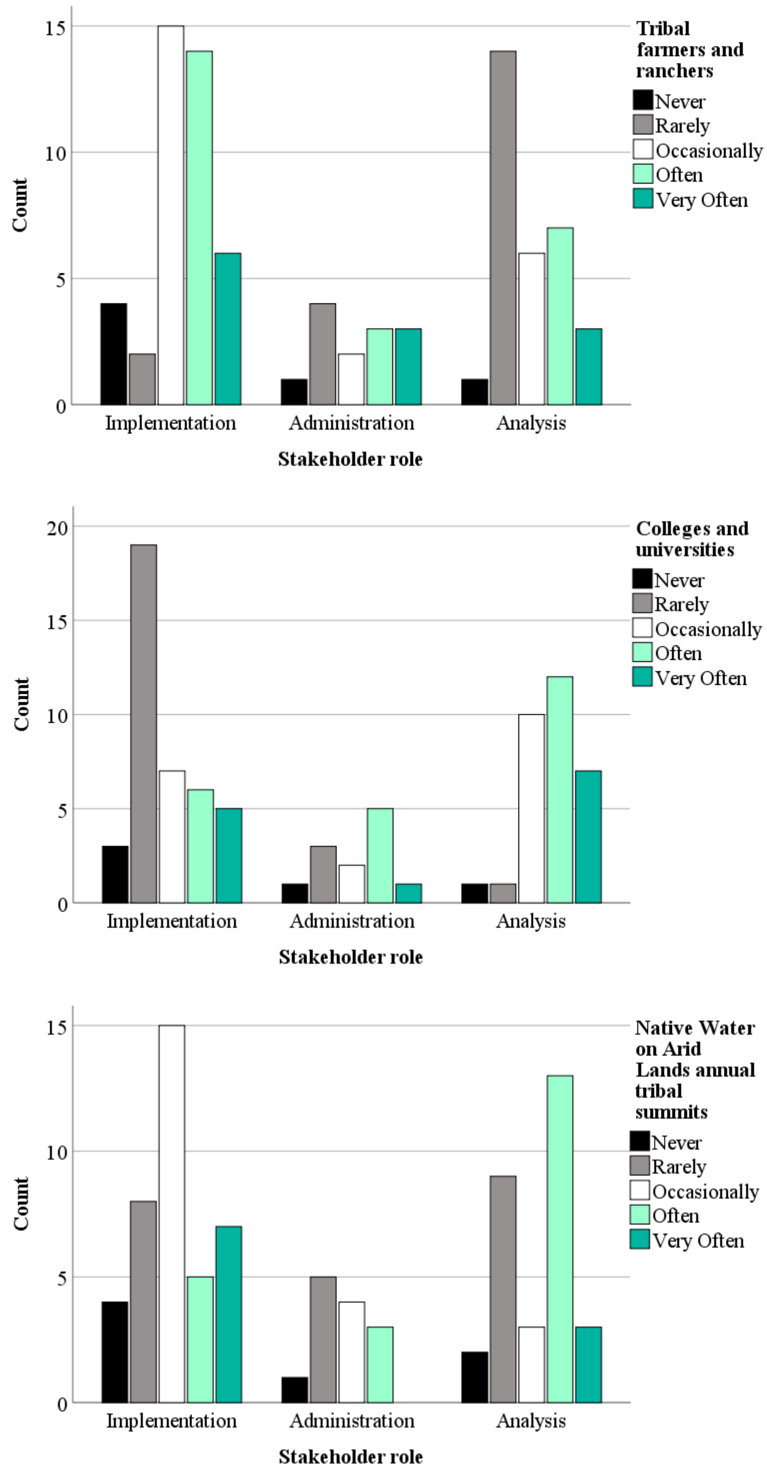


Figure 13. Cross-tabulation counts from statistically significant associations between **stakeholder role** and climate **data/information sources**, “Tribal farmers, and ranchers,” “Colleges and universities,” and “Native Water on Arid Lands annual tribal summits.”

The statistically significant associations between data and information source access frequency and stakeholder role suggest that the overall mean ranking of these topics may differ depending on stakeholder role. For example, when considering frequency of access to “tribal farmers and ranchers” by all respondents together, this source ranked seventh overall as compared to other sources. Because respondents grouped in implementation roles indicated they access “tribal farmers and ranchers” frequently, the mean score of this source may be significantly higher in rank compared to the other climate data and information sources. This is when only considering respondents grouped into implementation roles. For the data/information source, “colleges and universities,” respondents grouped in “implementation” roles indicated that they “rarely” access this source. The mean score ranking, therefore, would be lower if only considering respondents grouped in this category.

To analyze relationships between stakeholder role in climate adaptation and their climate adaptation priorities, the stakeholder role variable is cross-correlated with a grouping of responses to survey question 42, “The most challenging issue that climate uncertainty poses to tribal resources and communities involves” (see Figure 14). That is, responses to this question were grouped using a simplified grounded theory analysis strategy that resulted in the following categories: (1) water supply; (2) tribal agriculture; (3) ecological/environmental health; (4) tribal economies; and (5) human survival. The results from the cross-correlation analysis between the stakeholder role variable and this “key climate uncertainty concern” variable indicate that this association is statistically significant ($p = 0.084$). This relationship is demonstrated in Figure 15.

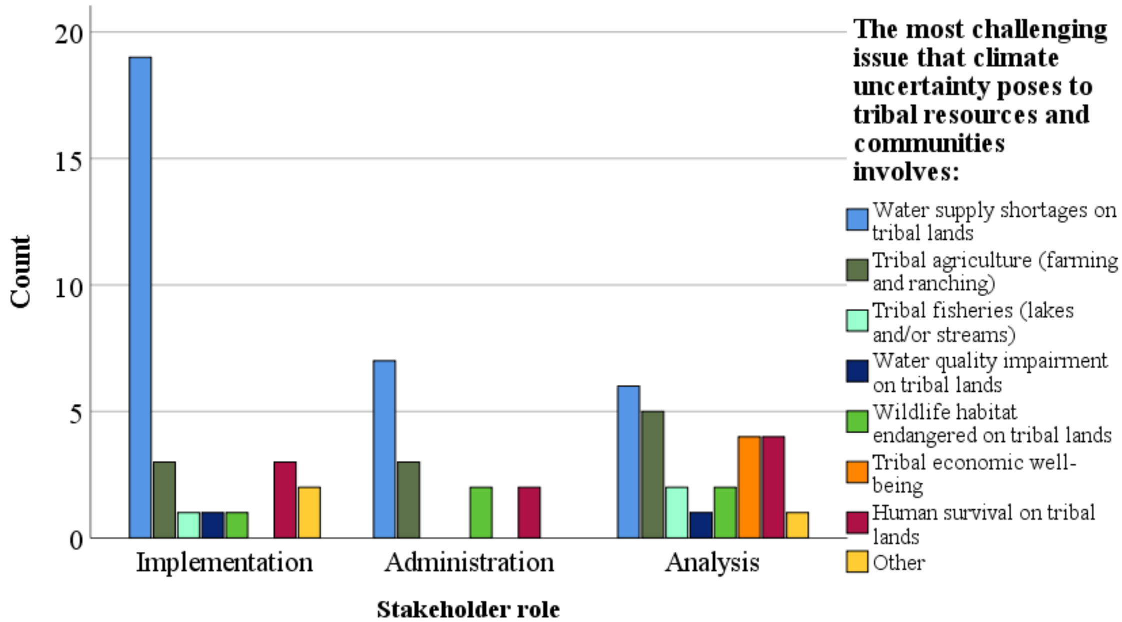


Figure 14. Cross-tabulation counts from statistically significant associations between **stakeholder role** and survey question 42, “The most challenging issue that climate uncertainty poses to tribal resources and communities involves.”

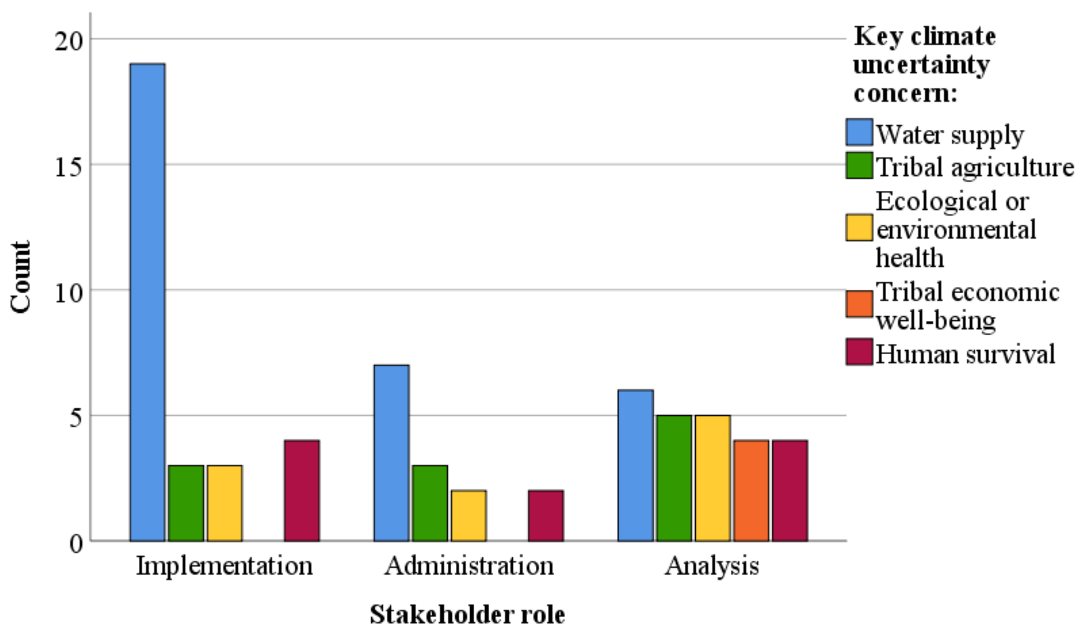


Figure 15. Cross-tabulation counts from statistically significant associations between **stakeholder role** and key **climate uncertainty** concern.

This result suggests that stakeholders in implementation roles are primarily and significantly concerned about water supply. While the difference is not quite as augmented as those in implementation roles, stakeholders in administrative roles have a similar distribution of concerns. The concerns of those in analysis roles, however, are more evenly distributed across the five categories. This is not a surprise considering most respondents assigned to the analysis role category are employed in education. That is, respondents who comprise this stakeholder category include researchers, educators, and outreach professionals. Their occupational priorities in climate adaptation initiatives are presumed to analyze all threats that climate change poses to Indigenous communities. Furthermore, the analysis stakeholder role category is the only respondent group that identified "tribal economic well-being" as "the most challenging issue that climate uncertainty poses to tribal resources and communities."

Using a simplified grounded theory approach to categorize the response items to survey question 42, the categories used in the previous cross-correlation analysis were coded and grouped into three final categories: (1) water supply; (2) environmental health; and (3) tribal economic well-being (see Figure 16).

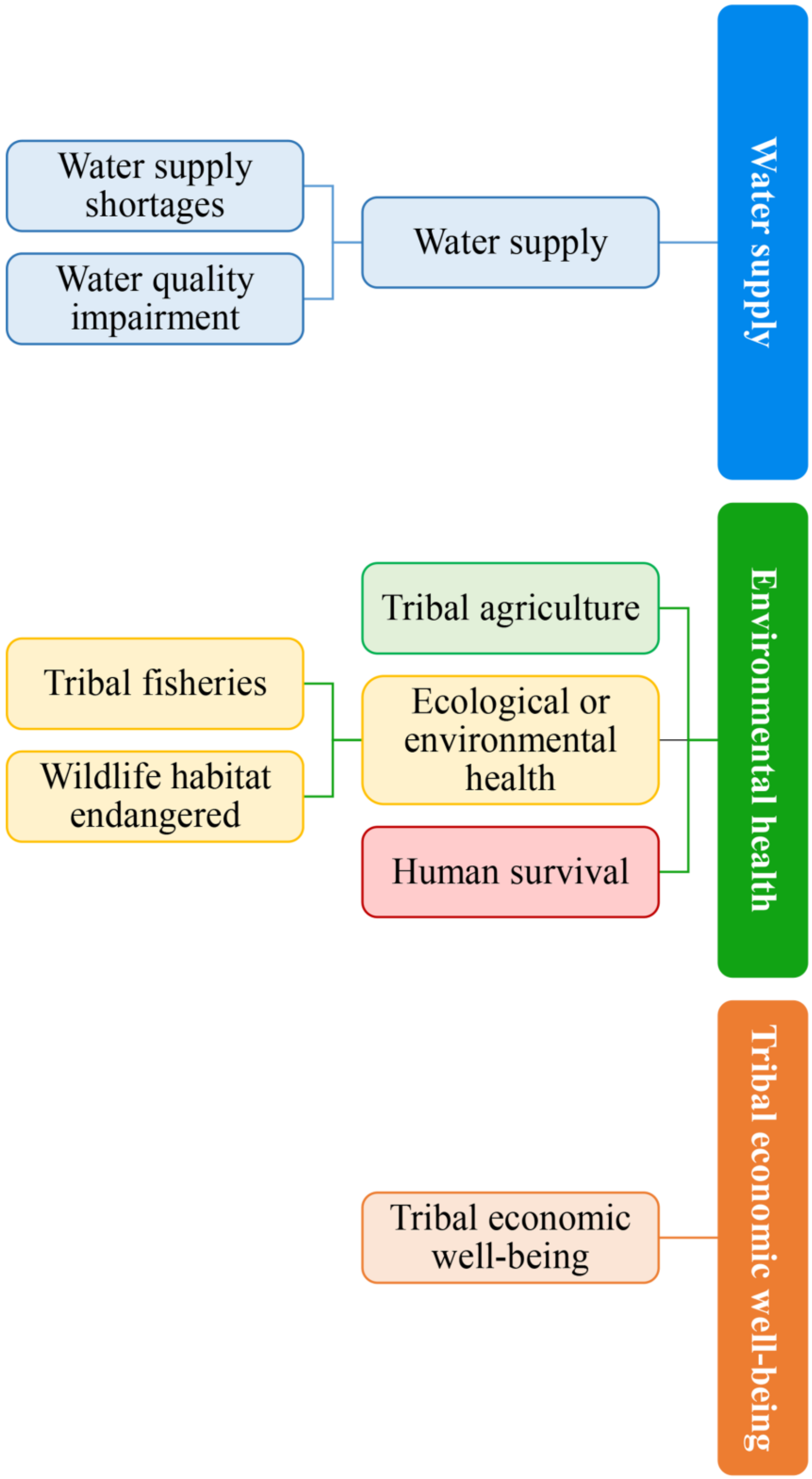


Figure 16. Grounded theory analysis of response items to survey question 42, “The most challenging issue that climate uncertainty poses to tribal resources and communities involves,” resulting in key **sectors of climate concern**.

The purpose of this categorization was to identify the cross-correlation frequency distribution of "Water supply" in relationship to all environmental health-related categories. The analysis resulted in three key sectors of climate concern on reservation lands. The resulting association of this cross-correlation analysis is statistically significant (p = 0.012), and the cross-tabulation result frequencies are reported in Figure 17. While these results are merely a broader representation of the results reported above in Figure 15, they also indicate that stakeholders in administrative roles may prioritize water supply issues and environmental health issues equally when considering all environmental-health related issues.

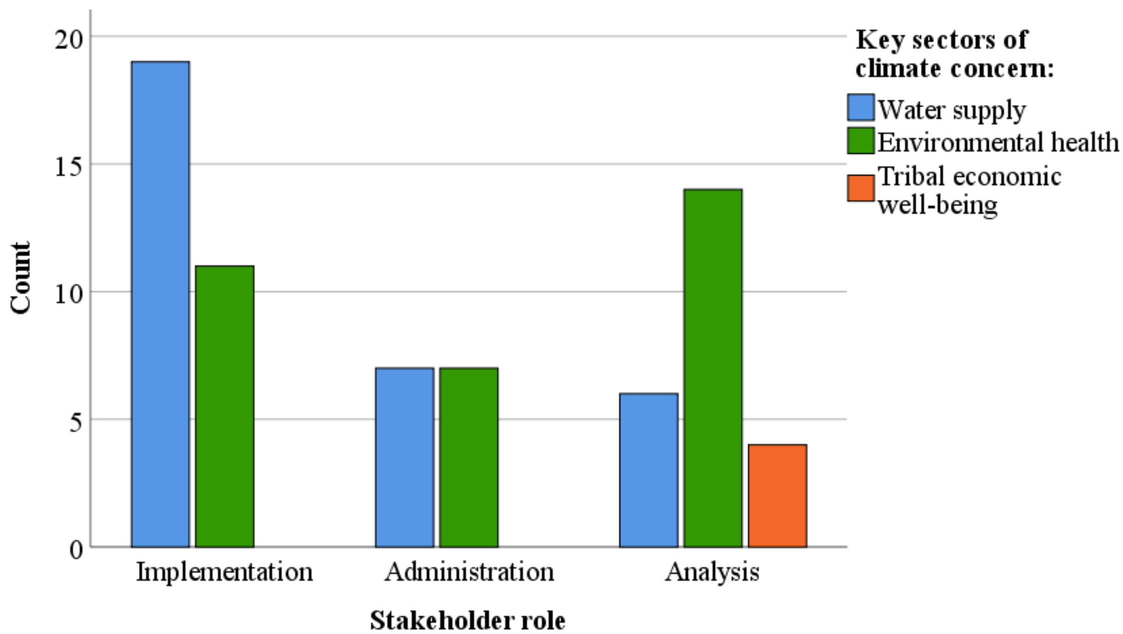


Figure 17. Cross-tabulation counts from the statistically significant association between **stakeholder role** and key **sectors of climate concern**.

4.5.2. Analyzing regional priorities. This section responds to the research question: "Do data/information priorities and accessed resources differ by location of reservation within the study region?" The intent behind this research question is to assess differences or similarities in regional priorities for climate data and information needs based on respondents' reported locations. Regional studies of Indigenous communities are relatively rare at least partially due to the diversity between Indigenous communities.

Aggregating this variable from reservation locations to a more regional scale is necessary in order to conduct a true regional assessment of stakeholder needs. The limited response rate (N = 99) distributed over a large geographic area reduces statistical significance when comparing differences in responses based on different communities. The intention of this study is to assess stakeholder climate information and data needs. It is not the intention to compare responses across Indigenous communities. Grouping data based on the location of respondents' reservations within a larger watershed region ensures no comparison across specific tribes and allows for a true regional analysis of needs. Differences in responses may provide important insight in to how to more effectively direct and improve data and information resources.

A flow-chart illustrating the codes used to identify the regional location categories is depicted in Figure 18. Respondents for this analysis either live or work on one or more of the 24 reservations as shown in Figure 18. Reservations are noted to demonstrate the dispersion of respondents across this regional study. The number of survey respondents self-reporting by each individual tribe and/or reservation is omitted purposefully in order to protect respondents' anonymity and tribal data sovereignty.

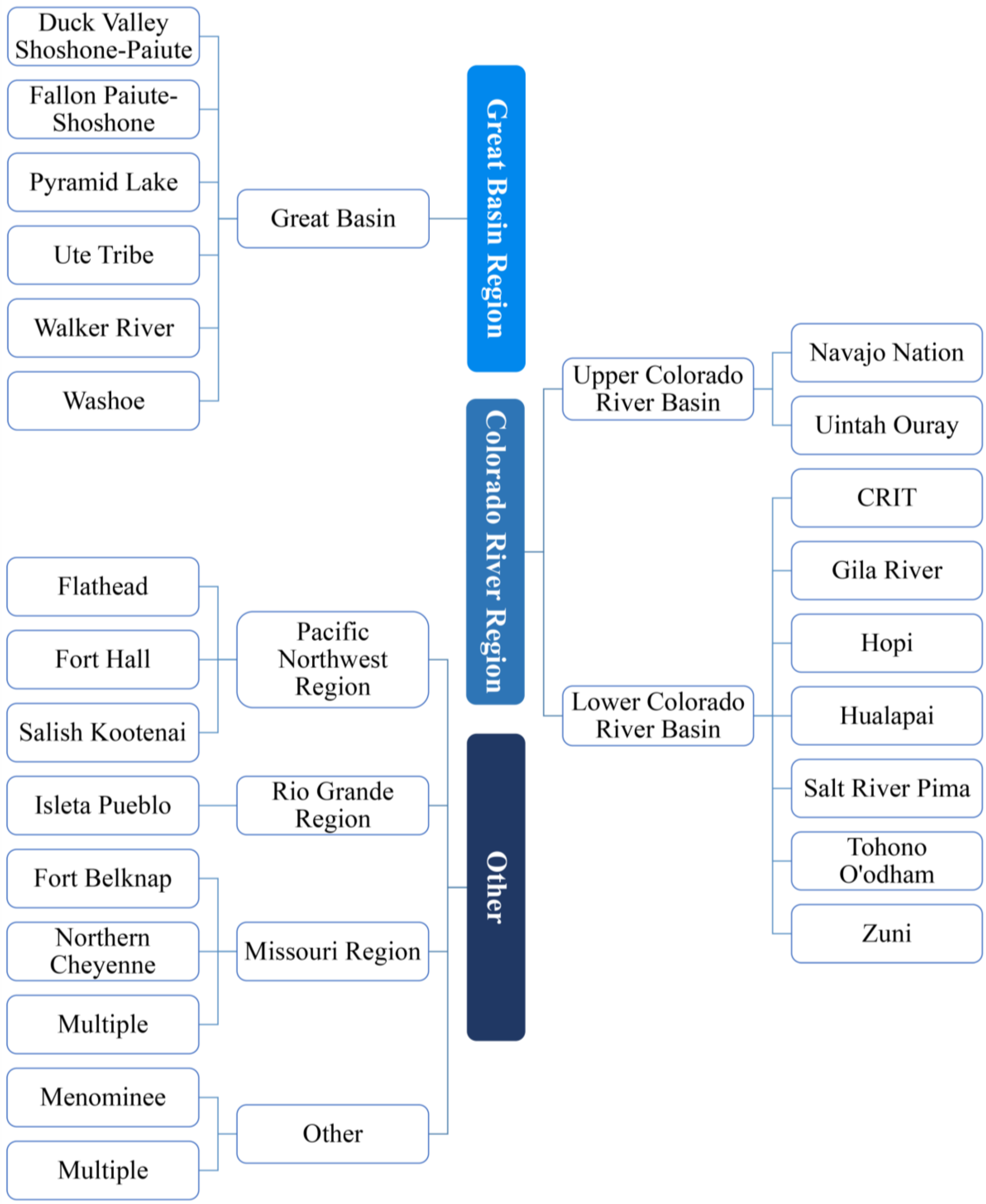


Figure 18. Coding and categorization process leading to the stakeholder region variable.

Chapter 2.2. describes the thesis study region (see page 12). Several survey respondents indicated they live or work outside of these study region boundaries. Respondents not located within the study region (Great Basin and Colorado River region) are grouped into an "other" category and thus treated as outlier observations in order to keep the focus of this study on the southwestern U.S., as it is defined for this study. As evidenced by the relatively high percentage of respondents living or working in Arizona and Nevada – the core states in the Great Basin and Colorado River region – it is not unreasonable to maintain the focus of this study on these two regions (see Figure 19). Figure 20 displays the percentage of respondents distributed across seven USGS water resource regions (2-digit HUCs). These seven watershed codes are grouped again and categorized into one of three overarching regions featured in this study. These regions are: (1) Great Basin Region; (2) Colorado River Region; and (3) other. Figure 21 displays the final distribution of respondents across the three regions used in the cross-correlation analysis of stakeholder region and responses to climate data and information priorities.

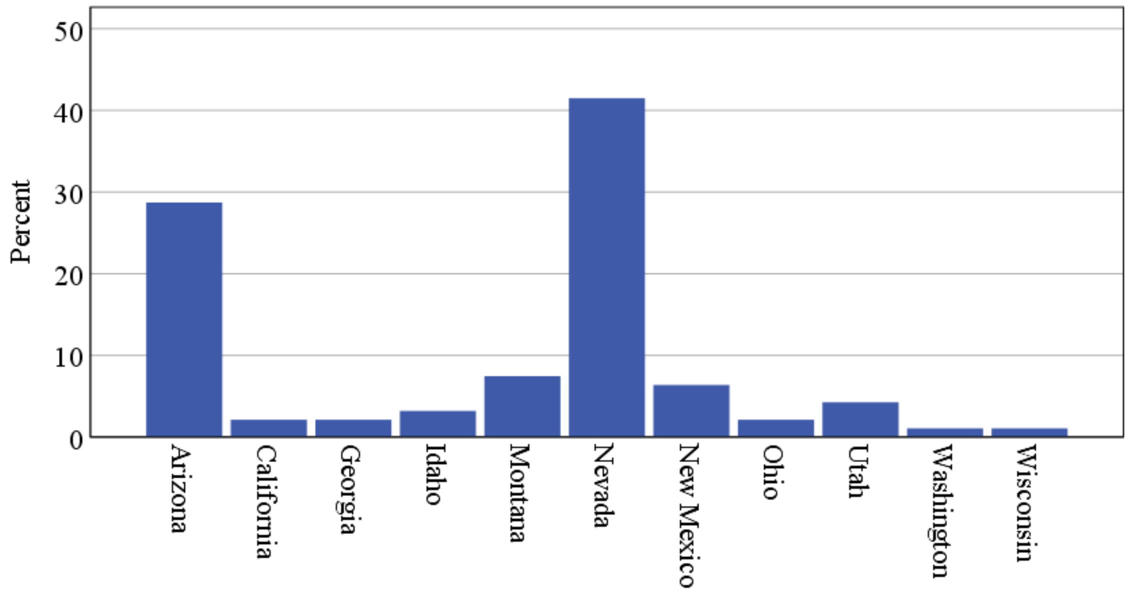


Figure 19. Percentage of respondents by state of residency/employment. Included to demonstrate the high frequency of participants living or working in those states most central to the study area, Arizona and Nevada.

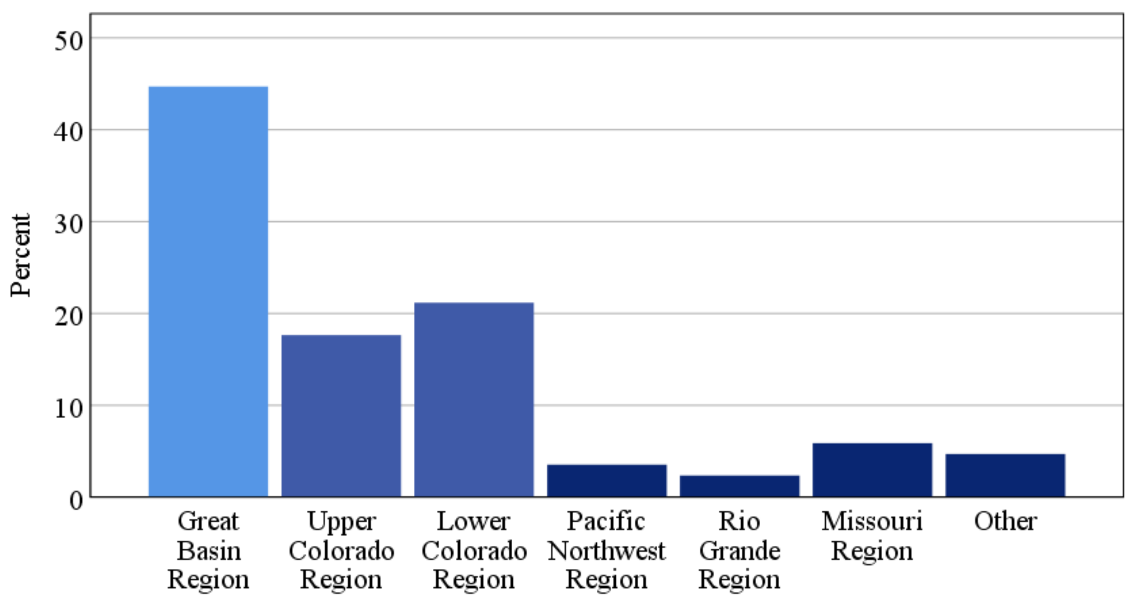


Figure 20. Percentage of respondents living or working within USGS water resource region at the HUC-2 level based on the location of the majority of indicated reservation.

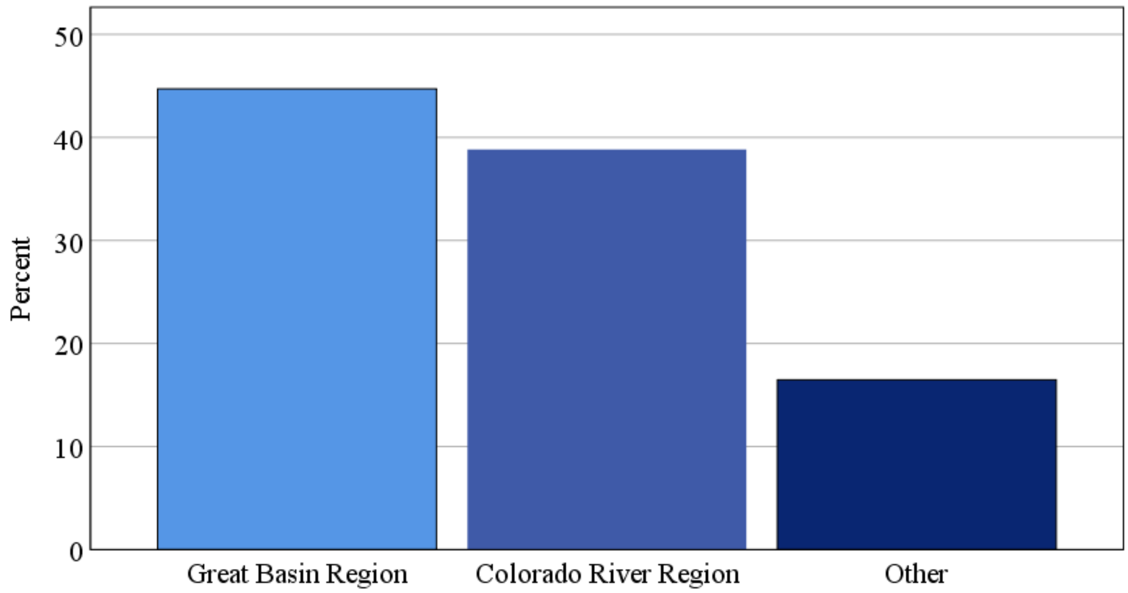


Figure 21. Percentage of respondents living or working within the study region - an aggregated variable used in cross-correlation analysis of stakeholder region with climate data and information priorities.

The significant majority of survey respondents lives or works in the Great Basin region and the Colorado River region (see Figure 21). This high representation of respondents within the study area ensures that overall results, including the priority ranking of climate data and information needs, are reasonably representative of stakeholders working and/or residing on reservation lands in the Southwest. Furthermore, cross-tabulation results of association with statistical significance will reveal climate data and information priorities that may have been skewed due to respondents grouped in the “other” category.

The same methodology in the section above is used to test for correlation between stakeholder region and climate data and information needs. The statistically significant associations calculated using the Pearson Chi-square test are reported below in Table 7 along with the associated significance value (p-value). The cross-correlation results are discussed for each association and are reported through graphical representations.

Table 7

Needs Correlating to Stakeholder Region

Overall Rank	Information Needs:	p-value
4	How to protect traditional knowledge that tribes incorporate into their adaptation plans	0.098
7	Adaptation strategies that address issues unique to tribal lands	0.066
8	How to conduct a climate resilience assessment	0.087
10	Meaning of future climate projections for individual reservations	0.035
Overall Rank	Data Needs:	p-value
8	Raw data collected from monitoring instruments	0.045
n/a	Scale of precipitation data (hourly v. daily v. monthly)	0.091
n/a	Scale of temperature data (hourly v. daily v. monthly)	0.051
n/a	Scale of streamflow data (hourly v. daily v. monthly)	0.052
Overall Rank	Data and information sources:	p-value
1	Tribal natural resource/water/land departments	0.060
7	Colleges and universities	0.028
8	Tribally owned and operated monitoring equipment	0.090
11	The Weather Channel; Weather.com; local news and radio	0.058

Note. Overall rank refers to the prioritized need rankings reported in tables 2 through 5. Cross-correlation results with statistically significant associations. Significance determined using a 90% confidence interval ($p < 0.10$) calculated using a Pearson's Chi-square test of association.

There are four statistically significant associations between regional location and responses to climate information needs. The cross-correlation results between the region variable, and the information priority, "How to protect traditional knowledge that tribes incorporated into their adaptation plans," suggest that this information need is of "high priority" to "very high priority" to respondents living or working within the Colorado River region, but for respondents living or working in the Great Basin region, this need rated comparatively lower (see Figure 22). The role of traditional knowledge in climate adaptation on reservation lands varies between tribes making it difficult to make assumptions about the reasoning behind this regional trend. This result may be attributed to the cultural diversity of Indigenous communities within the Colorado River region as compared to the Great Basin region. Federally-recognized tribes in the Great Basin who share similar cultural backgrounds may already have methods of sharing and protecting traditional knowledge across communities. This assumption, however, is not comprehensive, as many independent factors may influence this association. In order to better understand this relationship, additional analysis is necessary.

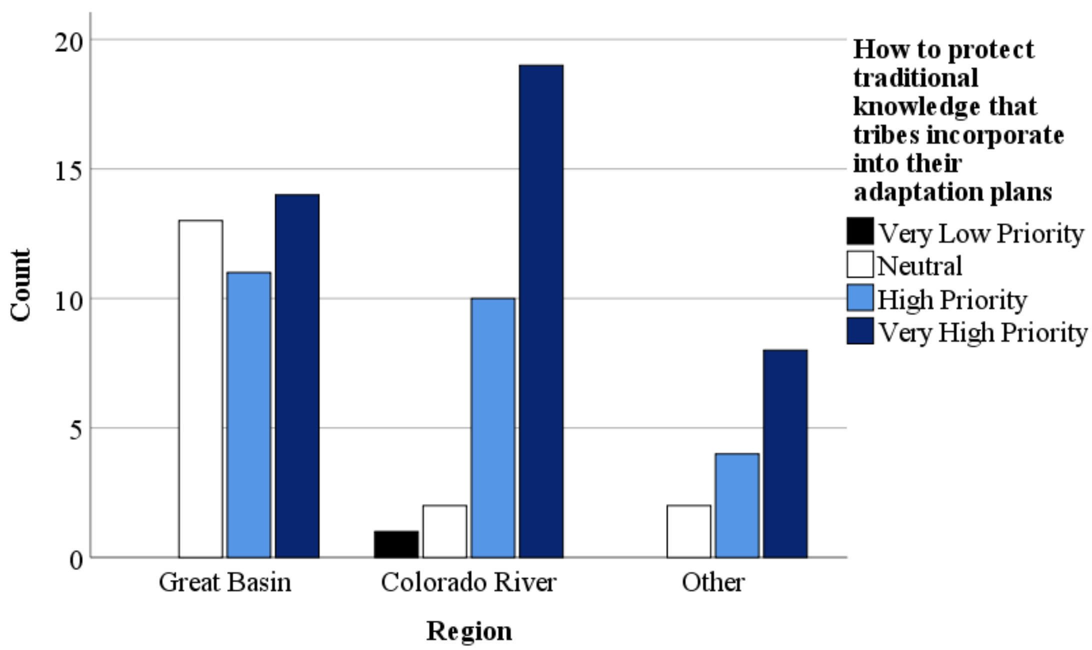


Figure 22. Cross-tabulation counts with a statistically significant association between the stakeholder **region** variable and the **climate information** variable, “How to protect traditional knowledge that tribes incorporate into their adaptation plans.”

The cross-correlation analysis between the stakeholder region variable and the climate information priority variable, “Adaptation strategies unique to tribal lands,” indicates a similar distribution of response associations. That is, respondents in the Colorado River region rated this climate information need as "high priority" and "very high priority" (see Figure 23). Respondents in the Great Basin region rated this variable comparatively lower, as "neutral."

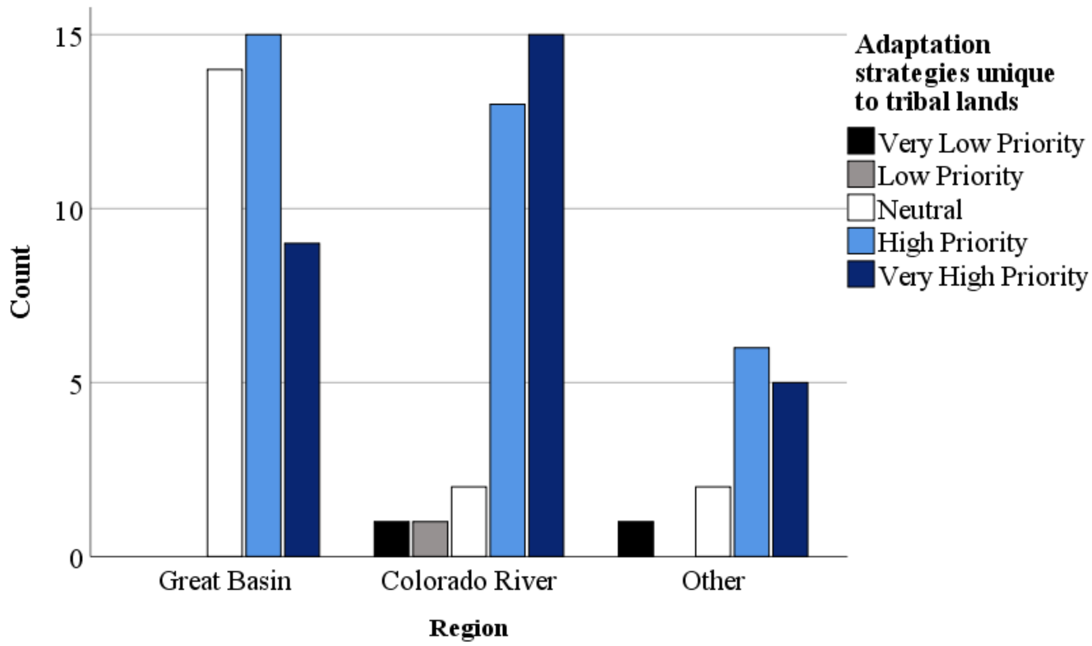


Figure 23. Cross-tabulation counts with a statistically significant association between the stakeholder **region** variable and the **climate information** variable, "Adaptation strategies unique to tribal lands."

The next ranked climate information priority variable with a statistically significant association with stakeholder region is, "How to conduct a climate resiliency assessment," (p = 0.087). The cross-tabulation result summary is depicted in Figure 24, and indicates that stakeholders in both the Colorado River region and the Great Basin region consider this topic to be of a "high priority." Respondents in the Great Basin region, however, had a slightly higher response counts in the "neutral" priority, and "high priority" categories, and a lower response count in the "very high priority" category than expected (see Appendix G). Priority response counts of stakeholders in the Colorado River region were in-line with the expected distribution of counts.

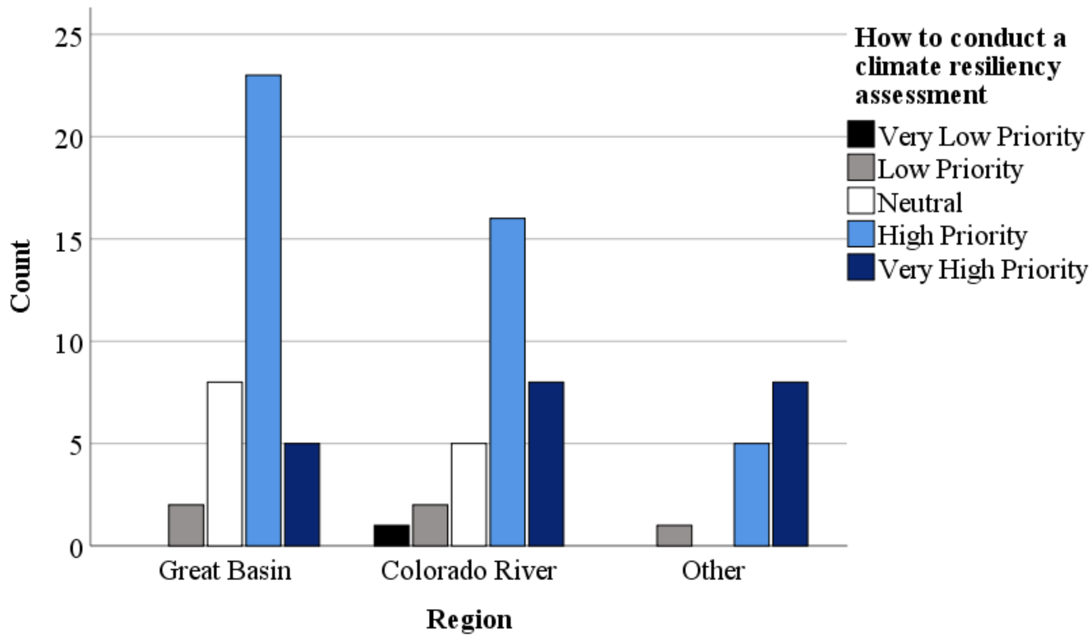


Figure 24. Cross-tabulation counts with a statistically significant association between the stakeholder **region** variable and the **climate information** variable, "How to conduct a climate resiliency assessment."

"Meaning of future climate projections for individual reservations" is the final climate information need variable with statistical significance association ($p = 0.035$) with the stakeholder region variable. The distribution of responses indicates that stakeholders in the Colorado River region are more likely to highly prioritize this topic compared to stakeholders in the Great Basin region (see Figure 25). This may suggest that the overall mean value ranking of this topic may be higher compared to the other climate information topic items if considering stakeholder needs in the Colorado River region independently.

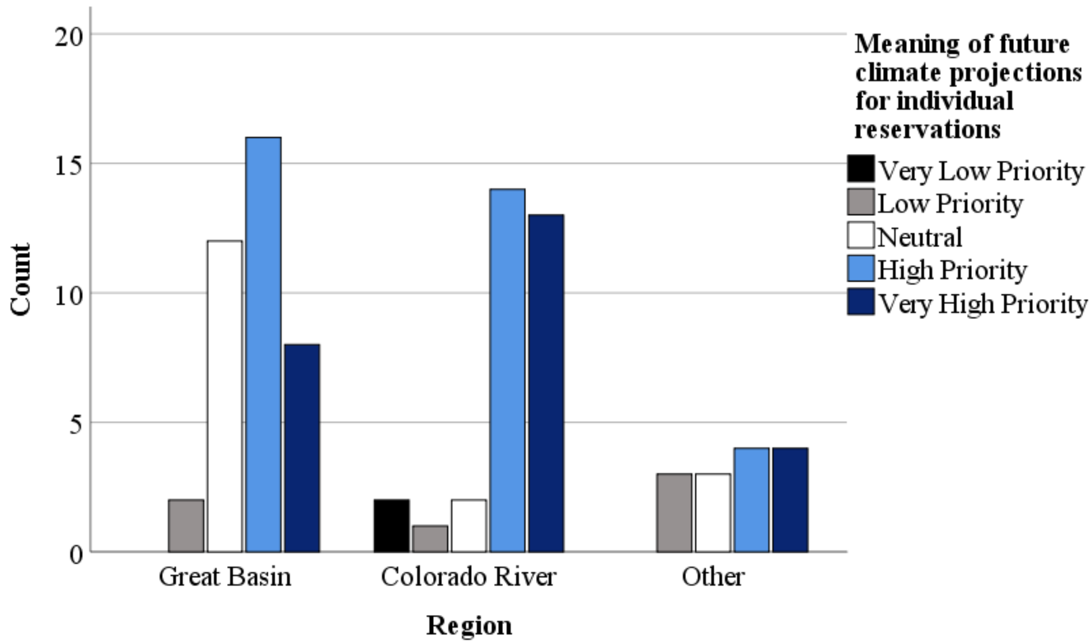


Figure 25. Cross-tabulation counts with a statistically significant association between the stakeholder **region** variable and the **climate information** variable, “Meaning of future climate projections for individual reservations.”

The relationship between stakeholder region and the climate data variable, “Raw data collected from monitoring equipment,” is statistically significant ($p = 0.045$). The cross-correlation analysis results reported in Figure 26 indicate that stakeholders in the Great Basin region may see this data type as less of a priority than stakeholders in the Colorado River region.

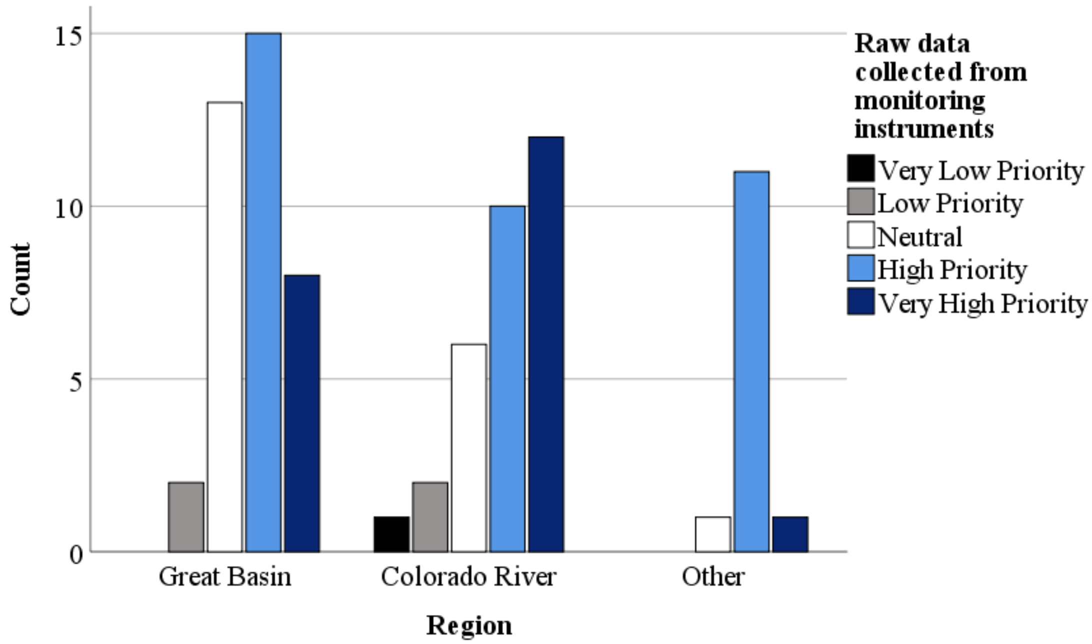


Figure 26. Cross-tabulation counts with a statistically significant association between the stakeholder **region** variable and the **climate data** variable, “Raw data collected from monitoring equipment.”

Survey respondents were asked to indicate to their priorities for climate data, and to indicate the scale of data: daily, hourly, or monthly (see Appendix D). Mean scores were not calculated for these responses because response categories are not of a Likert-type scale. These question items, therefore, were not considered during the overall ranking of data priorities. They were still included to test responses for association based on respondents’ demographic attributes.

Three climate data scale response items have statistically significant associations with the participant region variable (see Table 7). The climate data types include, precipitation, temperature, and streamflow. Respondents in the Great Basin region indicated with higher frequency that they are more likely to prioritize precipitation and temperature data at a monthly scale for climate adaptation (see Figure 27). Respondents in the Colorado River region, however, indicate that they are more likely to prioritize daily data for these two types.

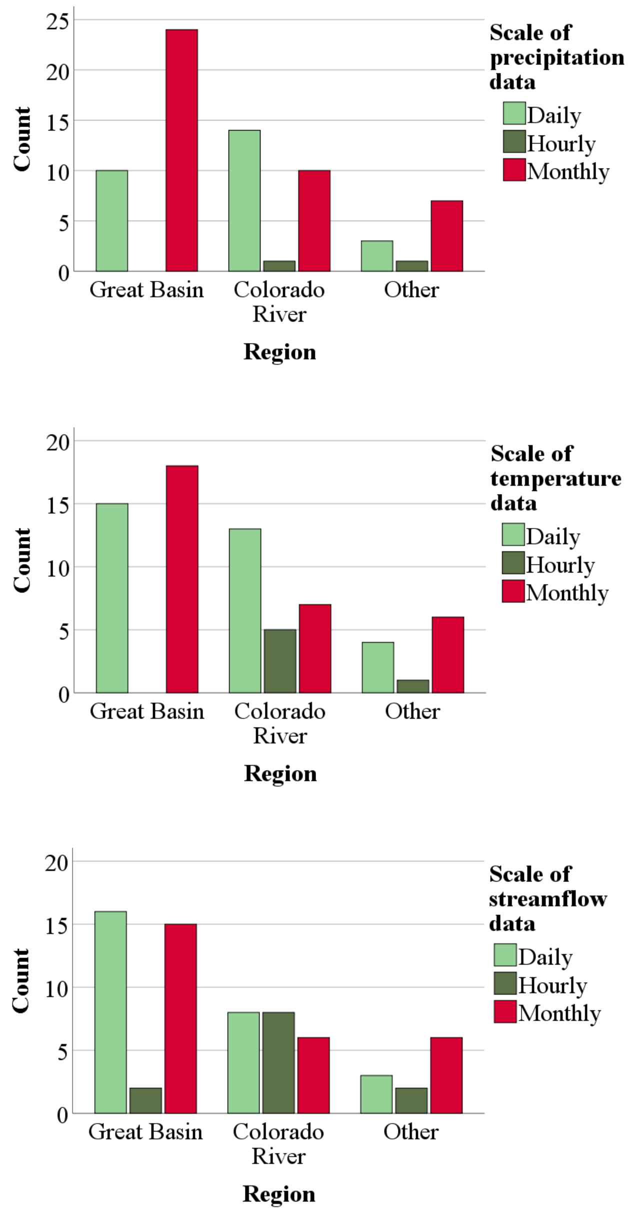


Figure 27. Cross-tabulation counts with statistically significant associations between the stakeholder **region** variable and the **scale of climate data** variables.

The cross-tabulated results suggest that stakeholder region influences the streamflow data scale needed. That is, respondents in the Great Basin region are nearly equally as likely to prioritize these data at both the daily and monthly scales while respondents in the Colorado River region are nearly equally as likely to prioritize these data at the hourly and daily scales (see Figure 27).

Cross-correlation analysis results between the stakeholder region variable and participant responses to climate data/information source variables are reported together in Figure 28 and Figure 29. Four associations have statistical significance: “Tribal natural resource/water/land departments” ($p = 0.060$), “Colleges, and universities” ($p = 0.028$), “Tribally owned and operated monitoring equipment” ($p = 0.090$), and “The Weather Channel; Weather.com; local news and radio” ($p = 0.058$).

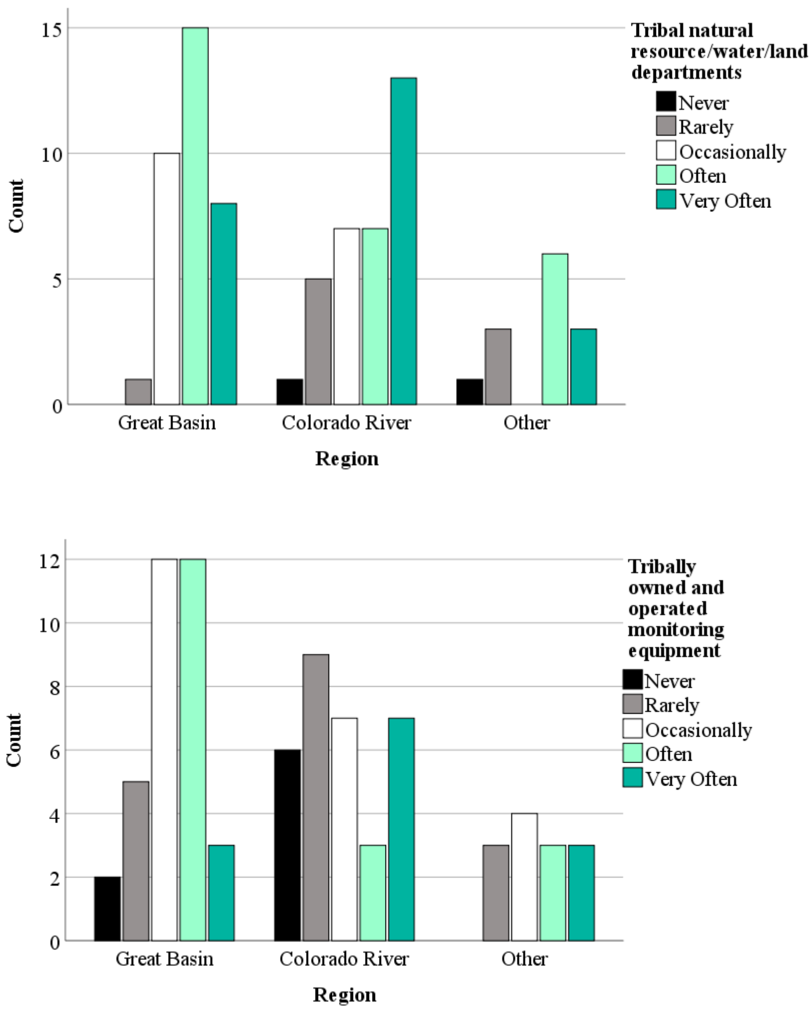


Figure 28. Cross-tabulation counts with statistically significant associations between the stakeholder **region** variable and the **data/information source** variables, "Tribal natural resource/water/land departments," and "Tribally owned and operated monitoring equipment." Note. These graphs do not have an equally distributed y-axis meaning that count frequencies cannot be compared across climate data/information source. For a detailed summary of count frequencies see Appendix G.

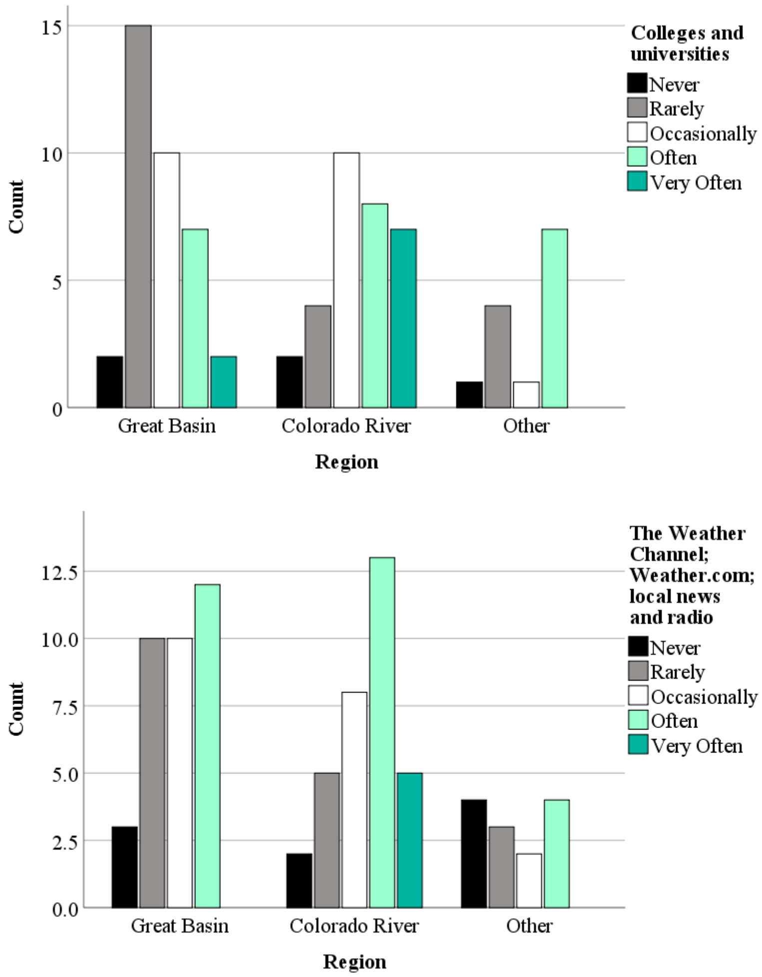


Figure 29. Cross-tabulation counts with statistically significant associations between the stakeholder region variable and the data/information source variables, "Colleges and universities," and "The Weather Channel; Weather.com; local news and radio." Note. These graphs do not have an equally distributed y-axis meaning that count frequencies cannot be compared across climate data/information source. For a detailed summary of count frequencies see Appendix G.

These associations are likely to be interrelated. For example, results suggest that stakeholders in the Great Basin region are less likely to be concerned about the misappropriation of traditional knowledge, are more likely to receive their climate data and information from tribal sources, and are less likely to access colleges and private weather information sources (the Weather Channel, Weather.com, local news, and radio) when compared to stakeholders in the Colorado River region. This result may also imply that stakeholders in the Colorado River region are more likely to be planning for climate change within an environment of diverse socio-cultural intersections. Also, stakeholders in the Great Basin region may be working at the local level with less outside influence due to the relative remoteness of reservations.

Although this observation is derived from the data and analysis results reported here, the data generated from this particular survey may not illustrate the myriad of components that may influence regional differences in prioritized climate data and information needs. For example, these associations may merely suggest that generally there is less available data at desired scales within these regions. Additional data collection through an increased survey sample size and further investigation, including focus group discussions, can help to determine causal relationships. That is, these results (significant at a 90% confidence interval) indicate that stakeholder region is associated with, but may not be a determinate factor in, the prioritization of particular climate data and information needs.

4.5.3. Educational attainment level priorities. This next set of analyses is included to test for differences in responses based on educational attainment levels. Educational levels may have implications for data and information accessibility due to exposure to and experience with multiple forms and sources of climate data and information. Groupings differ only slightly from the questionnaire response items in that “Less than high school” and “High School Diploma or equivalent” were grouped into a single category. Aside from this minor change in the distribution of responses to this question, this variable does not require further regrouping of categorical data.

Four levels of educational attainment are thus used to test for statistically-significant correlations. These include: (1) high school or less; (2) some college/technical or associates degree; (3) college degree (i.e., BS/BA); and (4) graduate degree (i.e., MS, JD, PhD, MD, etc.). The distribution of responses across these levels of educational attainment is depicted in Figure 30. These delineations are reasonably representative of the different levels of educational attainment characteristic of respondents in the study area.

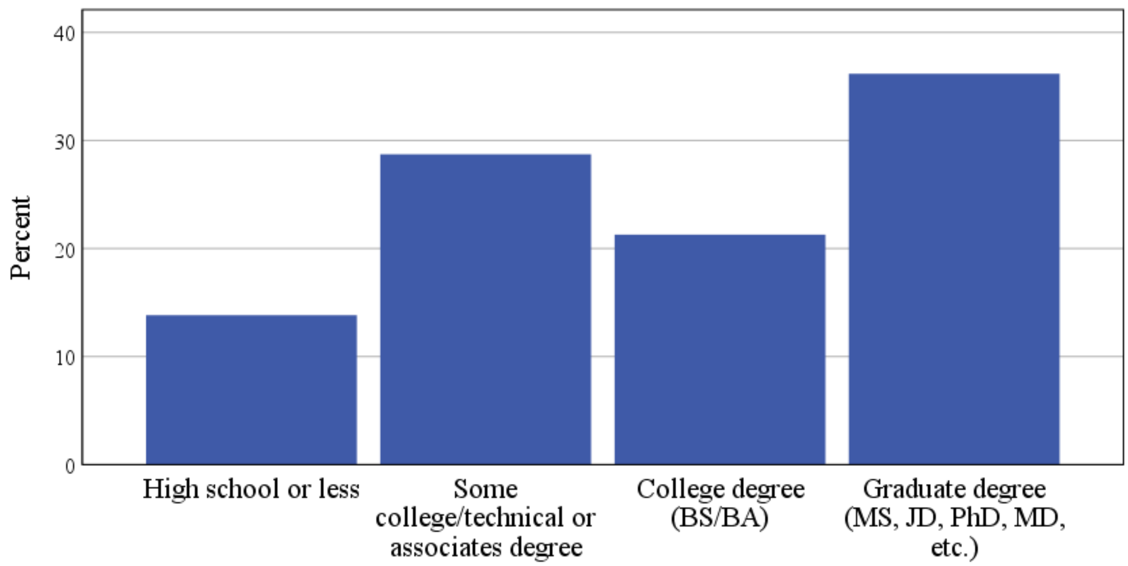


Figure 30. Percentage of respondents grouped into highest educational attainment level, based on responses to survey question 50.

The same methodology is employed here to test for correlation between stakeholder educational attainment levels and climate data and information needs. Statistically significant associations are reported in Table 8. Cross-correlation analysis summaries are depicted in Figure 31, Figure 32, Figure 33, Figure 34, and Figure 35.

These summaries are grouped based on the category in which the cross-analyzed variable exists (e.g. climate information, climate data, and/or climate data/information source).

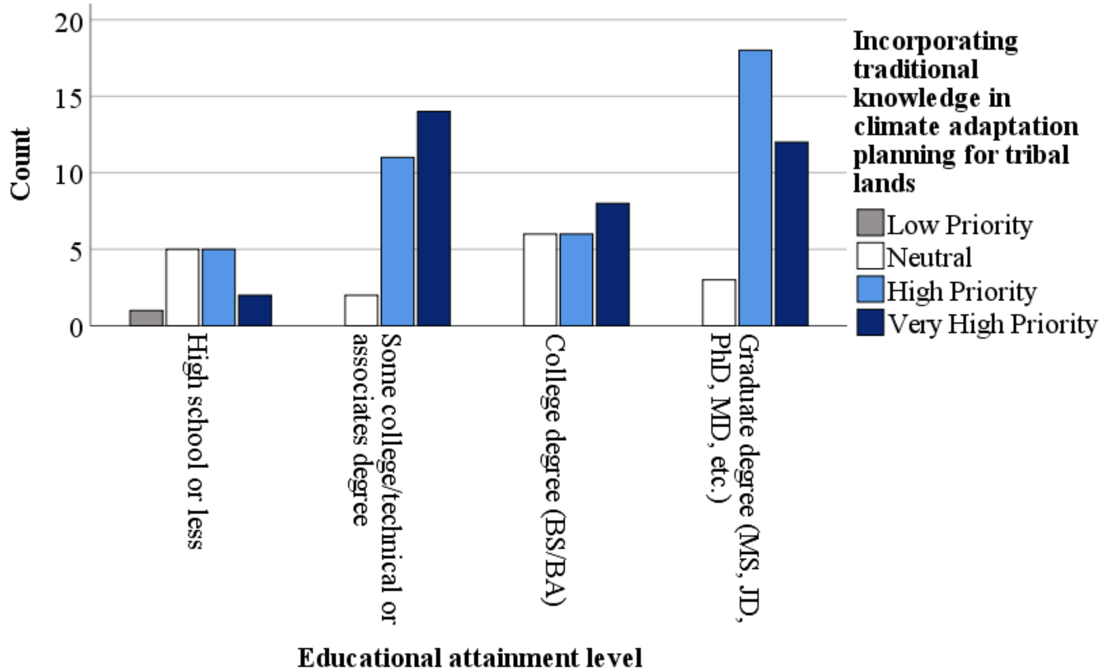
Table 8

Climate Data and Information Needs Correlating to Stakeholder Educational Attainment Levels

Overall Rank	Information needs	p-value
3	Role of traditional knowledge in climate adaptation planning for tribal lands	0.023
7	Adaptation strategies unique to tribal lands	0.072
Overall Rank	**Climate data needs**	**p-value**
6	Generalized reports or summaries on water resources and climate	0.037
n/a	Scale of streamflow data (hourly v. daily v. monthly)	0.039
n/a	Scale of generalized reports or summaries on water resources and climate (hourly v. daily v. monthly)	0.095
n/a	Scale of soil moisture data (hourly v. daily v. monthly)	0.079
n/a	Scale of raw data collected from monitoring instruments (hourly v. daily v. monthly)	0.026
Overall Rank	**Climate data/information source**	**p-value**
9	Native Water on Arid Lands Annual Tribal Summits	0.063

Note. Overall rank refers to the prioritized need rankings reported in tables 2 through 5. Cross-correlation results with statistically significant associations. Significance determined using a 90% confidence interval ($p < 0.10$) calculated using a Pearson's Chi-square test of association.

The distribution of response frequencies is similar for three of the educational attainment categories in their association with both climate information variables, "Role of traditional knowledge in climate adaptation planning for tribal lands," and "Adaptation strategies unique to tribal lands" (see Figure 31). Respondents who indicated high school as their highest level of educational attainment were more likely to rate both of these climate information variables as being of a more "neutral" (neither low nor high) priority than the expected count for these variables (see Appendix G). Respondents with some college education (associate or technical degrees) were more likely to rate both variables as being of a “very high priority” compared to their expected count (see Appendix G). Respondents with graduate education degrees (MS, JD, MD, PhD, etc.) were more likely to rate both climate information variables as being of “high priority.” While the distribution of responses between these three educational attainment level categories are similar for these two climate information variables, this is most likely coincidental, as these information variables aren’t particularly related. Respondents with undergraduate college degrees (BS, or BA) rated the role of traditional knowledge variable as being of a more “neutral” priority than the expected count, but rated the variable referring to adaptation strategies unique to tribal lands in-line with the expected count distribution of priorities for this variable (see Appendix G).



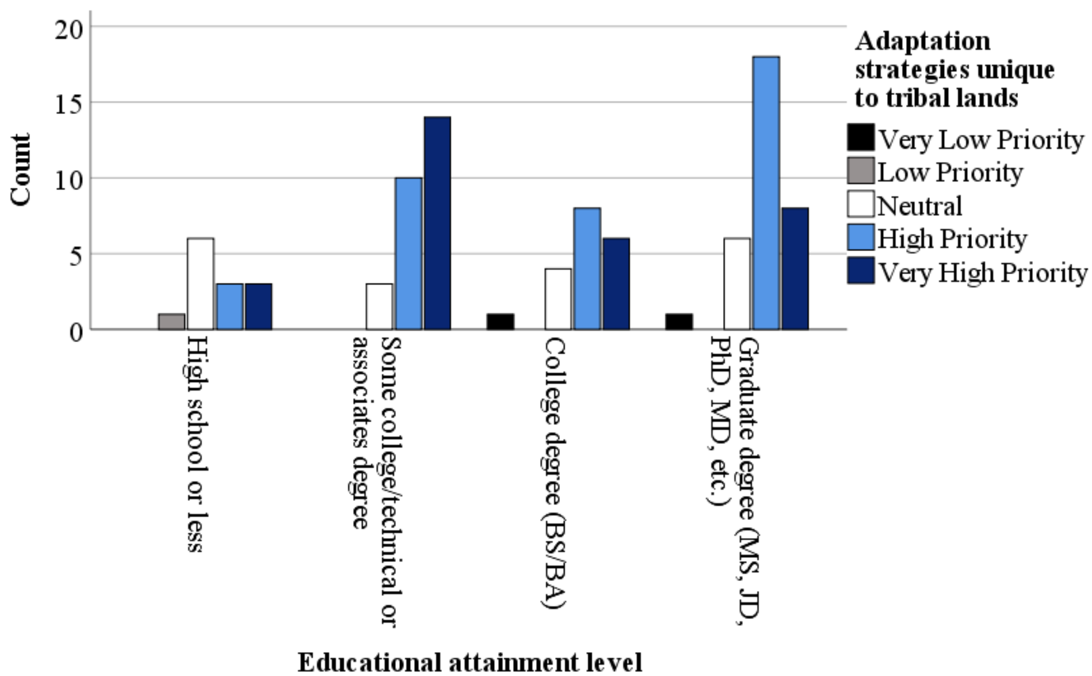


Figure 31. Cross-tabulation counts with statistically significant associations between the stakeholder **educational attainment level** variable and the **climate information** variables, "Incorporating traditional knowledge in climate adaptation planning for tribal lands," and "Adaptation strategies unique to tribal lands."

Educational attainment level has a statistically significant association with the climate data need, "General reports or summaries on water resources and climate information" (p = 0.037). Figure 32 shows the distribution of responses in this cross-tabulation. Respondents with undergraduate and graduate degrees prioritize this variable similar to their expected count distributions (i.e., majority indicating that this variable is of a "high priority") (see Appendix G). Respondents with high school educations are more likely to indicate that this variable is of "neutral" priority, and respondents with only some college education were significantly more likely to indicate this variable is of "high priority" relative to the other priority categories (see Figure 30). For a detailed summary of count frequencies see Appendix G.

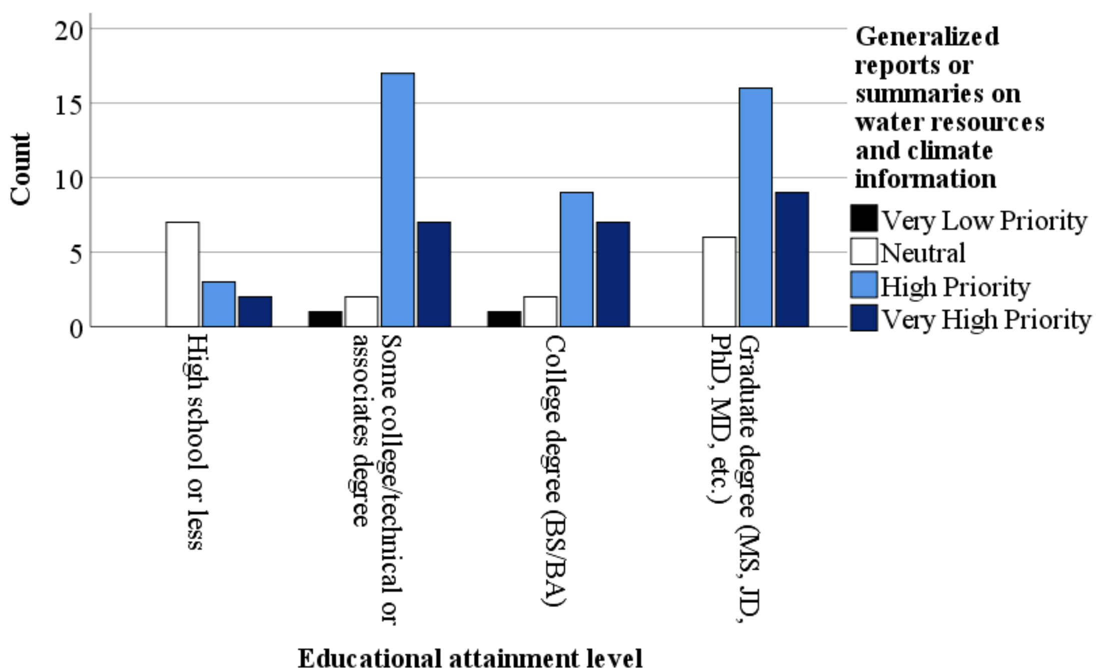


Figure 32. Cross-tabulation counts with statistically significant association between the stakeholder **educational attainment level** variable and the **climate data** variable, "Generalized reports or summaries on water resources and climate information."

The educational attainment level variable was also cross-correlated with the scale (daily, hourly, or monthly) of climate data variables. This analysis resulted in four statistically significant associations between educational attainment level and the needed scale of streamflow data (p = 0.039), generalized reports on climate information (p = 0.095), soil moisture data (p = 0.079), and raw data collected from monitoring equipment (p = 0.036). The distribution of needed scale of climate data attributed to educational attainment level varies (see Figures 33 and 34).

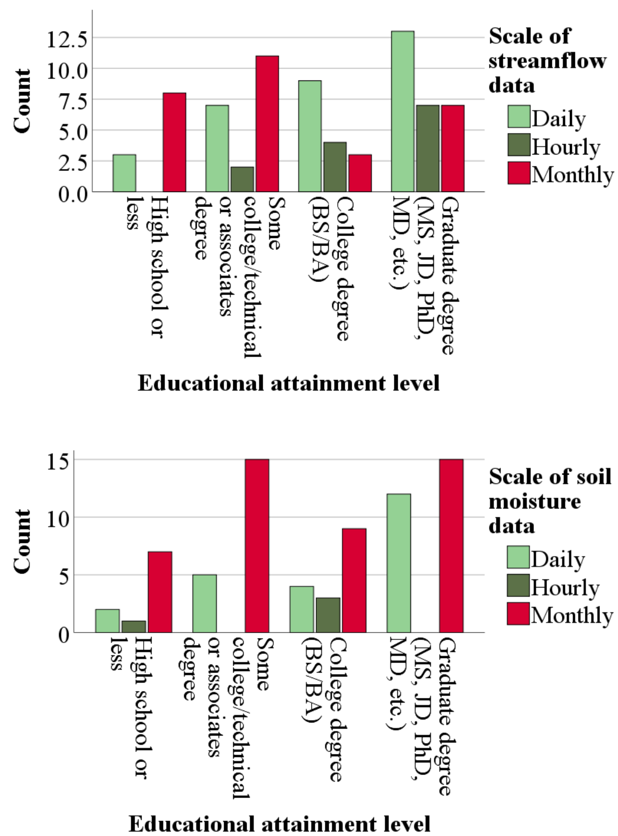


Figure 33. Cross-tabulation counts with statistically significant associations between the stakeholder **educational attainment level** variable and the **scale of climate data**, "scale of streamflow data," and "scale of soil moisture data." Note. These graphs do not have an equally distributed y-axis meaning that Count frequencies cannot be compared across here. For a detailed summary of count frequencies see Appendix G.

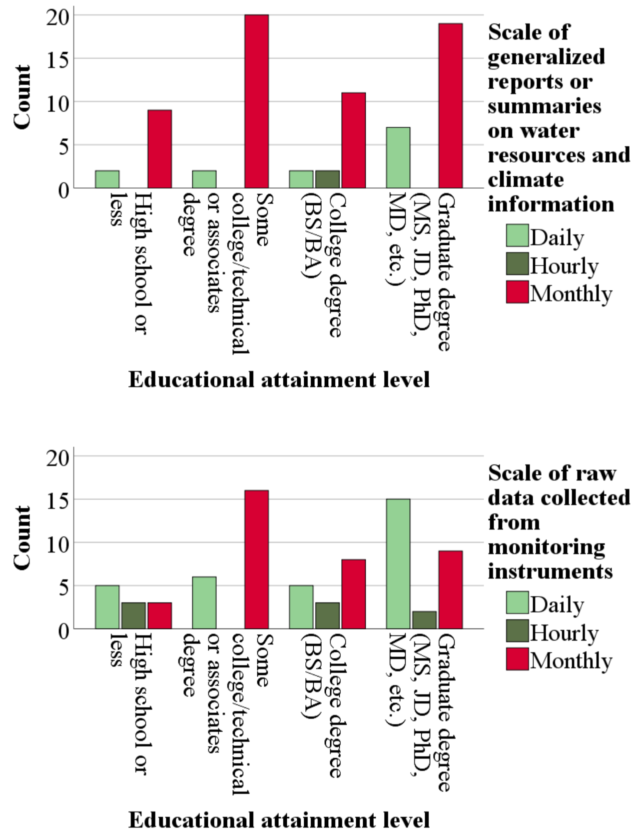


Figure 34. Cross-tabulation counts with statistically significant associations between the stakeholder **educational attainment level** variable and the **scale of climate data** variables, "scale of generalized reports or summaries on water resources and climate information," and "scale of raw data collected from monitoring instruments." Note. These graphs do not have an equally distributed y-axis meaning that Count frequencies cannot be compared across here. For a detailed summary of count frequencies see Appendix G.

Respondents with high school educations and those that attended some college were more likely to require streamflow data at a monthly scale while respondents with undergraduate and graduate degrees require these data at daily and hourly scales (see Figure 33). In regards to general climate summaries, respondents with high school educations did not vary from the expected distribution of response counts to each scale category (see Appendix G). Respondents with some college education had significantly higher counts in the monthly category than the expected distribution (see Appendix G) while respondents with undergraduate and graduate degrees required coarser scale data (see Figure 34). The remaining results for this correlation analysis are reported in Figure 34 and in Appendix G.

The climate data/information source variable, "Native Water on Arid Lands annual tribal summits," has a statistically significant association with educational attainment level ($p = 0.063$). The most significant difference in response count distributions involve respondents with some college education who indicated that they access this source for climate data and information "occasionally," "often," and "very often" with nearly equal frequency (see Figure 35). In contrast, respondents with graduate level degree educations indicate that they "rarely" access this source with the highest count frequency.

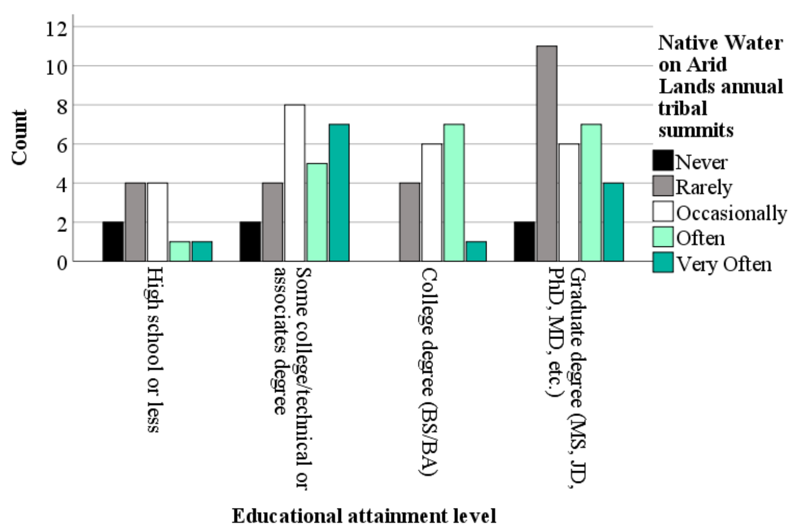


Figure 35. Cross-tabulation counts with statistically significant associations between the stakeholder **educational attainment level** variable and the **climate data/information source** variable, "Native Water on Arid Lands annual tribal summits."

Respondents with varied educational attainment levels appear to access the same climate information/data sources at the same frequencies aside from Native Water on Arid Lands Tribal Leadership Summits. This is an interesting finding given that educational attainment levels of stakeholders are related to the scale of data that they prioritize, but they are accessing the same data sources at similar frequencies. This finding may suggest that educational attainment levels neither improve nor restrict stakeholders' access to a variety of information resources.

As with the other correlative results, additional data collection from an increased sample size, or further investigation such as focus group discussions around these needs, can help determine causal relationships. That is, while these results are statistically significant at the 90% confidence interval, meaning educational attainment levels correlate with responses to certain climate information/data needs, this finding alone is insufficient to determine causal relationships.

4.5.4. Priorities based on gender. It is standard practice in social science survey research to test for statistical associations based on gender; furthermore, gender has shown to be an important variable in stakeholder relationships to climate science concepts (Smith et al., 2014). The majority (70%) of respondents in this study were male (n = 69) (see Figure 36). This may not be significantly disproportionate to the actual ratio of men to women of our target population.

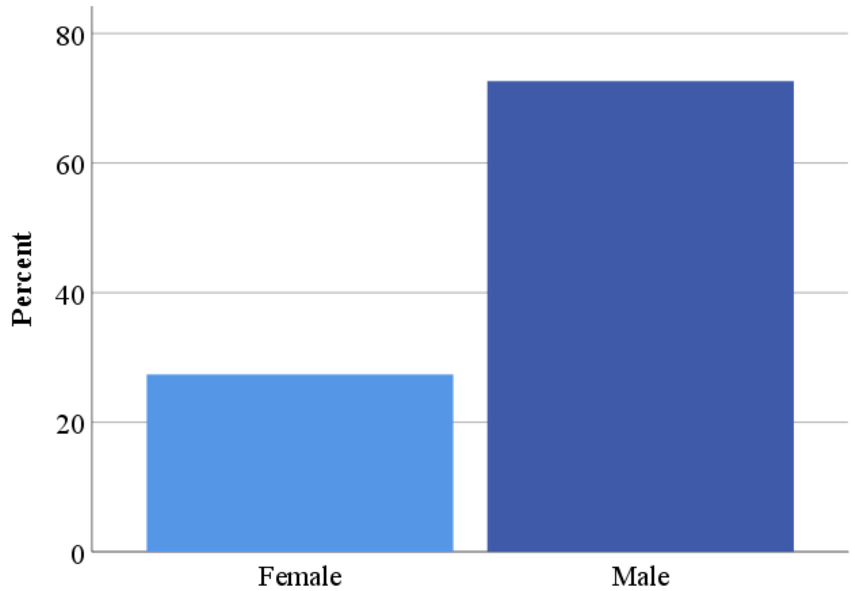


Figure 36. Gender distribution of survey participants. Male participants over double the number of female participants represented by the data.

Our target population includes individuals engaged (in any capacity) in climate adaptation initiatives on reservation lands. This often includes, but is not limited to, environmental land managers, water managers, tribal administrators, climate scientists, university professionals, and agriculturalists. In agriculture, women only 27% of the total farm operators, and only 12% of principle operators (Department of Agriculture, National Agriculture Statistics Service, 2014). In science, technology, engineering, and math (STEM) sectors, only 24% of the workforce are female (U.S. Department of Commerce, Economics and Statistics Administration, 2017). In higher education, 44% of full-time faculty in degree-granting institutions are female (U.S. Department of Education, National Center for Education Statistics, 2018). Under these considerations, within the targeted population of this study, the percentage of female respondents may reasonably representative in relation to their male counterparts.

Results from the cross-correlation analysis are reported in Table 9 and in Figures 37 and 38. Three topics tested significantly for association with gender. The climate data topics include, “precipitation data” (p-value = 0.040), and “generalized reports or summaries on water resources and climate information” (p-value = 0.040).

Table 9

Climate Information and Data Needs Correlating to Stakeholder Gender

Overall Rank	Climate data needs:	p-value
4	Precipitation data	0.040
n/a	Generalized reports or summaries on water resources and climate information	0.040
Overall Rank	**Climate data/information source:**	**p-value**
11	The Weather Channel; Weather.com; local news and radio	0.028

Note. Overall rank refers to the prioritized need rankings reported in tables 2 through 5. Cross-correlation results with statistically significant associations. Significance determined using a 90% confidence interval ($p < 0.10$) calculated using a Pearson’s Chi-square test of association.

The overall distributions of responses represented by the bar graphs in Figure 37 and Figure 38 depict the count differences of the two gender variables when cross-tabulated with climate data/information needs. For a statistically significant association between two categorical variables to exist, a difference in the distribution of responses for each category would also need to exist. This is clearly evident in Figure 38 where the distribution of responses within the female category is concave, and the distribution of responses within the male category is convex. When cross-tabulated, if there were no significant association, the clustered bar chart for each category would have a similar shape.

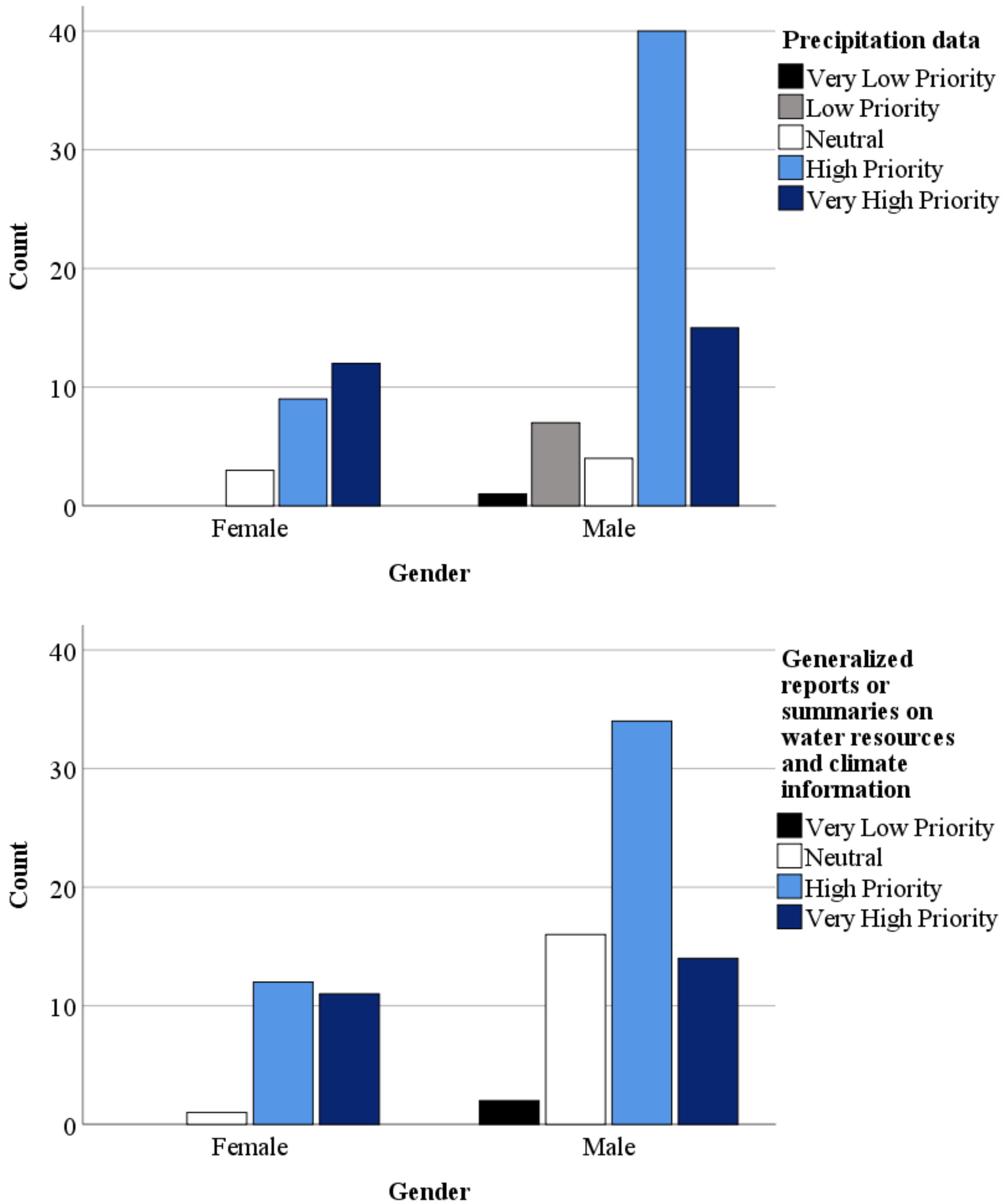


Figure 37. Cross-tabulation counts with statistically significant associations between stakeholder **gender** and the **climate data** variables, “Precipitation data,” and “Generalized reports or summaries on water resources, and climate information.”

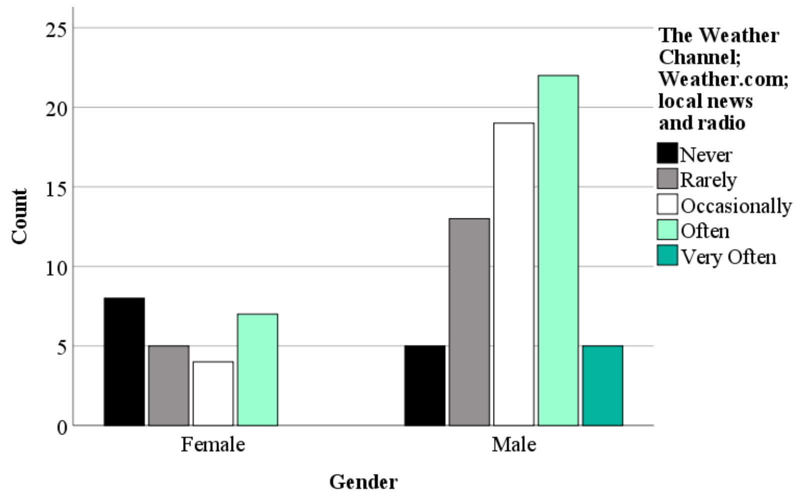


Figure 38. Cross-tabulation counts with statistically significant associations between stakeholder **gender** and the climate **data/information source** variable, 'The Weather Channel; Weather.com; local news and radio."

Female respondents were more likely to assign precipitation data a "very high priority" relative to their expected count, and male respondents assigned "high priority" to this topic relative to their expected count (see Appendix G). For generalized reports, more female respondents rated this as a "very high priority" relative to their expected count, and more male respondents rated this information/data need as a "neutral" priority. The last topic with a statistically significant association is the frequency of access of "the Weather Channel, Weather.com, or local news and radio" for climate information. While female respondents were more likely to "never" access this source relative to their expected count, male respondents were more likely to access this source "occasionally" and "frequently" relative to their expected count (see Appendix G).

4.5.5. Priorities based on age. Age groups are an important variable for any association analysis in social science research because they may indicate generational differences in responses. The significant majority (nearly 40%) of respondents are within the “55-64” age group while the smallest percentage of respondents are within the “16-24” age group (see Figure 39). The majority of respondents age 55-64 is nearly double any other age group, which is likely attributed to the sampling location at the Native Waters on Arid Lands Tribal Leadership Summit. That is, this summit targets tribal leaders, agriculturalists, land managers, and university research and outreach professionals, and requires significant funds to attend; therefore, it is expected that most survey respondents are probably mid-career and/or mature professionals.

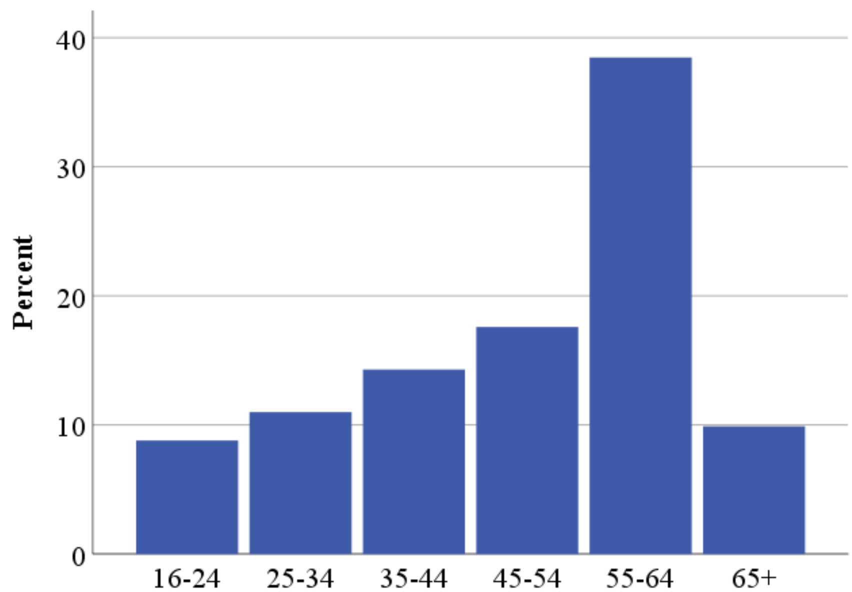


Figure 39. Age group distribution of participants.

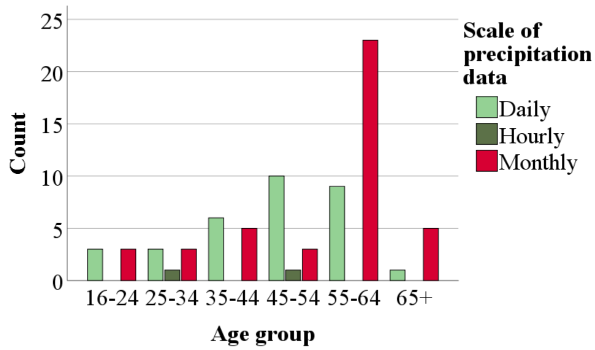
The only two topics with statistically significant associations with age are, the “scale of precipitation data: daily v. hourly v. monthly” (p-value = 0.061), and the “scale of water quality data: daily v. hourly v. monthly” (p = 0.055) (see Table 10). Cross-tabulation counts from the cross-correlation analysis are depicted in Figure 40. Very few respondents in any age group (e.g. no more than one per age group) indicated that they desire these data types at the hourly scale. For the younger age groups, “16-24,” “25-34,” the counts for “daily” and “monthly” precipitation data were evenly split. For water quality data, respondents in the “16-24” age group indicated they require this data at a “daily” scale. Respondents in the “35-44” and “45-54” age groups had higher counts in the “daily” scale for precipitation data, and higher counts in the “monthly” scale for water-quality data (see Figure 40). Age groups older than 55 years were more likely to require both data types at a “monthly” scale rather than “daily” or “hourly” scales. Considering only two climate information/data need variables and no climate/data source variables were identified as having statistically significant associations with age group, it is reasonable to assume that age is not a critical factor in the determination of priorities.

Table 10

Climate Information and Data Need Priorities Correlating with Stakeholder Age

Overall Rank	Climate Data Types	p-value
n/a	Scale of precipitation data (hourly v. daily v. monthly)	0.061
n/a	Scale of water quality data (hourly v. daily v. monthly)	0.055

Note. Cross-correlation results with statistically significant associations. Significance determined using a 90% confidence interval ($p < 0.10$) calculated using a Pearson’s Chi-square test of association.



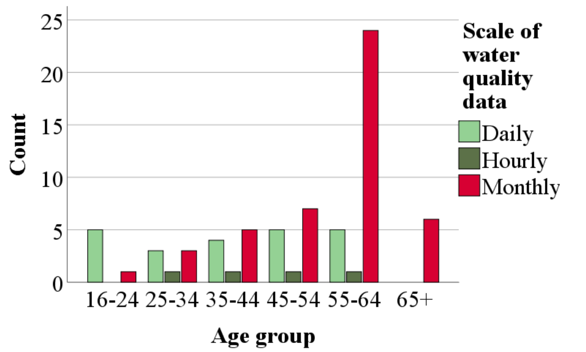


Figure 40. Cross-tabulation counts with statistically significant associations between the stakeholder **age group** variable and the **scale of climate data** variables, “Scale of precipitation data,” and “Scale of water quality data.”

Chapter 5

5.0 Implications and conclusions.

This study assesses and reports the climate information and data needs of Indigenous communities on reservation lands in the southwestern United States through the lens of individuals engaged in or interested in climate adaptation. That is, it applies socio-hydrological research framework to acquire new information about the potential influence of human perspectives on water supply and management in the face of climate uncertainty (Sivapalan, Savenije, & Bloschl, 2012). This emergent interdisciplinary field requires analyses of site-specific human-water systems and thus regional analyses (Nusser, 2017).

To this end, this thesis presents multi-step rationale and procedures for determining study area boundaries that depict arid snow-fed dependent regions featuring a significant number of federally-recognized tribes on reservation lands. A 50-question item survey is developed to examine human needs and interaction with pertinent climate information and data resources that can inform water management and climate adaptation on reservation lands. Using purposeful and convenience sampling strategies, the survey is administered to attendees of two annual tribal outreach summits focused on climate adaptation on reservation lands within the study area.

Survey respondents prioritize as their highest information/data need "Assessing climate impacts on tribal lands, water, and economies" (see Table 2). When land, water and economic impacts are considered separately, respondents indicate climate impacts on water resources as their greatest concern (see Figure 16). Survey respondents rank water quality data as the highest priority need followed by streamflow data. These results suggest strong relationships between Indigenous communities in these arid, snow-fed dependent regions and the hydrologic systems on which they depend.

Respondents also prioritize food security on reservation lands and incorporating traditional knowledge into climate adaptation initiatives, while also protecting traditional knowledge. In this arid study area, these identified needs imply significant socio-hydrologic relationships. That is, agricultural production in the Southwest is predominantly snow-dependent and thus, driven by summer water availability, limited by water scarcity, and increasingly impacted by climate change (Elias, Reyes, Steele, & Rango, 2018).

The persistence of Indigenous communities in a region characterized by historical climate extremes and water scarcity implies that climate resilience is an inherent part of the cultural makeup of these communities. Integrating traditional knowledge and values into adaptation strategies may be particularly advantageous, and perhaps a continuance of sustainable practices that have persisted and endured for thousands of years (Chief et al., 2016; Guatam et al., 2012)

Respondents indicate that the most frequently accessed climate data/information resource is tribal natural resource departments. This suggests that directing resources that increase the technical capacity of these departments to monitor, research, assess, and disseminate climate impact and adaptation information may be particularly beneficial to the adaptation initiatives of Indigenous communities. This capacity building may also contribute to strategies that assist in the protection of traditional knowledge. That is, the integration of traditional knowledge with climate impact analyses and adaptation is most likely to occur at the local or community scale rather through collaborative partnerships with outside entities (Klenk et al., 2017).

Additionally, this study demonstrates that certain experiential demographic attributes of respondents influence their prioritization and use of information and data for climate adaptation planning. The most significant findings suggest stakeholder role (a variable developed from respondent occupational information) in climate adaptation initiatives (either implementation, administration or analysis) is significantly associated with priority response differences to climate information/data needs, as well as frequently accessed sources of information. Respondents in analysis stakeholder roles (primarily research/education/outreach professionals) are more likely to identify economic impacts as a key concern due to climate uncertainty, while respondents in implementation (primarily land and water managers and farmers/ranchers), and administrative roles (primarily tribal government officials) significantly identify impacts on water resources as their primary concern. Additionally, respondents' geographic region was significantly associated with scale of climate data prioritized for their work, as well as respondent prioritization of protecting traditional knowledge. Other demographic variables including education, gender, and age, had less influence overall in associated response frequencies in the cross-correlative analyses.

Findings from this study can assist efforts to enhance the climate resiliency of Indigenous communities by reducing assumptions about climate information and data needs. Specifically, these assessment results uphold Indigenous data sovereignty and values by offering information to help focus applied climate adaptation research and educational outreach. The results also identify the demographic attributes of individuals who may willingly partner in integrative climate research with Indigenous communities on reservation lands.

5.1. Study limitations. This study presents a regional assessment of climate information and data needs specific to Indigenous communities on reservation lands. The overall response size of 99 participants makes it challenging to identify statistical significance or to determine causal relationships in the quantitative analyses of assessment data. While a ranking of information and data needs using mean scores produces a list of priorities, most mean scores are associated with large standard deviations; therefore, increasing the number of respondents is necessary to achieve smaller standard deviations, and to test the extent to which the mean-score ranks from this study are upheld with a larger sample size.

While collecting survey data during a conference setting represents both purposeful and convenience sampling methodologies, used to ensure regional representation, the results may not be readily generalizable to the larger regional population. An example of this is demonstrated by the age distribution of respondents to this survey. The high percentage of respondents ages 55-64 (see Figure 37) may indicate that the sampling strategy employed here excludes early-career professionals engaged in climate adaptation initiatives on reservation lands. That is, summit attendance requires substantial registration fees and travel funds, which can limit the participation of early career professionals, students, and/or community members interested or active in climate adaptation.

Survey respondents rated most needs featured in this survey as either “high priority” or “very high priority.” This may be a result of sampling at a conference focused on climate change impacts to water resources on reservation lands. It can be assumed that summit attendees would prioritize all of the needs featured in the assessment survey. The results reported here, however, can still inform additional research and guide early engagement with Indigenous communities seeking assistance.

Experimentation with varied modes of survey administration may inform these potential study limitations and also increase sample size. For instance, administering an identical survey instrument online may be one method to address the limitations noted here. This may ensure that the results are more representative of tribal departmental goals, tribal leadership, and the future generation of climate scientists and planners on reservation lands.

5.2. Collaboration ethics and protecting Indigenous data sovereignty. Comprehensive climate adaptation planning on reservation lands incorporates multiple forms of information, data, knowledge, and processes. It recognizes and honors the sovereignty of tribal communities and incorporates well-rounded vulnerability/resiliency assessments that address potential cultural, political, and economic impacts of climate uncertainty (Klenk et al., 2017; Maldonado et al., 2016; Williams & Hardison, 2013). It is informed by both local and traditional knowledge as well as climate and environmental data and model projections (Cochran et al., 2013; Maldonado et al., 2016).

The ability for Indigenous communities to conduct this work independently is possible, but results from this needs assessment suggest that those engaged in climate adaptation initiatives may have limited capacity and resources necessary to assess climate impacts on their reservations and/or communities (see Table 2). For these communities, engaging in collaborative research efforts with outside agencies, organizations, and universities may help to meet community adaptation goals.

Furthermore, researchers are increasingly encouraged and expected to engage with Indigenous communities to ensure that research findings are useful to decision making processes (Meadow et al., 2015; Singletary & Sterle, 2018). Engaging with Indigenous communities and weaving traditional knowledge into scientific research pursuits has demonstrated mutually beneficial results for both researchers and Indigenous communities (Fernald et al., 2015; Granderson, 2017; Ignatowski & Rosales, 2013; Klenk et al., 2017; Lemelin et al., 2010; Maldonado et al., 2016; Murphy, 2011; Williams & Hardison, 2013).

Given the historical exploitation of Indigenous traditional knowledge and community resources, however, many Indigenous communities are rightfully hesitant to partner with outside agencies, groups, and individuals (Savaresi, 2018). To help address these challenges, researchers propose increasing the use of participatory and collaborative research frameworks (Climate and Traditional Knowledges Workgroup, 2014). Such research approaches, and the partnerships they require, should ensure prior and informed consent concerning the use of primary and secondary data and information including how it will be used and shared. These additional, yet critical, steps in research agendas honor the co-production of any resulting new knowledge and information (Klenk et al., 2017; Maldonado et al., 2016).

This thesis is unique in that it offers a regional assessment of information and data needs to support climate adaptation on reservation lands. Because of complex sociological, cultural, economic, and environmental diversity among Indigenous communities, it is inappropriate to comparatively analyze survey responses by reservation or tribes. It may also be inappropriate, to extrapolate results from regional and/or case studies as being representative of Indigenous communities at larger geographic scales. This thesis attempts to overcome this paradox by using community-based research methodologies, such as participatory research, and by intentionally deviating from western science frameworks for reporting both primary and secondary data.

One of the most important and foundational aspects of ethical engagement with Indigenous communities is achieving prior and informed consent from each community included in a research study. Consent is defined differently by each Indigenous community but typically requires approval from tribal Internal Review Boards, and/or a tribal resolution approving the research from a governing body as outlined through its Constitutions and/or Law and Order codes. Considering that there are 49 Indigenous communities in this study area (see Table 1), the resources needed to achieve consent from each tribal government would make it very difficult to conduct survey research with each of these 49 communities. Including a community in this study without achieving consent, however, is unethical. This study overcomes this limitation by omitting tribal-specific data and analysis from the results and from reporting survey response frequency counts by tribe (see Appendix G). That is, instead of reporting results by tribe or reservation, results are analyzed and reported using respondents' occupational information (i.e., stakeholder role), educational attainment level, regional location, gender, and age.

Indigenous data sovereignty is an emerging concept used to describe the right of Indigenous communities to determine the collection, analysis, and dissemination of data involving their communities and natural resources (Kukutai & Taylor, 2016). This principle, however, contrasts with western science research frameworks that guide the collection, analysis, reporting, and dissemination of data. That is, western science frameworks tend to acknowledge the researcher(s), institution(s), or fiscal sponsor(s) responsible for the collection of data as the owner of the data. These outside entities, therefore, rather than the Indigenous communities from which the data are collected, have final authority over the use and dissemination of the data.

While this study sought and received approval from the University of Nevada, Reno Office of Research Integrity, Internal Review Board, additional steps were taken to honor the data sovereignty of the Indigenous communities located within the study area. For example, this study uses both secondary data (see Appendix B), and primary data (see Appendix F) to characterize and assess the climate information and data needs of Indigenous communities. These data, however, are reported categorically by regional geographic location, rather than by individual Indigenous community to ensure the protection of these communities from unintended harm. Community-specific data obtained through secondary sources have already been disseminated publicly. This thesis, however, recognizes that some of these data, specifically historical data, may not have been collected through the use of ethical research protocols (Harding et al., 2011). Therefore, the analysis featured here treats the secondary data collected with the same protections as primary data. While this study protects the anonymity of each individual research participant, which includes the consent to be included in this study, it did not acquire the official consent from the Indigenous communities in the study area represented by the sample population. Dissemination of parsed out or community-specific data, under these ethical considerations specific to Indigenous communities, would therefore require official consent from each Indigenous community.

It is important that researchers and local Indigenous knowledge holders are aware of both the limitations and the opportunities associated with these different forms and sources of information and knowledge (Lebel, 2013; Lofmarck & Lidskog, 2016). Strategies are necessary to evaluate the value of collaboratively generated science to local decision-making (Wall, Meadow, & Horganic, 2017), otherwise such information may not be useful as it may not fit into local decision-making contexts (Kalafatis et al., 2015). Overcoming these barriers will require creative collaborative research tailored to specific community characteristics and researchers skilled in these approaches.

5.3. Recommendations for future research. Investigations into the relationships between Indigenous communities and hydrologic systems in the southwestern U.S. can enhance the resiliency of these communities and also benefit the larger population of this region. For example, Indigenous communities hold nearly 46% of the total water allocations of the Central Arizona Project, which delivers water entitlements from the Colorado River to enhance water security in Arizona (Central Arizona Project, 2016). Future research with these Indigenous communities can be conducted through focus groups, interviews, and/or scenario studies. Additionally, future research should explore the relationships and roles between collaborative partners in socio-hydrologic research and the opportunities and barriers associated with these collaborations. This is necessary to create research frameworks that help to integrate social science research with hydrologic research. It may also improve decision-making support tools for land and water managers by making such tools more applicable to Indigenous community priorities. In addition to providing a sound framework to pursue coupled human–water systems research, the socio-hydrologic research approach, through the innovative lens as presented here, can inform policy and efforts to enhance climate resiliency (Nusser, 2017).

References

Anderson, T. L., & Parker, D. P. (2008). Economic development lessons from and for North American Indian economies. Australian Journal of Agricultural and Resource Economics, 53(1), 105–127. doi: 10.1111/j.1467-8489.2007.00426.x

Angelstam, P., Andersson, K., Annerstedt, M., Axelsson, R., Elbakidze, M., Garrido, P., …. Stjernquist, I. (2013). Solving problems in social-ecological systems: Definition, practice and barriers of transdisciplinary research. Ambio, 42(2), 254-265. doi:10.1007/s13280-012-0372-4

Arizona Water Settlement Act. Public Law 108-451. 118 STAT. 3499. (2004).

Arizona Department of Water Resources. (2010). Appendix G: Indian water rights claims and settlements. Arizona Water Atlas, 1, 162-168.

Armstrong, N. R., Shallcross, R. C., Ogden, K., Snyder, S., Achilli, A., & Armstrong, E. L. (2018). Challenges and opportunities at the nexus of energy, water, and food: A perspective from the southwest United States. MRS Energy & Sustainability: A Review Journal, 5(6), 1-18. doi:10.1557/mre.2018.2

Azar, C., Holmberg, J., & Lindgren, K. (1996). Socio-ecological indicators for sustainability. Ecological Economics, 18(2), 89-112. doi:10.1016/0921-8009(96)00028-6

Banner, S. (2005). How the Indians lost their land: Law and power on the frontier. Cambridge, MA: Belknap Press of Harvard University Press.

Benham, C. F., & Daniell, K. A. (2016). Putting transdisciplinary research into practice: A participatory approach to understanding change in coastal social-ecological systems. Ocean & Coastal Management, 128, 29-39. doi:10.1016/j.ocecoaman.2016.04.005

Bennett, K. E., Blanco, J. R. U., Jonko, A., Bohn, T. J., Atchley, A. L., Urban, N. M., & Middleton, R. S. (2018). Global sensitivity of simulated water balance indicators under future climate change in the Colorado Basin. Water Resources Research, 54(1), 132-149. doi:10.1002/2017wr020471

Bennett, T. M. B., Maynard, N. G., Cochran, P., Gough, R., Lynn, K., Maldano, G., … Cozzetto, K. (2014). Ch. 12: Indigenous peoples, lands, and resources. Climate Change Impacts in the United States: The Third National Climate Assessment, 297-317. doi:10.7930/J09G5JR1

Berkes, F., Colding, J., & Folke, C. (2000). Rediscovery of traditional ecological knowledge as adaptive management. Ecological Applications, 10(5), 1251-1262. doi:10.2307/2641280

Bernard, H. R. (2013). Social research methods: Qualitative and quantitative approaches (2nd ed.). Thousand Oaks, CA: AGE Publications, Inc.

Blodgett, A. T., Schinke, R. J., Smith, B., Peltier, D., & Pheasant, C. (2011). In Indigenous words: Exploring vignettes as a narrative strategy for presenting the research voices of Aboriginal community members. Qualitative Inquiry, 17(6), 522-533. doi:10.1177/1077800411409885

Booth, D. T., Cox, S. E., Simonds, G., & Sant, E. D. (2012). Willow cover as a stream-recovery indicator under a conservation grazing plan. Ecological Indicators, 18, 512-519. doi:10.1016/j.ecolind.2011.12.017

Brewer II, J. P., & Kronk Warner, K. A. (2015). Protecting Indigenous knowledge in the age of climate change. Georgetown International Environmental Law Review, 27(4), 585-628.

Carmines, E. G., & Zeller, R. A. (1979). Reliability and validity assessment. Beverly Hills, CA: Sage Publications.

Cayan, D. R., Das, T., Pierce, D. W., Barnett, T. P., Tyree, M., & Gershunov, A. (2010). Future dryness in the Southwest U.S. and the hydrology of the early 21st century drought. Proceedings of the National Academy of Sciences of the United States of America, 107(50), 21271-21276. doi:10.1073/pnas.0912391107

Central Arizona Project. (2016). Tribal water. Central Arizona Project. Received from: https://www.cap-az.com/tribal-water

Chen, X., Wang, D. B., Tian, F. Q., & Sivapalan, M. (2016). From channelization to restoration: socio-hydrologic modeling with changing community preferences in the Kissimmee River Basin, Florida. Water Resources Research, 52(2), 1227-1244. doi:10.1002/2015wr018194

Cherokee Nation v. Virginia. 30 U.S. 1 (1831).

Cheveau, M., Imbeau, L., Drapeau, P., & Belanger, L. (2008). Current status and future directions of traditional ecological knowledge in forest management: a review. Forestry Chronicle, 84(2), 231-243. doi:10.5558/tfc84231-2

Chief, K., Daigle, J. J., Lynn, K., & Whyte, K. P. (2014). Indigenous experience in the U.S. with climate change and environmental stewardship in the Anthropocene. In V. A. Sample, & Bixler, R. P. (Eds.). Forest conservation and management in the Anthropocene: Conference proceedings. Proceedings. RMRS-P-71. Fort Collins, CO: U.S. Department of Agriculture, Forest Service. Rocky Mountain Research Station. p. 161-176. Retrieved from https://www.fs.usda.gov/treesearch/pubs/46584

Chief, K., Meadow, A., & Whyte, K. (2016). Engaging southwestern tribes in sustainable water resources topics and management. Water, 8(8). doi:10.3390/w8080350

Climate and Traditional Knowledges Workgroup. (2014). Guidelines for considering traditional knowledge in climate initiatives (Version 1.0). Retrieved from https://climatetkw.files.wordpress.com/2014/09/tks_guidelines_v1.pdf

Cochran, P., Huntington, O. H., Pungowiyi, C., Tom, S., Chapin, F. S., Huntington, H. P., . . . Trainor, S. F. (2013). Indigenous frameworks for observing and responding to climate change in Alaska. Climatic Change, 120(3), 557. doi:10.1007/s10584-014-1187-z

Coffey, W., & Tsosie, R. (2001). Rethinking the tribal sovereignty doctrine: cultural sovereignty and the collective future of Indian nations. Stanford Law and Policy Review, 12(2), 191-221. Retrieved from https://heinonline.org/HOL/Page?handle=hein.journals/stanlp12&collection=journals&id=197&started=&endid=228

Colby, B., & Orr, P. (2005). Economic tradeoffs in preserving riparian habitat. Natural Resources Journal, 45(1), 15-31. Retrieved from https://digitalrepository.unm.edu/nrj/vol45/iss1/3

Colby, B., Thorson, J., & Britton, S. (2005). Negotiating tribal water rights: Fulfilling promises in the arid West. Tucson, AZ: University of Arizona Press.

Colorado River Indian Tribes. (2009). About the Mohave, Chemehuevi, Hopi, and Navajo tribes. Colorado River Indian Tribes. Retrieved from http://www.crit-nsn.gov/crit_contents/about/

Cosens, B., & Chaffin, B. C. (2016). Adaptive governance of water resources shared with Indigenous peoples: the role of law. Water, 8(3). doi:10.3390/w8030097

Cozzetto, K., Chief, K., Dittmer, K., Brubaker, M., Gough, R., Souza, K., . . . Chavan, P. (2013). Climate change impacts on the water resources of American Indians and Alaska Natives in the U.S. Climatic Change, 120(3), 569-584. doi:10.1007/s10584-013-0852-y

Cristea, N. C., Lundquist, J. D., Loheide, S. P., Lowry, C. S., & Moore, C. E. (2014). Modelling how vegetation cover affects climate change impacts on streamflow timing and magnitude in the snowmelt-dominated upper Tuolumne Basin, Sierra Nevada. Hydrological Processes, 28(12), 3896-3918. doi:10.1002/hyp.9909

Datta, R., Khyang, N. U., Khyang, H. K. P., Kheyang, H. A. P., Khyang, M. C., & Chapola, J. (2015). Participatory action research and researcher's responsibilities: an experience with an Indigenous community. International Journal of Social Research Methodology, 18(6), 581-599. doi:10.1080/13645579.2014.927492

Davidson-Hunt, I. J., & Berkes, F., (2001). Changing resource management paradigms, traditional ecological knowledge, and non-timber forest products. Forest Communities in the Third Millennium: Linking Research Business and Policy toward a Sustainable Non-Timber Forest Product Sector, 217, 78-92. Retrieved from https://www.fs.usda.gov/treesearch/pubs/44704

Deol, S., & Colby, B. (2018). Tribal economies: water settlements, agriculture, and gaming in the Western U.S. Journal of Contemporary Water Research & Education, 163(1), 45-63. doi.org/10.1111/j.1936-704X.2018.03269.x

Dettinger, M., Udall, B., & Georgakakos, A. (2015). Western water and climate change. Ecological Applications, 25(8), 2069-2093. doi.org/10.1890/15-0938.1

Di Baldassarre, G., Viglione, A., Carr, G., Kuil, L., Yan, K., Brandimarte, L., & Bloschl, G. (2015). Debates - perspectives on socio-hydrology: Capturing feedbacks between physical and social processes. Water Resources Research, 51(6), 4770-4781. doi:10.1002/2014wr016416

Dickinson, W. R. (2006). Geotectonic evolution of the Great Basin. Geosphere, 2(7), 353-368. doi:10.1130/ges00054.1

Dillman, D. A. (1978). Mail and telephone surveys: The total design method. New York, NY: Wiley.

Dingman, S. L. (2015). Physical hydrology (3rd ed.). Long Grove, IL: Waveland Press, Inc.

Donatuto, J. L., Satterfield, T. A., & Gregory, R. (2011). Poisoning the body to nourish the soul: prioritizing health risks and impacts in a Native American community. Health, Risk & Society, 13(2), 103-127. doi:10.1080/13698575.2011.556186

Draut, A. E., Redsteer, M. H., & Amoroso, L. (2013). Recent seasonal variations in arid landscape cover and Aeolian sand mobility, Navajo Nation, southwestern United States. Climates, Landscapes, and Civilizations, 198, 51-60. doi: 10.1029/2012GM001214

Drozdoff, L., Entsminger, J., Barbee, J., King, J., Boyle, D., Walker, M., … Cage, C. (2015). Nevada Drought Forum: Recommendations Report. Nevada Drought Forum. Retrieved from http://www.dri.edu/images/stories/divisions/dhs/dhsfaculty/Justin-Huntington/Executive_Summary_ASTP.pdf

Emm, S., Lewis, S., & Breazeale, D. (2002). Walker River Paiute Indian reservation agriculture and natural resource focus group session results. University of Nevada Cooperative Extension Fact Sheet (FS-02-46). Retrieved from https://www.unce.unr.edu/publications/files/nr/2002/FS0246.pdf

Falloon, P., & Betts, R. (2010). Climate impacts on European agriculture and water management in the context of adaptation and mitigation - the importance of an integrated approach. Science of the Total Environment, 408(23), 5667-5687. doi:10.1016/j.scitotenv.2009.05.002

Federal Water Pollution Control Act Amendments of 1972, Pub. L. 92-500, 86 Stat. 816 (1972).

Fernald, A., Guldan, S., Boykin, K., Cibils, A., Gonzales, M., Hurd, B., . . . Steele, C. (2015). Linked hydrologic and social systems that support resilience of traditional irrigation communities. Hydrology and Earth System Sciences, 19(1), 293-307. doi:10.5194/hess-19-293-2015

Ficklin, D. L., Stewart, I. T., & Maurer, E. P. (2012). Projections of 21st century Sierra Nevada local hydrologic low components using an ensemble of general circulation models. Journal of the American Water Resources Association, 48(6), 1104-1125. doi:10.1111/j.1752-1688.2012.00675.x

Fillmore, H. (2017). Using the Washoe language to inform hydrologic and environmental models. Groundwater, 55(5), 626-629. doi:10.1111/gwat.12571

Fillmore, H., Singletary, L., & Phillips, J. (2018). Assessing Tribal college priorities for enhancing climate adaptation on reservation lands. Journal of Contemporary Water Research & Education, 163(1), 64-78. doi:10.1111/j.1936-704X.2018.03270.x

Ford, J. D., Berrang-Ford, L. & Paterson, J. (2011). A systematic review of observed climate change adaptation in developed nations. Climatic Change, 106(2), 327. doi:10.1007/s10584-011-0045-5

Fowler, F. J. (2014). Survey research methods (5th ed.). Boston, MA: SAGE Publications, Inc.

Fritze, H., Stewart, I. T., & Pebesma, E. (2011). Shifts in Western North American snowmelt runoff regimes for the recent warm decades. Journal of Hydrometeorology, 12(5), 989-1006. doi:10.1175/2011jhm1360.1

Gamble, J. L., Balbus, J., Berger, M., Bouye, K., Campbell, V., Chief, K., … Wolkin, A. F. (2016). Ch. 9: Populations of concern. The impacts of climate change on human health in the United States: A scientific assessment. U.S. Global Change Research Program, Washington, DC, 247–286. doi:10.7930/J0Q81B0T

Gautam, M. R., Chief, K., & Smith, W. J. (2013). Climate change in arid lands and Native American socioeconomic vulnerability: the case of the Pyramid Lake Paiute Tribe. Climatic Change, 120(3), 585-599. doi:10.1007/s10584-013-0737-0

Gila River Indian Community. (2015). About. Gila River Indian community. Retrieved from http://www.gilariver.org/

Gilles, J. L., Thomas, J. L., Valdivia, C., & Yucra, E. S. (2013). Laggards or leaders: conservers of traditional agricultural knowledge in Bolivia. Rural Sociology, 78(1), 51-74. doi:10.1111/ruso.12001

Glaser, B. G., & Strauss, A. L. (1967). The discovery of grounded theory. strategies for qualitative research. Chicago, IL: Aldine.

Glass, R. D., Morton, J. M., King, J. E., Krueger-Henney, P., Moses, M. S., Sabati, S., & Richardson, T. (2018). The ethical stakes of collaborative community-based social science research. Urban Education, 53(4), 503-531. doi:10.1177/0042085918762522

Global Native. (2010). A Gila River Indian Community Farming Co. Retrieved from http://www.global-native.com/

Granderson, A. A. (2017). The role of traditional knowledge in building adaptive capacity for climate change: perspectives from Vanuatu. Weather Climate and Society, 9(3), 545-561. doi:10.1175/wcas-d-16-0094.1

Greetham, S. H. (2018). Water planning, tribal voices, and creative approaches: seeking new paths through tribal-state water conflict collaboration on state water planning efforts. Natural Resources Journal, 58(1), 1-49. Retrieved from https://digitalrepository.unm.edu/nrj/vol58/iss1/3

Gunda, T., Turner, B. L., & Tidwell, V. C. (2018). The influential role of sociocultural feedbacks on community-managed irrigation system behaviors during times of water stress. Water Resources Research, 54(4), 2697-2714. doi:10.1002/2017wr021223

Hales, J. E. (1974). Southwestern United States summer monsoon source Gulf of Mexico or Pacific Ocean. Journal of Applied Meteorology, 13(3), 331-342. doi:10.1175/1520-0450(1974)013

Harding, A., Harper, B., Stone, D., O'Neill, C., Berger, P., Harris, S., & Donatuto, J. (2012). Conducting research with Tribal communities: sovereignty, ethics, and data-sharing issues. Environmental Health Perspectives, 120(1), 6-10. doi:10.1289/ehp.1103904

Hawkes, J. S., & Marsh, W. H. 2004. Discovering statistics (2nd ed.). Irving, TX: Hawkes Learning Systems and Quant Systems.

Heinselman, P. L., & Schultz, D. M. (2006). Intraseasonal variability of summer storms over central Arizona during 1997 and 1999. Weather and Forecasting, 21(4), 559-578. doi:10.1175/waf929.1

Hidalgo, H. G., Das, T., Dettinger, M. D., Cayan, D. R., Pierce, D. W., Barnett, T. P., . . . Nozawa, T. (2009). Detection and attribution of streamflow timing changes to climate change in the western United States. Journal of Climate, 22(13), 3838-3855. doi:10.1175/2009jcli2470.1

Hopi Tribe. (2015). Hopi Tribe official website. Received from: http://www.hopi-nsn.gov/

Houghton, J. G. (1979). Model for orographic precipitation in the North-Central Great Basin. Monthly Weather Review, 107(11), 1462-1475. doi:10.1175/1520-0493(1979)107

Howat, I. M., & Tulaczyk, S. (2005). Climate sensitivity of spring snowpack in the Sierra Nevada. Journal of Geophysical Research-Earth Surface, 110(F4), 9. doi:10.1029/2005jf000356

Hunter, C., Gironas, J., Bolster, D., & Karavitis, C. A. (2015). A dynamic, multivariate sustainability measure for robust analysis of water management under climate and demand uncertainty in an arid environment. Water, 7(11), 5928-5958. doi:10.3390/w7115928

Ignatowski, J. A., & Rosales, J. (2013). Identifying the exposure of two subsistence villages in Alaska to climate change using traditional ecological knowledge. Climatic Change, 121(2), 285-299. doi:10.1007/s10584-013-0883-4

Indian Reorganization Act of 1934, Pub. L. 73-383, 48 Stat. 984. (1934).

Jantarasami, L. C., Novak, R., Delgado, R., Marino, E., McNeeley, S., Narducci, C., … Powys Whyte, K. (2018). Tribes and Indigenous peoples. Impacts, risks, and adaptation in the United States: Fourth national climate assessment, 2(15), 572–603. doi:10.7930/NCA4.2018.CH15

Johnson v. M'Intosh, 21 U.S. 543. (1823).

Jones, K. W., Cannon, J. B., Saavedra, F. A., Kampf, S. K., Addington, R. N., Cheng, A. S., . . . Wolk, B. (2017). Return on investment from fuel treatments to reduce severe wildfire and erosion in a watershed investment program in Colorado. Journal of Environmental Management, 198, 66-77. doi:10.1016/j.jenvman.2017.05.023

Jones, T. L., Brown, G. M., Raab, L. M., McVickar, J. L., Spaulding, W. G., Kennett, D. J., . . . Walker, P. L. (1999). Environmental imperatives reconsidered - demographic crises in western North America during the Medieval Climatic Anomaly. Current Anthropology, 40(2), 137-170. doi:10.1086/200002

Kalafatis, S. E., Lemos, M. C., Lo, Y. J., & Frank, K. A. (2015). Increasing information usability for climate adaptation: the role of knowledge networks and communities of practice. Global Environmental Change 32, 30–39. doi:10.1016/j.gloenvcha.2015.02.007

Klein, J. T. (2008). Evaluation of interdisciplinary and transdisciplinary research - a literature review. American Journal of Preventive Medicine, 35(2), S116-S123. doi:10.1016/j.amepre.2008.05.010

Klenk, N., Fiume, A., Meehan, K., & Gibbes, C. (2017). Local knowledge in climate adaptation research: Moving knowledge frameworks from extraction to co-production. Wiley Interdisciplinary Reviews-Climate Change, 8(5), 15. doi:10.1002/wcc.475

Kliskey, A., Alessa, L., Wandersee, S., Williams, P., Trammell, J., Powell, J., . . . Wipfli, M. (2017). A science of integration: Frameworks, processes, and products in a place-based, integrative study. Sustainability Science, 12(2), 293-303. doi:10.1007/s11625-016-0391-3

Knowles, N., Dettinger, M. D., & Cayan, D. R. (2006). Trends in snowfall versus rainfall in the western United States. Journal of Climate, 19(18), 4545-4559. doi:10.1175/jcli3850.1

Kools, S., McCarthy, M., Durham, R., & Robrecht, L. (1996). Dimensional analysis: Broadening the conception of grounded theory. Qualitative Health Research, 6(3), 312-330. doi:10.1177/104973239600600302

Kovach, M. (2010). Conversational method in Indigenous research. First Peoples Child & Family Review, 5(1), 40-48. Retrieved from https://fncaringsociety.com/sites/default/files/online-journal/vol5num1/Kovach_pp40.pdf

Kukutai, T., & Taylor, J. (2016). Indigenous data sovereignty: Toward an agenda. Canberra: Australian National University Press, Research Monograph 38.

Lacey, J., Howden, S. M., Cvitanovic, C., & Dowd, A. M. (2015). Informed adaptation: Ethical considerations for adaptation researchers and decision-makers. Global Environmental Change, 32, 200–210. doi:10.1016/j.gloenvcha.2015.03.011

Lebel, L. (2013). Local knowledge and adaptation to climate change in natural resource-based societies of the Asia-Pacific. Mitigation Adaptation Strategies Global Change, 18, 1057-1076. doi:10.1007/s11027-012-9407-1

Lemelin, H., Matthews, D., Mattina, C., McIntyre, N., Johnston, M., Koster, R., & Weenusk First Nation at Peawanuck. (2010). Climate change, wellbeing and resilience in the Weenusk First Nation at Peawanuck: The Moccasin Telegraph goes global. Rural and Remote Health, 10(2), 18. Retrieved from http://www.rrh.org.au

Leung, L. R., Qian, Y., & Bian, X. D. (2003). Hydroclimate of the western United States based on observations and regional climate simulation of 1981-2000. Part I: Seasonal statistics. Journal of Climate, 16(12), 1892-1911. doi:10.1175/1520-0442(2003)016<1892:hotwus>2.0.co;2

Li, D. Y., Wrzesien, M. L., Durand, M., Adam, J., & Lettenmaier, D. P. (2017). How much runoff originates as snow in the western United States, and how will that change in the future? Geophysical Research Letters, 44(12), 6163-6172. doi:10.1002/2017gl073551

Limerick, P. N. (2001). Something in the soil: Legacies and reckonings in the New West. New York, NY: W. Norton & Company.

Loehman, R., Flatley, W., Holsinger, L., & Thode, A. (2018). Can land management buffer impacts of climate changes and altered fire regimes on ecosystems of the southwestern United States? Forests, 9(4), 29. doi:10.3390/f9040192

Lofmarck, E., & Lidskog, R. (2016). Bumping against the boundary: IPBES and the knowledge divide. Environmental Science & Policy, 69, 22-28. doi:10.1016/j.envsci.2016.12.008

Lombard, K. A., Beresford, S. A. A., Ornelas, I. J., Topaha, C., Becenti, T., Thomas, D., & Vela, J. G. (2014). Healthy gardens/healthy lives: Navajo perceptions of growing food locally to prevent diabetes and cancer. Health Promotion Practice, 15(2), 223-231. doi:10.1177/1524839913492328.

Long, C. (2013). Navajo People – The Dine. Navajo People. Retrieved from http://navajopeople.org/

MacDonald, G. M. (2010). Water, climate change, and sustainability in the Southwest. Proceedings of the National Academy of Sciences of the United States of America, 107(50), 21256-21262. doi:10.1073/pnas.0909651107

Maldonado, J., Bennett, T. M. B., Chief, K., Cochran, P., Cozzetto, K., Gough, B., . . . Voggesser, G. (2016). Engagement with Indigenous peoples and honoring traditional knowledge systems. Climatic Change, 135(1), 111-126. doi:10.1007/s10584-015-1535-7

Mason, L., White, G., Morishima, G., Alvarado, E., Andrew, L., Clark, F., … Wilder, S. (2012). Listening and learning from traditional knowledge and western science: A dialogue on contemporary challenges of forest health and wildfire. Journal of Forestry, 110(4), 187-193. doi:10.5849/jof.11-006

McGregor, D. (2012). Traditional knowledge: Considerations for protecting water in Ontario. The International Indigenous Policy Journal, 3(3), 11. doi:10.18584/iipj.2012.3.3.11

Meadow, A. M., Ferguson, D. B., Guido, Z., Horangic, A., Owen, G., & Wall, T. (2015). Moving toward the deliberate coproduction of climate science knowledge. Weather Climate and Society, 7(2), 179-191. doi:10.1175/wcas-d-14-00050.1

Mensing, S., Strachan, S., Arnone, J., Fenstermaker, L., Biondi, F., Devitt, D., … Fritzinger, E. (2013). A network for observing great basin climate change. EOS, 94(11), 105-112. doi:10.1002/2013EO110001

Miller, W. P., & Piechota, T. C. (2011). Trends in western United States snowpack and related upper Colorado River Basin streamflow. Journal of the American Water Resources Association, 47(6), 1197-1210. doi:10.1111/j.1752-1688.2011.00565.x

Munroe, J. S. (2006). Investigating the spatial distribution of summit flats in the Uinta Mountains of northeastern Utah, USA. Geomorphology, 75(3-4), 437-449. doi:10.1016/j.geomorph.2005.07.030

Murphy, B. L. (2011). From interdisciplinary to inter-epistemological approaches: Confronting the challenges of integrated climate change research. Canadian Geographer, 55(4), 490-509. doi:10.1111/j.1541-0064.2011.00388.x

Navajo Nation Department of Information and Technology. (2011). History. Navajo Nation Official Website. Retrieved from http://www.navajo-nsn.gov/

Navajo Nation Department of Agriculture. (2007). Home. Navajo Nation. Retrieved from http://www.agriculture.navajo-nsn.gov/

Null, S. E., & Prudencio, L. (2016). Climate change effects on water allocations with season dependent water rights. Science of the Total Environment, 571, 943-954. doi:10.1016/j.scitotenv.2016.07.081

Nusser, M. (2017). Socio-hydrology: A new perspective on mountain waterscapes at the nexus of natural and social processes. Mountain Research and Development, 37(4), 518–520 518. doi:10.1659/MRD-JOURNAL-D-17-00101.1

Okumura, M. (2018). Adaptation strategies for risk and uncertainty: The role of an interdisciplinary approach including natural and human sciences. Global Warming and Human - Nature Dimension in Northern Eurasia, 197-206. Tokyo: Springer-Verlag Tokyo.

Oubeidillah, A. A., Tootle, G. A., Moser, C., Piechota, T., & Lamb, K. (2011). Upper Colorado River and Great Basin streamflow and snowpack forecasting using Pacific oceanic-atmospheric variability. Journal of Hydrology, 410(3-4), 169-177. doi:10.1016/j.jhydrol.2011.09.030

Pacheco-Cobos, L., Rosetti, M. F., Esquivel, A. M., & Hudson, R. (2015). Towards a traditional ecological knowledge-based monitoring scheme: A proposal for the case of edible mushrooms. Biodiversity and Conservation, 24(5), 1253-1269. doi:10.1007/s10531-014-0856-6

Pande, S., & Sivapalan, M. (2017). Progress in socio-hydrology: A meta-analysis of challenges and opportunities. Water, 4(4). doi:10.1002/wat2.1193

Pascale, S., Boos, W. R., Bordoni, S., Delworth, T. L., Kapnick, S. B., Murakami, H., . . . Zhang, W. (2017). Weakening of the North American monsoon with global warming. Nature Climate Change, 7(11), 806. doi:10.1038/nclimate3412

Pevar, S. L. (2012). The rights of Indians and Tribes (4th ed.). New York, NY: Oxford University Press.

Pisani, D. J. (1992). Water law and localism in the West. Halcyon, 14, 33–55.

Prucha, F. P. (1984). The great father: The United States government and the American Indians. Lincoln, NE: University of Nebraska Press.

Rajagopal, S., Dominguez, F., Gupta, H. V., Troch, P. A., & Castro, C. L. (2014). Physical mechanisms related to climate-induced drying of two semiarid watersheds in the southwestern United States. Journal of Hydrometeorology, 15(4), 1404-1418. doi:10.1175/jhm-d-13-0106.1

Ranco, D., Arnett, A., Latty, E., Remsburg, A., Dunckel, K., Quigley, E., … Secord, T. (2012). Two Maine forest pests: A comparison of approaches to understanding threats to hemlock and ash trees in Maine. Maine Policy Review, 21(1), 76-89. Retrieved from http://digitalcommons.library.umaine.edu/mpr/vol21/iss1/12/

Reisner, M. (1986). Cadillac desert: The American West and its disappearing water. New York, NY: Viking.

Reynolds, L. V., Shafroth, P. B., & Poff, N. L. (2015). Modeled intermittency risk for small streams in the Upper Colorado River Basin under climate change. Journal of Hydrology, 523, 768-780. doi:10.1016/j.jhydrol.2015.02.025

Riedlinger, D., & Berkes, F. (2001). Contributions of traditional knowledge to understanding climate change in the Canadian Arctic. Polar Record, 37(203), 315–328. doi:10.1017/S0032247400017058

Robitaille, P. A., Shahi, C., Smith, M. A., & Luckai, N. (2017). Growing together: A principle-based approach to building collaborative Indigenous partnerships in Canada's forest sector. Forestry Chronicle, 93(1), 44-57. doi:10.5558/tfc2017-010

Russ, J., & Stratmann, T. (2016). Divided interests: The increasing detrimental fractionation of Indian land ownership. Unlocking the Wealth of Indian Nations. Edited by Terry L. Anderson. Lanham, MD: Lexington Books. doi:10.2139/ssrn.2353711

Sandefur, G. D., Rindfuss, R. R., & Cohen, B. (1996). Changing numbers, changing needs: American Indian demography and public health. National Research Council Committee on Population. Washington, DC: National Academies Press.

Savaresi, A. (2018). Traditional knowledge and climate change: a new legal frontier? Journal of Human Rights and the Environment, 9(1), 32-50. doi:10.4337/jhre.2018.01.02

Seager, R., Ting, M., Li, C., Naik, N., Cook, B., Nakamura, J., & Liu, H. (2013). Projections of declining surface-water availability for the southwestern United States. Nature Climate Change, 3(5), 482-486. doi:10.1038/nclimate1787

Senhorst, H. A. J., & Zwolsman, J. J. G. (2005). Climate change and effects on water quality: A first impression. Water Science and Technology, 51(5), 53-59. doi:10.2166/wst.2005.0107

Shamo, M., Basso, M., & Reeve, P. (2012). Historical grazing on the Ashley National Forest. FS Agreement (No. 10-CS-11046000-035). Retrieved from https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5446223.pdf

Shoshone-Paiute Tribes of the Duck Valley Reservation Water Rights Settlement. Public Law No. 111-11; 123 Stat 1405. (2009).

Simpson, L. R. (2004). Anticolonial strategies for the recovery and maintenance of Indigenous knowledge. American Indian Quarterly, 38(3), 373-384. Retrieved from https://www.jstor.org/stable/4138923

Singletary, L., Emm, S., Loma'omvaya, M., Clark, J., Livingston, M., & Kotutwa Johnson, M. (2014). People of the land: Sustaining agriculture on the Hopi Reservation. Reno, NV: University of Nevada Cooperative Extension Curriculum Material (CM-14-02).

Singletary, L., Emm, S., Brummer, F. A., Hill, G. C., Lewis, S., & Hebb, V. (2016). Results of an assessment to identify potential barriers to sustainable agriculture on American Indian reservations in the western United States. Journal of Agricultural Education & Extension, 22(4), 375-387. doi:10.1080/1389224x.2015.1074591

Singletary, L., & Sterle, K. (2017). Collaborative modeling to assess drought resiliency of snow-fed river dependent communities in the western United States: A case study in the Truckee-Carson River System. Water, 9, 99. doi:10.3390/w9020099

Singletary, L., & Sterle, K. (2018). Collaborative modeling to assess and enhance the climate resiliency of snow-fed river dependent communities. In Lachapelle, P. R., and D. Albrecht. (Eds.). Addressing Climate Change at the Community Level in the United States. New York, NY: Routledge.

Sivapalan, M., Savenije, H. H. G., & Bloschl, G. (2012). Socio-hydrology: A new science of people and water. Hydrological Processes, 26(8):1270-1276. doi:10.1002/hyp.8426

Sivapalan, M., & Bloschl, G. (2015). Time scale interactions and the coevolution of humans and water. Water Resources Research, 51(9), 6988-7022. doi:10.1002/2015WR017896

Smith, W. J., Liu, Z. W., Safi, A. S., & Chief, K. (2014). Climate change perception, observation and policy support in rural Nevada: A comparative analysis of Native Americans, non-native ranchers and farmers and mainstream America. Environmental Science & Policy, 42, 101-122. doi:10.1016/j.envsci.2014.03.007

State of Arizona v. State of California. On Bill of Complaint. 547. No. 8 Orig. Decree. (2006).

State of Nevada Division of Water Resources Department. (1992). Nevada water facts. Retrieved from http://water.nv.gov/WaterPlanning/wat- fact/intro.cfm

State of Nevada Division of Water Resources. (2013). Walker River chronology. NV Division of Water Resources. Received from: http://water.nv.gov/mapping/chronologies/walker/part3.cfm

Stewart, I. T., Cayan, D. R., & Dettinger, M. D. (2005). Changes toward earlier streamflow timing across western North America. Journal of Climate, 18(8), 1136-1155. doi:10.1175/jcli3321.1

Sundjordet, S. (2017). Let them plant their own: implications of interactive crop-loss processes during drought in Hopi maize fields. Journal of Ethnobiology, 37(2), 241-259. doi:10.2993/0278-0771-37.2.241

Tarlock, A. D. (2001). The future of prior appropriation in the New West. Natural Resources Journal, 41, 769–793. Retrieved from https://digitalrepository.unm.edu/nrj/vol41/iss4/2

Tendeng, B., Asselin, H., & Imbeau, L. (2016). Moose (Alces americanus) habitat suitability in temperate deciduous forests based on Algonquin traditional knowledge and on a habitat suitability index. Ecoscience, 23(3-4), 77-87. doi:10.1080/11956860.2016.1263923

Tengo, M., Hill, R., Malmer, P., Raymond, C. M., Spierenburg, M., Danielsen, F., . . . Folke, C. (2017). Weaving knowledge systems in IPBES, CBD and beyond-lessons learned for sustainability. Current Opinion in Environmental Sustainability, 26-27, 17-25. doi:10.1016/j.cosust.2016.12.005

Tennant, C. J., Crosby, B. T., & Godsey, S. E. (2015). Elevation-dependent responses of streamflow to climate warming. Hydrological Processes, 29(6), 991-1001. doi:10.1002/hyp.10203

Thompson, S. A. (1999). Water use, management, and planning in the United States. San Diego, CA: Academic Press.

Thorne, J. H., Choe, H., Stine, P. A., Chambers, J. C., Holguin, A., Kerr, A. C., & Schwartz, M. W. (2018). Climate change vulnerability assessment of forests in the southwestern United States. Climatic Change, 148(3), 387-402. doi:10.1007/s10584-017-2010-4

Tiller, V. (2015). Tiller's guide to Indian country: An economic profiles of American Indian Reservations (3rd ed.). Albuquerque, NM: Bow Arrow Publishing Company.

Truckee-Carson-Pyramid Lake Water Rights Settlement Act. Public Law 101-618, 104 STAT. 3294. (1990).

U.S. Bureau of Reclamation. (2015). Listing of individual water entitlements in the state of Arizona – Fourth Priority. Retrieved from http://www.usbr.gov/lc/region/g4000/contracts/entitlements.html

U.S. Constitution. Art. I, § 8.

U.S. Department of Agriculture, National Agriculture Statistics Service. (2014). Women farmers. Census of agriculture (ACH 12-12). Retrieved from https://www.nass.usda.gov/Publications/Highlights/2014/Highlights_Women_Farmers.pdf

U.S. Department of Agriculture. (2014). 2012 U.S. Census of agriculture: American Indian Reservations (AC-12-S-5). Retrieved from https://www.nass.usda.gov/Publications/AgCensus/2012/Online_Resources/American_Indian_Reservations/AMINDIAN.pdf

U.S. Department of Commerce, Economics and Statistics Administration. (2017). Women in STEM: 2017 update (ESA Issue Brief #06-17). Retrieved from https://www.commerce.gov/sites/default/files/migrated/reports/women-in-stem-2017-update.pdf

U.S. Department of Education, National Center for Education Statistics. (2018). The condition of education 2018 (NCES 2018-144). Retrieved from https://nces.ed.gov/programs/coe/indicator_csc.asp

U.S. Department of the Interior, Bureau of Indian Affairs. (1974). The Uintah and Ouray Indian reservation: its resources and development potential. United States

Department of the Interior, Bureau of Indian Affairs Planning Support Group, (Report No. 214).

Vano, J. A, Udall, B., Cayan, D. R., Overpeck, J. T., Brekke, L. D., Das, T., … Lettenmaier, D. P. (2014). Understanding uncertainties in future Colorado River streamflow. Bulletin of the American Meteorological Society, 95, 59-78. doi:10.1175/BAMS-D-12-00228.1

Vernooy, R., Sthapit, B., Otieno, G., Shrestha, P., & Gupta, A. (2017). The roles of community seed banks in climate change adaption. Development in Practice, 27(3), 316-327. doi:10.1080/09614524.2017.1294653

Vogel, R. M., Lall, U., Cai, X. M., Rajagopalan, B., Weiskel, P. K., Hooper, R. P., & Matalas, N. C. (2015). Hydrology: the interdisciplinary science of water. Water Resources Research, 51(6), 4409-4430. doi:10.1002/2015wr017049

Vogt, W. P. (1993). Dictionary of statistics and methodology: A nontechnical guide for the social sciences. Newbury Park, CA: Sage Publications.

Von Heland, J., & Folke, C. (2014). A social contract with the ancestors – culture and ecosystem services in southern Madagascar. Global Environmental Change, 24, 251–264. doi:10.1016/j.gloenvcha.2013.11.003

Wall, T., Meadow, A. M., & Horganic, A. (2017). Developing evaluation indicators to improve the process of coproducing usable climate science. Weather, Climate, and Society, 9, 95-107. doi:10.1175/WCAS-D-16-0008.1

Walston, R. E. (1989). The public trust doctrine in the water rights context. Natural Resources Journal, 29(2), 585-592. Retrieved from https://digitalrepository.unm.edu/nrj/vol29/iss2/14

Warner, J. F., Wesselink, A. J., & Geldof, G. D. (2018). The politics of adaptive climate management: Scientific recipes and lived reality. Climate Change, 9(3), 8. doi:10.1002/wcc.515

Western States Water Council (2011). Publications. Retrieved from http://www.westernstateswater.org/wp-content/uploads/2012/10/SETTABLE-2011-08-15-11-1.pdf

Williams, T., & Hardison, P. (2013). Culture, law, risk and governance: Contexts of traditional knowledge in climate change adaptation. Climatic Change, 120(3), 531-544. doi:10.1007/s10584-013-0850-0

Wine, M. L., & Cadol, D. (2016). Hydrologic effects of large southwestern United States wildfires significantly increase regional water supply: Fact or fiction? Environmental Research Letters, 11(8), 13. doi:10.1088/1748-9326/11/8/085006

Wine, M. L., Makhnin, O., & Cadol, D. (2018). Nonlinear long-term large watershed hydrologic response to wildfire and climatic dynamics locally increases water yields. Earths Future, 6(7), 997-1006. doi:10.1029/2018ef000930

Winters v. United States, 207 U.S. 564. (1908).

Worcestor v. Virginia, 31 U.S. 515. (1832).

Worland, S. C., Steinschneider, S., & Hornberger, G. M. (2018). Drivers of variability in public-supply water use across the contiguous United States. Water Resources Research, 54(3), 1868-1889. doi:10.1002/2017wr021268

Xia, X. H., Wu, Q., Mou, X. L., & Lai, Y. J. (2015). Potential impacts of climate change on the water quality of different water bodies. Journal of Environmental Informatics, 25(2), 85-98. doi:10.3808/jei.201400263

Yu, Z. B., Jiang, P., Gautam, M. R., Zhang, Y., & Acharya, K. (2015). Changes of seasonal storm properties in California and Nevada from an ensemble of climate projections. Journal of Geophysical Research-Atmospheres, 120(7), 2676-2688. doi:10.1002/2014jd022414

Zampieri, M., Scoccimarro, E., Gualdi, S., & Navarra, A. (2015). Observed shift towards earlier spring discharge in the main Alpine rivers. Science of the Total Environment, 503, 222-232. doi:10.1016/j.scitotenv.2014.06.036

Appendix A
Calculating Climate Summaries

National Oceanic and Atmospheric Administration (NOAA) climate data made available through the National Centers for Environmental Information (NCEI) GIS Map portal online were used to calculate normal climate summaries.

Data accessed: 1981-2010 normal temperature and precipitation data from NOAA climate/weather stations located within Great Basin, Upper Colorado, and Lower Colorado - Hydrologic Unit Code (HUC) at the 2-digit scale - water resource region boundaries. Summaries for the data used from each boundary layer are included below:

Table A1

Climate Summaries for the Great Basin region, Upper Colorado River region, and Lower Colorado River region

USGS Water Resource Region	Stations Count	Ave Precip (inches)	Stations Count	Ave Min Temp (F)	Ave Max Temp (F)
Great Basin	185	13.84	188	33.77	62.56
Upper Colorado	158	12.83	155	32.61	61.12
Lower Colorado	214	13.06	202	46.26	76.37
Totals	**557**	**13.25**	**545**	**38.07**	**67.27**

Note. Data retrieved from https://gis.ncdc.noaa.gov/maps/ncei. Data used here were accessed July 11, 2018. Calculations were made using Microsoft Excel Version 14.7.3.

Appendix B
Tribal Secondary Data Summaries

Represented tribes. (29 total): Colorado River Indian Tribes, Confederated tribes of Goshute, Duckwater Shoshone Tribe, Fort McDermitt Paiute and Shoshone Tribes, Fort Mojave Indian Tribe, Gila River, Havasupai Tribe, Hopi Tribe, Hualapai Indian Tribe, Jicarilla Apache Nation, Kaibab Band of Paiute Indians, Moapa Band of Paiute Indians, Navajo Nation, Paiute Indian Tribe, Utah (Five constituent bands: Cedar Band, Kanosh Band, Koosharem Band, Indian Peaks Band, and Shivwits Band), Paiute Shoshone Tribe of Fallon, Pueblo of Acoma, Pueblo of Laguna, Pyramid Lake Paiute Tribe, Shoshone-Paiute Tribes of Duck Valley, Skull Valley Band of Goshute Indians, Te-Moak Tribe of Western Shoshone Indians (Four constituent bands: Battle Mountain Band; Elko Band; South Fork Band and Wells Band), Ute Indian Tribe of Uintah and Ouray, Ute Mountain Tribe, Walker River Paiute Tribe, Washoe Tribe, Yavapai-Apache Nation of Camp Verde, Yerington Paiute Tribe, Yomba Shoshone Tribe, and Zuni Tribe.

Total reservation lands: 26,000,000 acres* (Tiller, 2015)

Total land in agriculture or range: 22,100,000 acres* (Emm, Lewis, & Breazeale, 2002; Global Native, 2010; Navajo Nation Department of Agriculture, 2007; Shamo, Basso, & Reeve, 2012; Tiller, 2015; U.S. Department of Agriculture, 2014; U.S. Department of the Interior, Bureau of Indian Affairs, 1974).

Average percent of total land in agriculture: 47% (Emm, et al., 2002; Global Native, 2010; Navajo Nation Department of Agriculture, 2007; Shamo, et al., 2012; Tiller, 2015; U.S. Department of Agriculture, 2014; U.S. Department of the Interior, Bureau of Indian Affairs, 1974).

Number of tribes with pre-contact agriculture: 8 (Colorado River Indian Tribes, 2009; Gila River Indian Community, 2015; Hopi Tribe, 2015; Long, 2013; Navajo Nation Department of Information and Technology, 2011; Tiller, 2015).

Number of tribes with at least 50% of land in agriculture or range: 25 (Emm, et al., 2002; Global Native, 2010; Navajo Nation Department of Agriculture, 2007; Shamo, et al., 2012; Tiller, 2015; U.S. Department of Agriculture, 2014; U.S. Department of the Interior, Bureau of Indian Affairs, 1974).

Total water right entitlement: 3,500,000 acre-feet/Acre* (Arizona Water Settlement Act, 2004; Arizona Department of Water Resources, 2010; Colby, Thorson, & Britton, 2005; Shoshone-Paiute Tribes of the Duck Valley Reservation Water Rights Settlement Act, 2009; State of Arizona v. State of California, 2006; State of Nevada Division of Water Resources Department, 1992; State of Nevada Division of Water Resources Department, 2013; Truckee-Carson-Pyramid Lake Water Rights Settlement Act, 1990; U.S. Bureau of Reclamation, 2015; Western States Water Council, 2011).

Number of tribes with water right adjudications: 27 (Colby, Thorson, & Britton, 2005)

*Note. All data rounded to the nearest one-hundred-thousand.

Appendix C
Maps of USGS weather monitoring stations

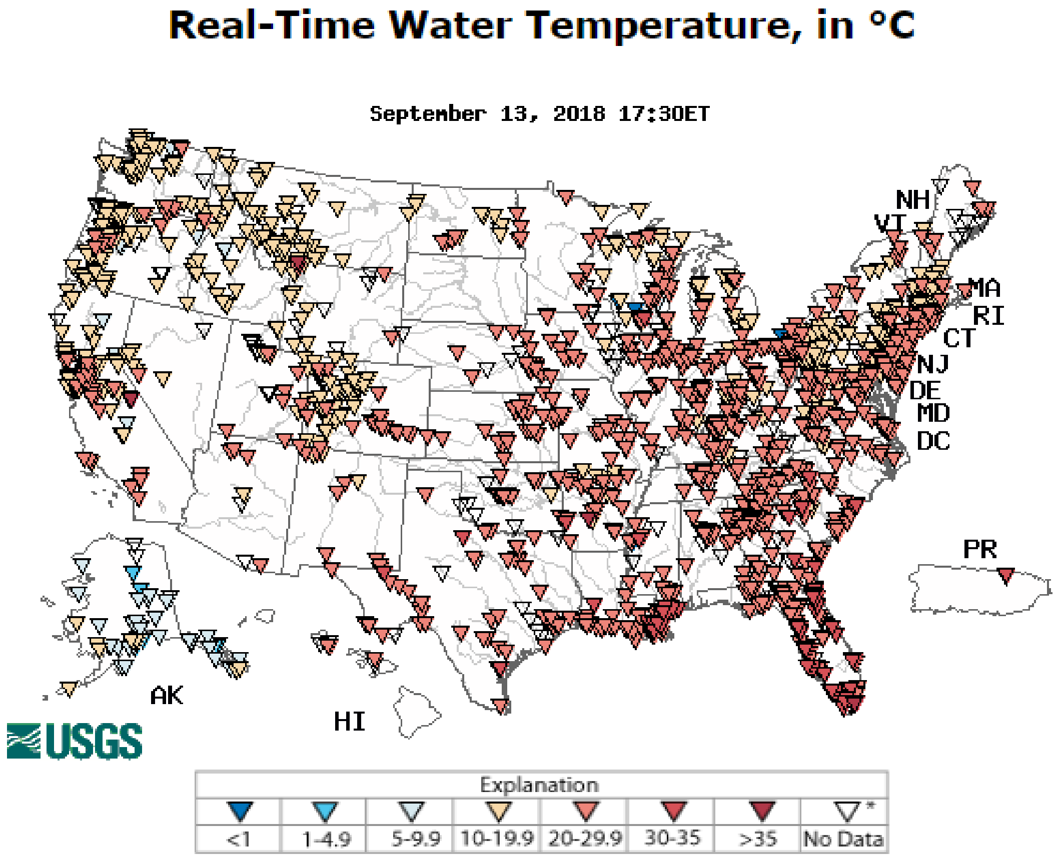


Figure C1. Map of real-time water temperature. Retrieved from https://waterdata.usgs.gov/nwis/rt.

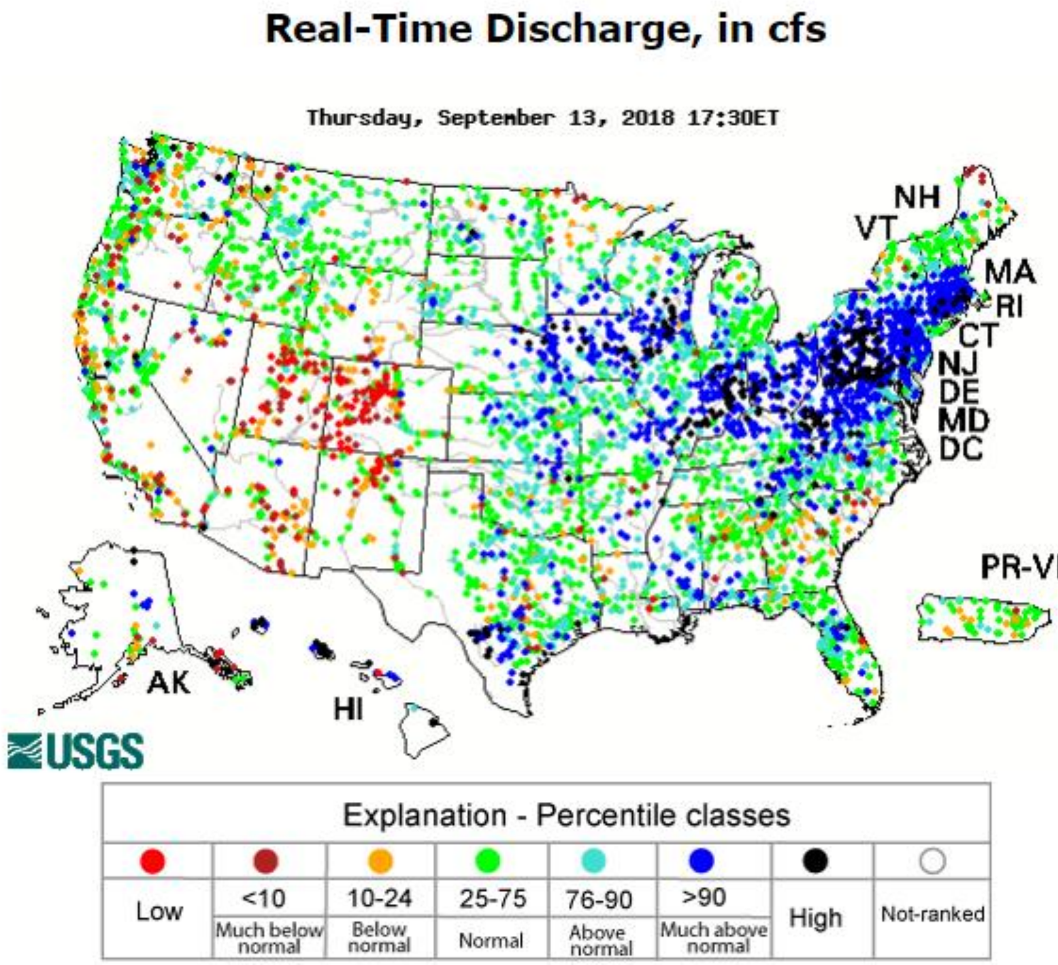


Figure C2. Map of real-time water discharge. Retrieved from https://waterdata.usgs.gov/nwis/rt.

Appendix D
Survey instrument

Native Waters on Arid Lands

Tribal Climate Planning Information Needs Assessment

Part I. Please prioritize the following information needs to support climate adaptation planning on tribal lands. On a scale of 1 to 5 with 1 being "Very Low Priority" and 5 being "Very High Priority," please circle the number that best answers each question.

To adapt to and plan for climate uncertainty, tribal communities need information about…	Very Low Priority 1	Low Priority 2	Neutral 3	High Priority 4	Very High Priority 5
1. How to conduct a climate resiliency assessment	1	2	3	4	5
2. Climate change impacts on tribal lands, water and economies	1	2	3	4	5
3. Enhancing tribal food security and sovereignty	1	2	3	4	5
4. Adaptation strategies unique to tribal lands	1	2	3	4	5
5. Incorporating Traditional Knowledge in climate adaptation planning for tribal lands	1	2	3	4	5
6. How to protect Traditional Knowledge that tribes incorporate into their adaptation plans	1	2	3	4	5
7. Examples of other tribes' climate adaptation plans	1	2	3	4	5
8. How to finance implementation of climate adaptation plans	1	2	3	4	5
9. Meaning of future climate projections for individual reservations	1	2	3	4	5
10. Selecting equipment to monitor/collect data to inform tribal climate	1	2	3	4	5
11. How to finance monitoring/data collection on tribal lands	1	2	3	4	5
12. Training tribal employees to ensure consistent data monitoring and collection on tribal lands	1	2	3	4	5
13. Precipitation data (check one below ↓ and rate priority →) [hourly___; daily___; monthly ___]	1	2	3	4	5
14. Temperature data (check one below ↓ and rate priority →) [hourly____; daily____; monthly ____]	1	2	3	4	5
15. Streamflow data (check one below ↓ and rate priority →) [hourly____; daily____; monthly ____]	1	2	3	4	5
16. Soil moisture data (check one below ↓ and rate priority →) [hourly____; daily____; monthly ____]	1	2	3	4	5
17. Snowpack data (check one below ↓ and rate priority →) [hourly____; daily____; monthly ____]	1	2	3	4	5
18. Water quality data (check one below ↓ and rate priority →) [hourly____; daily____; monthly ____]	1	2	3	4	5
19. Raw data collected from monitoring instruments (check one below ↓ and rate priority →) [hourly____; daily____; monthly ____]	1	2	3	4	5
20. Generalized reports or summaries on water resources and climate information (check one below ↓ and rate priority →) [hourly____; daily____; monthly ____]	1	2	3	4	5

21. At your job what portion of annual operating budget should be allocated to support climate adaptation on tribal lands? (select one best answer):
    - ☐ 0 %
    - ☐ 6-10 %
    - ☐ 16-20 %
    - ☐ Greater than 25%
    - ☐ 1-5 %
    - ☐ 11-15 %
    - ☐ 21-25 %

22. I work for:
    - ☐ Tribal Government (which department) ___________________
    - ☐ Local/County Government
    - ☐ Tribal College/Universities
    - ☐ State Government
    - ☐ Other Colleges/Universities
    - ☐ Federal Government
    - ☐ Cooperative Extension FRTEP
    - ☐ Private Sector Business
    - ☐ Self Employed______________________

23. If applicable, I work in (select department):
    - ☐ Agriculture/Range Management
    - ☐ Cultural Resources
    - ☐ Water Resources
    - ☐ Education
    - ☐ Environment

Part II. The following questions ask about sources of information you currently use in climate adaptation planning. On a scale of 1 to 5 with 1 being "Use Never" and 5 being "Use Very Often," please circle the number that best answers each question.

In climate adaptation planning, we are currently using information provided by…	Never 1	Rarely 2	Occasionally 3	Often 4	Very Often 5
24. Tribal farmers and ranchers	1	2	3	4	5
25. Tribal oral histories	1	2	3	4	5
26. Traditional Knowledge holders	1	2	3	4	5
27. Tribal natural resource/water/land departments	1	2	3	4	5
28. Tribally owned and operated monitoring equipment	1	2	3	4	5
29. Tribal colleges and universities	1	2	3	4	5
30. Other colleges and universities	1	2	3	4	5
31. The Weather Channel; Weather.com; local news and radio	1	2	3	4	5
32. National Oceanic Atmospheric Administration (NOAA); Nationa Weather Service; NRCS Snotel	1	2	3	4	5
33. USDA Climate Hubs	1	2	3	4	5
34. US Geological Survey Stream Gages	1	2	3	4	5
35. Bureau of Indian Affairs climate planning program	1	2	3	4	5
36. *Native Water on Arid Lands* Annual Tribal Summits	1	2	3	4	5
37. I use other information not listed above: (please explain) ______________________					

38. I use or will use climate science information/data in my work with (select one best answer):
    - ☐ Tribal department involved in natural resources/land/water management/planning
    - ☐ Tribal government or administration
    - ☐ Farming or ranching on tribal lands
    - ☐ Teaching and working with grade school aged tribal youth
    - ☐ As a college/university faculty, staff or student
    - ☐ Other: ____

39. How do you prefer to receive outreach information to support climate planning? (select one best answer)
    - ☐ Printed material
    - ☐ Webinars
    - ☐ Radio and TV
    - ☐ Online information or data portal
    - ☐ Annual tribal summit
    - ☐ Other (please describe)____

40. What is needed most to support climate adaptation on tribal lands?

____

41. What level of risk do you think climate uncertainty poses to tribal resources and communities: (select one best answer)

☐ No risk ☐ Minor risk ☐ Neutral ☐ Major risk ☐ Extreme risk

42. The most challenging issue that climate uncertainty poses to tribal resources and communities involves: (select one best answer)

☐ Water supply shortages on tribal lands
☐ Tribal agriculture (farming and ranching)
☐ Tribal fisheries (lakes and/or streams)
☐ Water quality impairment on tribal lands
☐ Wildlife habitat endangered on tribal lands
☐ Tribal economic well being
☐ Human survival on tribal lands
☐ Other: ____________________

Part III. Please tell us something about yourself:

43. In which state do you live or work? ________________________________

44. On which the reservation(s) do you live [or work]: ____

45. If applicable, indicate how many years have you lived on a reservation? __________ years

46. If applicable, please indicate whether the reservation land is primarily: (check one):

☐ Assigned trust land
☐ Combination of Allotted and Fee Simple
☐ Combination of Assigned and Allotted
☐ Fee simple land
☐ Allotted trust land
☐ Public domain allotted trust land
☐ Reservation
☐ Other:_____________________

47. What is your age? ________ years

48. What is your ethnic origin? (check one):

☐ Native American ☐ Hispanic/Latino ☐ Black
☐ White ☐ Asian/Pacific Is. ☐ Other

49. What is your gender? (check one): ☐ Male ☐ Female

50. My highest level of education completed is (check one):

☐ Less than high school
☐ High school diploma/GED
☐ Some college/technical
☐ Technical or Associate degree
☐ College degree (BS, BA)
☐ Graduate degree (MS, JD, PhD, MD)

Native Waters on Arid Lands is an integrated research and Extension program based at the University of Nevada, Reno and funded by a USDA-NIFA-AFRI grant (#2015-69007-23190). The authors wish to thank the participating Native American tribes for their leadership in shaping this program. We also acknowledge the program contributions of our partnering institutions: Tribal Colleges and Universities, First Americans Land-grant Consortium, University of Arizona, Utah State University, Federally Recognized Tribal Extension Programs and Desert Research Institute.

Appendix E
Survey assessment question items - rationale and descriptions

Part I

Part I of the survey includes 20 questions intended to assess climate information and data needs of Indigenous stakeholders to enhance the climate resiliency of water resources on reservation lands. The targeted sample population is composed entirely of individuals who are already engaged or interested in being engaged in climate adaptation initiatives on reservation lands rather than the broader reservation community. Targeting this sample population ensures that individuals have a reasonable understanding of the complexities of climate adaptation on reservation lands, and have insight into specific information and data needs.

Part I. Please prioritize the following information needs to support climate adaptation planning on tribal lands. On a scale of 1 to 5 with 1 being "Very Low Priority" and 5 being "Very High Priority," please circle the number that best answers each question.

To adapt to and plan for climate uncertainty, tribal communities need information about…

1. How to conduct a climate resiliency assessment

An overview of literature suggests that climate adaptation planning requires an understanding and evaluation of resilient and vulnerable aspects of a community (Ford et al. 2011). We chose to use the term "resiliency" rather than "vulnerability" because of its connotation. In working with Indigenous communities, many individuals will opt out of discussions that describe conditions that have the potential to be devastating or that have been devastating in the past. In practice, assessing resiliency can provide similar results as assessing vulnerability, but the narrative focuses on positive aspects of the community rather than weaker aspects in terms of resiliency.

2. Climate change impacts on tribal lands, water, and economies

This question is intended to encompass research activities that look at specific climate impacts on resources, which vary greatly between communities. For example, we could have subdivided this item to create additional and more specific questions such as, "Rising atmospheric temperature impacts on water resources. Shifting monsoonal rain impacts on soil erosion. Increasing late summer dry periods impacts on agriculture." These are more informative, but are too specific for the scale of our study.

3. Enhancing tribal food security and sovereignty

Results from a previous survey conducted with tribal college and university professionals suggest this is a high priority of concern among Indigenous communities in relation to climate adaptation (Fillmore et al., 2018). Food security and sovereignty are both intentionally referenced, for different individuals and communities define these two terms differently. For example, some communities may prioritize adaptation strategies that enhance local ecological health to provide and improve habitat for native species of nutritional value (Donatuto, Satterfield, & Gregory, 2011). Others may specifically reference small community gardens to help improve access to fresh fruits and vegetables in rural areas where access to affordable food and/or grocery stores may be limited (Lombard et al. 2014). While the climate impacts and adaptation strategies for these different activities vary, the end goal is similar – enhance food security. The terms "food security" and "food sovereignty" are often used interchangeably. Both terms are used here to encompass strategies that may include cooperating with outside communities and entities to enhance access to food sources.

4. Adaptation strategies unique to tribal lands

This question is phrased this way to acknowledge that reservation communities may have unique barriers preventing certain adaptation strategies that could work elsewhere, but to also acknowledge that they may have unique opportunities available as well (Chief et al. 2014). Some studies suggest that Indigenous communities may have more of a willingness to work together to respond to and adapt to climate change impacts than non-Native communities (Gautam et al. 2013, Chief 2012).

5. Incorporating traditional knowledge in climate adaptation planning for tribal lands

A survey conducted following the first NWAL Tribal Leadership Summit asked participants to rate the featured summit topics. The results specifically indicated that traditional knowledge as the most important to summit participants. Furthermore, this is a highly investigated topic in studies related to Indigenous communities and land-use practices (T. M. B. Bennett et al., 2014; Chief et al., 2016; Maldonado et al., 2016). Because of the sensitive nature of using traditional knowledge to inform land-use practices, we specify "tribal lands" in this question item to avoid an interpretation that non-Native land managers may misappropriate these practices on lands outside reservations. However, many Indigenous communities have been working collaboratively with non-Native entities to re-incorporate Indigenous presence and traditional land-use practices on federal, state, and other lands to enhance the health of these ecosystems (Chief et al., 2014). While it seems clear that Indigenous communities are interested in, and value incorporating traditional knowledge into climate adaptation planning initiatives, how to do this effectively and appropriately not only varies among communities, but is not exactly well-understood.

6. How to protect traditional knowledge that tribes incorporate into their adaptation plans

While this topic is related to the previous question, it is more specific to the challenges related to using sensitive information in community initiatives. This becomes more important when working with outside entities to develop plans because of the lack of legal protection available to Indigenous communities (Klenk et al., 2017; Saveresi, 2018; Williams & Hardison, 2013).

7. Examples of other tribes' climate adaptation plans

We acknowledge that each Indigenous community has unique needs and strategies for climate adaptation planning. This is an important aspect of collaborative ethics – ensuring that individual tribes are treated as sovereign entities. Through informal discussions, however, it appears that some of the most valuable information used in decision-making processes comes from different tribes with similar issues. Many tribes may choose not to share their climate adaptation plans with outside entities particularly if they contain sensitive information or information about protecting business enterprises. This question is included assess the priority of this type of information in the development of climate adaptation plans.

8. How to finance implementation of climate adaptation plans

Many tribes rely heavily on outside grants to fund their operations (Tiller 2015). This issue is raised often when discussing climate adaptation on reservation lands. Many communities may have a desperate need to implement climate adaptation strategies, but lack the fiscal capacity to engage in these efforts. Other tribes may already have the resources to incorporate this work in ongoing activities.

9. Meaning of future climate projections for individual reservations

This question item helps distinguish between information that tribes already have access to, but may not be able to discern and/or use for their individual reservations. For example, large climate models predicting future global changes in temperature and precipitation are available, such as the IPCC projections for the U.S. These climate projections, however, usually offer coarse information about regions rather than high-resolution local information. Because of the spatial variability over small areas in the Great Basin and Southwest, and because very small changes in temperature and precipitation, relative to more moderate climates, can have large impacts on communities, some of these coarse projections may not be helpful at the reservation level.

10. Selecting equipment to monitor/collect data to inform tribal climate

Environmental data availability in rural areas of the Great Basin and Southwest are scarce on both reservation and non-tribal lands. Developing new data collection sites are imperative to monitor climate change. Environmental monitoring and data collection equipment vary in terms of usefulness. Rain gauges, for example, collect precipitation data in primarily rain-fed ecosystems. In the Great Basin, however, where much of the precipitation falls as snow, rain gauges are not the most effective tools to assess water availability.

11. How to finance monitoring/data collection on tribal lands

Developing new data collection sites and choosing the monitoring equipment require funding. Because climate data are scarce in the Great Basin and Southwest, federal/state funding and/or opportunities to collaborate with other agencies and institutions to help develop these monitoring sites are necessary.

12. Training tribal employees to ensure consistent data monitoring and collection on tribal lands

Maintaining consistent data availability for scientific uses also requires training personnel to retrieve and analyze data at consistent time intervals. This is a challenge when many environmental programs on reservations are funded by external grants for a limited time. This was an issue raised during one of the future climate scenario sessions at the first (2015) NWAL Tribal Leadership Summit. That is, tribes who already have monitoring equipment in place may lack adequately trained staff to retrieve and analyze data outputs. Additionally, high staff turn-over may impact tribal capacity to complete grant funded climate monitoring initiatives.

Questions 13 – 20 ask specifically about environmental data types and the necessary time-step scale preferred for each type. These are all necessary components of any analysis related to regional climate assessments and may vary significantly over relatively small areas. Static data were omitted, such as elevation and topography.

13. Precipitation data (check on below, and rate priority)
(hourly_; daily_; monthly_)

Precipitation includes both rain and snow precipitation, the prioritization of which is determined by location. While most ecosystems in our study area are snow fed, some are also rain fed. This is a necessary data component for climate analyses, and to inform water-availability. It is also important information to support most land and water management decisions.

14. Temperature data (check on below, and rate priority)
(hourly_; daily_; monthly_)

Temperature is an important component to climate and has compounding effects on nearly all climate processes. Temperature data are relatively easy to obtain.

15. Streamflow data (check on below, and rate priority)
(hourly_; daily_; monthly_)

Streamflow data are important to water management decisions. These data are particularly important in determining water availability in a region, for agricultural operations, and for ensuring environmental flows for aquatic species.

16. Soil-moisture data (check on below, and rate priority)
(hourly_; daily_; monthly_)

These data are particularly important to agricultural operations. These data will become more important as temperatures rise, and evapotranspiration rates increase leaving less water available during the growing season.

17. Snowpack data (check on below, and rate priority)
(hourly_; daily_; monthly_)

This is an important measurement for all snow-fed ecosystems to predict annual water budgets. Because snowpack also acts as an upper-watershed water storage mechanism, information about snowpack can be used to predict both flooding events and drought. Many major river systems in the arid western U.S. are primarily snow-fed.

18. Water quality data (check on below, and rate priority)
(hourly_; daily_; monthly_)

Water quality data are not necessarily readily available, and are not often at the forefront of climate change related discussions; however, water quality (even when compared to water quantity) was a prioritized topic during discussions with Indigenous stakeholders attending.

Questions 19 and 20 are related to questions 10-12 and are intended for comparative analysis. These questions are intended to help identify the types of data that are “accessible” to tribal stakeholders. That is, for example, the USGS provides a variety of streamflow data available for download online. This is one definition of “accessible” streamflow information. If individuals lack the education or training or ability to understand and analyze these data, providing raw streamflow data does not actually make it “accessible” information. These data are “inaccessible” because training and experience are necessary.

19. Raw data collected from monitoring instruments (check on below, and rate priority)
(hourly_; daily_; monthly_)

Many issues surfaced when discussing the use of raw data during tribal summits. Many individuals recognized the need for more local climate monitoring equipment installed on reservation lands, but suggested that even with local monitoring equipment, however, some tribes might not have the internal capacity to use the resulting information.

20. Generalized reports or summaries on water resources and climate information (check on below, and rate priority)
(hourly_; daily_; monthly_)

This question is included to provide survey participants with an “accessible” climate data/information choice. Decisions based on generalized climate reports assumes the risk of compounding uncertainty.

Questions 21-23 are not part of the Likert-type scale priority list, and are used independently to test for correlations between priorities and responses to these questions.

21. At your job what portion of annual operating budget should be allocated to support climate adaptation on tribal lands? (select best answer):

0%	6-10%	16-20%	Greater than 25%
1-5%	11-15%	21-25%	

This question is included to better understand how “climate adaptation” fits into overall work priorities.

22. I work for:

Tribal Government (which department)	Local/County Government
Tribal Colleges/Universities	State Government
Other Colleges/Universities	Federal Government
Cooperative Extension/FRTEP	Private Sector Business
Self Employed___	

This background question is used in cross-correlation analysis to identify statistical relationships with employment role.

23. If applicable, I work in (select department):

Agriculture/Range Management	Cultural Resources
Water Resources	Education
Environment	

This question is used in cross-correlation analysis to identify statistical relationships dependent on vocation. Note: this question was added after analyzing 2016 data. Including this question was warranted based on a significant majority of survey participants that indicated they worked for Tribal Government in question 22. The written-in responses can be grouped into the five groups listed above.

Part II

Part II of the survey is intended to better understand sources of climate data and information already in use to support water management decisions, and climate adaptation planning decisions. This item identifies types of information being used and the importance to survey participants based on how frequently they are accessed. Furthermore, results from this section may be used to determine strategic places to offer climate adaptation related information. For questions 24-37, participants are asked to rate, using a Likert-type scale, how often they access information from the sources listed. The sources of information listed in this section are supported by literature as advantageous and necessary sources of information for land management decisions and for climate adaptation planning. Cross-correlation analyses, using respondents' demographic information and their responses to these questions, lends insight into the different roles that individuals may play in collaborative and climate adaptation planning initiatives.

Part II. The following questions ask about sources of information you currently use in climate adaptation planning. On a scale of 1 to 5 with 1 being "Use Never" and 5 being "Use Very Often," please circle the number that best answers each question.

In climate adaptation planning, we are currently using information provided by…

24. Tribal farmers and ranchers

Tribal farmers and ranchers can be a strategic source of local climate information. For tribes who practice traditional agriculture, these individuals may also hold traditional knowledge culturally related to climate adaptation. Successful agricultural and ranching operations depend on knowledge of local climate as well as seasonal, and annual variability. They may also have private weather monitoring equipment they use to help inform their practices, and thus have data that are not already available to the public.

25. Tribal oral histories

These are historical accounts and knowledge passed down orally from one generation to the next. Access to this type of knowledge is relatively easy for community members to obtain. Many cite conversations over morning coffee as a place for sharing. It includes both local knowledge and traditional knowledge. The usefulness of this knowledge to inform decision-making processes, however, varies. This question encompasses knowledge and information that is not formally documented but is still readily used.

26. Traditional knowledge holders

Traditional knowledge is an important component of climate adaptation planning on reservation lands. "Traditional knowledge holders" rather than "elders" recognizes that there are and have always been multiple generations of individuals that carry and pass on traditional knowledge in Indigenous communities. Knowledge held by these individuals, although valued, may not always be accessible. There are often many protocols for how traditional knowledge can be shared and used at the individual, community, and societal level. This may make this particular source of information inaccessible to the majority of individuals concerned about climate adaptation on reservation lands. For it to be included in planning initiatives, careful attention would need to be given to forming collaborative partnerships.

27. Tribal natural resource/water/land departments

Tribal departments may be an important source of information to Indigenous communities because of their focused management of reservation lands. These departments are typically responsible for providing land and water management information for the communities that they serve. This is particularly important when this information may have consequences on human health. They may also have the authority to engage in outside partnerships to increase tribal access to information.

28. Tribally owned and operated monitoring equipment

Including this source differentiates between data collected from local/reservation monitoring equipment and data from outside sources.

29. Tribal colleges and universities

A previous study suggests that tribal colleges and universities may be advantageous resources to assist tribes with climate and environmental planning activities. This may be particularly true on reservations where tribal colleges and universities are chartered by local tribes (Fillmore et al., 2018). While several tribal colleges and universities (1994 land grant institution) are located within the Colorado River region, the Great Basin currently lacks a 1994 institution.

30. Other colleges and universities

Land grant institutions in both the Great Basin and in the Colorado River region have extension outreach personnel working with Indigenous communities. They provide educational opportunities to help coordinate efforts to promote agriculture in these regions. Furthermore, ongoing collaboration between university researchers and Indigenous communities in these areas has been in place for decades. This may suggest that some of these individuals – researchers and those working for Indigenous communities – may access information from these institutions.

31. The Weather Channel, Weather.com, local news and radio

This question item tracks the relevance of media-related sources of climate information. This type of information is not always considered unbiased or reliable for scientific study. It is, however, information accessible to a broader audience.

32. National Oceanic Atmospheric Administration (NOAA); National Weather Service; NRCS Snotel

These sources of climate and weather information are publicly available and give real-time climate and weather data. These sources of data are typically considered to be reliable for scientific study. Some of these data are summarized for general public consumption.

33. USDA Climate Hubs

USDA climate hubs are primarily climate data and information portals specifically designed to support stakeholder decisions. Information is focused on enhancing climate resiliency in the United States and data are summarized regionally and by topic. Links are also provided to other online stakeholder support tools and data resources. There are currently two active websites that are active for these hubs.

34. U.S. Geological Survey (USGS) Stream Gages

Stream gage data are available in real time and online through the USGS website. These data are standard information to determine water availability of a region. These can be particularly important for water managers to monitor water levels and to determine allocations.

35. Bureau of Indian Affairs climate planning program

This program offers funding to tribes to support tribal climate change adaptation and planning projects. For tribes awarded this funding and assistance, this could be a significant source of support for their climate adaptation planning efforts. Furthermore, because Indigenous communities have a direct connection to the U.S. Bureau of Indian Affairs, relative to other federal agencies, these programs may be tailored to assist with the diverse adaptation and resiliency needs of reservation communities.

36. Native Water on Arid Lands Annual Tribal Summits

This source of information was included per the request of the organizers of this tribal leadership summit. Responses to this question can also provide insight into the types of data and information can support decision-making. In retrospect, expanding this question to include, “or similar conferences/summits” would be more informative.

37. I use other information not listed above (please explain):_____

While this list of climate data and information sources may seem comprehensive, it is difficult to encompass the entire breadth of resources possible. This open-ended question is included to provide participants the opportunity to include sources other than those listed.

Questions 38-42 are not part of the Likert-type scale frequency list of questions, and will be analyzed separately.

38. I use or will use climate science information/data in my work with (select one best answer):
_Tribal department involved in natural resources/land/water management/planning
_Tribal government or administration

_Farming or ranching on tribal lands
_Teaching and working with grade school aged tribal youth
_As a college/university faculty, staff, or student
_Other: _______

This question is related to questions 22 and 23, as it asks about professional role. It is included separately, however, to identify how individuals use data and information. An interest in climate resiliency on tribal lands may or may not be related to professional role. Members of Indigenous communities often serve their communities in a multitude of ways. For example, while someone may work for their tribal government, they may also have their own farm or ranch. However, their priorities for climate change resiliency may be to ensure that the youth on their reservation are informed of impacts and have the tools to consider and develop community solutions to these impacts. The "Other" answer option is to ensure that participants have the opportunity to respond to this question even if their primary use of climate data and information is not listed.

39. How do you prefer to receive outreach information to support climate planning? (select one best answer)

_Printed Material	_Webinars
_Radio and TV	_Online information or data portal
_Annual tribal summit	_Other (please describe) ______

This question item is to summarize the most convenient and effective methods of data and information dissemination for the various stakeholders represented by our target population. While the items listed encompass primary means of public information consumption, we included an "Other" option to allow participants to include formats that may have been overlooked.

40. What is needed most to support climate adaptation on tribal lands? ____

This open-ended question is included to allow participants to provide feedback on topics that may have been inadvertently excluded. It may also support or refute priority results from Part I of the survey. Including open-ended questions ensures that survey participants can still provide information that may have been overlooked in the development of the survey.

41. What level of risk do you think climate uncertainty poses to tribal resources and communities: (select one best answer)
_No risk _Minor risk _Neutral _Major risk _Extreme Risk

This question asks specifically about climate uncertainty rather than climate change impacts. This is to help develop better insight into the need for data and information to support decision-making processes that enhance resiliency.

42. The most challenging issue that climate uncertainty poses to tribal resources and communities involves: (select one best answer)

_Water supply shortages on tribal lands
_Wildlife habitat endangered on tribal lands
_Tribal agriculture (farming and ranching)
_Tribal economic wellbeing
_Tribal fisheries (lakes and/or streams)
_Human survival on tribal lands
_Water quality impairment on tribal lands
_Other: _______

This question, like the one above, asks participants to consider the issue of climate uncertainty. Here, however, we ask them to indicate the specific resource about which they are most concerned. The topics listed here are based on literature related to climate resiliency planning (Cozzetto et al., 2013). Although related, water quantity and water quality are listed as separate issues due perhaps to stakeholders' differing values. Aquatic and terrestrial ecosystems are also listed separately for the same reason. For example, some tribes may relate their personal and cultural resiliency to the resiliency of their aquatic habitats while terrestrial habitats may hold a lesser value. Tribal agriculture is included because of its significant relationship to climate, and because of the emphasis on ensuring food security and/or food sovereignty on reservation lands (Fillmore et al., 2018). While human survival on tribal lands may imply a far-reaching impact, Indigenous communities often consider future generations when they discuss their values, decisions, and decision-making processes. Furthermore, many, if not all, of these reservations are already located in extreme climates where basic resources – such as access to potable water – are scarce. These issues warrant including human survival as being potentially impacted by climate uncertainty.

Part III

Part III of the survey specifically asks for demographic and background information. These questions will be used to determine if there are relationships or differences between a participant's background and his/her responses to the various questions. Responses can be grouped and coded for cross-correlation.

Part III. Please tell us something about yourself:

43. In which state do you live or work? _____

44. On which reservation(s) do you live [or work]: ________

45. If applicable, indicated how many years have you lived on a reservation? __ years

Question 45 is included examine if correlated difference in priorities exist between individuals that have lived or worked on reservations for many years and individuals whose work on reservations is relatively recent.

46. If applicable, please indicate whether the reservation land is primarily: (check one)

_Assigned trust land
_Fee simple land
_Reservation

_Combination of Allotted and Fee Simple	_Allotted trust land	_Other
_Combination of Assigned and Allotted	_Public domain allotted trust land	

Question 46 is intended to examine the association between land-tenure status and climate information/data needs.

47. What is your age? ___ years

48. What is your ethnic origin? (check one):

_Native American	_Hispanic/Latino	_Black
_White	_Asian/Pacific Is.	_Other

49. What is your gender (check one):
_Male _Female

While there is a growing call in social science research to include an additional option for individuals who may not conform to binary representations of gender, this was not considered during the development of this survey.

50. My highest level of education completed is: (check one)

_Less than high school	_Technical or Associate degree
_High school diploma/GED	_College Degree (BS, BA)
_Some college/technical	_Graduate Degree (MS, JD, PhD, MD)

Appendix F
Results

The following are response frequencies (counts) for each survey question:

		Response Frequency (Counts)							
	Survey question: To adapt to and plan for climate uncertainty, tribal communities need information about…	Very Low Priority	Low Priority	Neutral	High Priority	Very High Priority	Valid Total	Missing	Total
1	How to conduct a climate resiliency assessment	1	5	16	50	25	97	1	98
2	Climate change impacts on tribal lands, water and economies	2	1	10	34	50	97	1	98
3	Enhancing tribal food security and sovereignty	2	3	14	34	43	96	2	98
4	Adaptation strategies unique to tribal lands	2	1	19	41	32	95	3	98
5	Incorporating traditional knowledge in climate adaptation planning for tribal lands	0	1	18	42	36	97	1	98
6	How to protect traditional knowledge that tribes incorporate into their adaptation plans	2	0	21	31	43	97	1	98
7	Examples of other tribes' climate adaptation plans	2	5	28	46	16	97	1	98
8	How to finance implementation of climate adaptation plans	1	3	21	33	38	96	2	98
9	Meaning of future climate projections for individual reservations	2	7	22	36	30	97	1	98
10	Selecting equipment to monitor/collect data to inform tribal climate	1	6	26	36	28	97	1	98
11	How to finance monitoring/data collection on tribal lands	2	3	26	39	27	97	1	98
12	Training tribal employees to ensure consistent data monitoring and collection on tribal lands	1	4	21	33	38	97	1	98
13	Precipitation data (check one below and rate priority)	1	7	7	52	27	94	4	98

14	Temperature data (check one below and rate priority)	1	3	12	50	26	92	6	98
15	Streamflow data (check one below and rate priority)	1	2	15	46	28	92	6	98
16	Soil moisture data (check one below and rate priority)	1	5	19	44	25	94	4	98
17	Snowpack data (check one below and rate priority)	3	2	12	46	28	91	7	98
18	Water quality data (check one below and rate priority)	1	2	10	43	37	93	5	98
19	Raw data collected from monitoring instruments (check one below and rate priority)	1	6	24	39	24	94	4	98
20	Generalized reports or summaries on water resources and climate information (check one below and rate priority)	2	0	18	47	26	93	5	98

		Response Frequency (Counts)					
	Survey question: To adapt to and plan for climate uncertainty, tribal communities need information about…	Daily	Hourly	Monthly	Valid Total	Missing	Total
13b	Scale of precipitation data	33	2	47	82	16	98
14b	Scale of temperature data	38	8	34	80	18	98
15b	Scale of streamflow data	35	13	30	78	20	98
16b	Scale of soil moisture data	25	4	48	77	21	98
17b	Scale of snowpack data	19	4	53	76	22	98
18b	Scale of water quality data	23	4	51	78	20	98
19b	Scale of raw data collected from monitoring instruments	31	8	40	79	19	98
20b	Scale of generalized reports or summaries on water resources and climate information	13	2	63	78	20	98

Survey Question 21: At your job what portion of annual operating budget should be allocated to support climate adaptation on tribal lands? (select one answer)

0%	1-5%	6-10%	11-15%	16-20%	21-25%	26% or Greater	Valid Total	Missing	Total
5	17	15	5	14	13	11	80	18	98

Question 22: I work for:

Cooperative extension FRTEP	Federal government	Other colleges/university	Private sector business	Self employed	State government	Tribal college/university	Tribal government	Valid Total	Missing	Total
10	5	9	1	10	1	11	42	89	9	98

Question 23: If applicable, I work in: (select department)

Agriculture	Cultural	Education	Environmental	Other government	Tribal government	Water resources	Valid Total	Missing	Total
20	2	33	9	6	6	14	90	8	98

Note. This variable and response categories were established through grounded theory using responses to question 22 and question 23.

Respondent role in climate adaptation initiatives on reservation lands:

Implementation	Administration	Analysis	Valid Total	Missing	Total
43	14	33	90	8	98

	Survey question: In climate adaptation planning, we are currently using information/data provided by…	Response Frequency (Counts) Never	Rarely	Occasionally	Often	Very Often	Valid Total	Missing	Total
24	Tribal farmers and ranchers	6	21	27	25	13	92	6	98
25	Tribal oral histories	5	11	36	30	9	91	7	98
26	Traditional knowledge holders	7	8	36	30	9	90	8	98
27	Tribal natural resource/water/land departments	3	10	20	31	26	90	8	98
28	Tribally owned and operated monitoring equipment	9	18	25	20	16	88	10	98
29	Tribal colleges and universities	18	27	25	9	11	90	8	98
30	Other colleges and universities	5	25	21	26	13	90	8	98
31	The Weather Channel; Weather.com; local news and radio	13	19	24	29	6	91	7	98
32	National Oceanic Atmospheric Administration (NOAA); National Weather Service; NRCS Snotel	5	18	21	33	14	91	7	98
33	USDA Climate Hubs	9	25	21	30	6	91	7	98
34	US Geological Survey Stream Gages	7	12	26	29	17	91	7	98
35	Bureau of Indian Affairs climate planning program	12	22	28	19	9	90	8	98
36	Native Water on Arid Lands Annual Tribal Summits	7	23	24	22	13	89	9	98

Question 37, "I use other information not listed above (please explain) ________" produces narrative or qualitative data and thus are omitted from Appendix F frequency count (quantitative) data summary. Furthermore, data from this question was not used in any analysis within this thesis. Coding and grouping this data for quantitative analysis may occur at a later date.

Question 38: I use or will use climate science information/data in my work with (select one best answer):

As a college/university faculty, staff or student	Farming or ranching on tribal lands	Tribal department involved in natural resources/land/water management/planning	Tribal government or administration	Teaching and working with grade school aged tribal ,	Other	Valid Total	Missing	Total
23	21	30	6	3	3	86	12	98

Question 39: How do you prefer to receive outreach information to support climate planning? (select one best answer)

Printed material	Radio and TV	Annual tribal summit	Webinars	Online information or data portal	Other	Valid Total	Missing	Total
13	3	16	6	38	3	79	19	98

Question 40, “What is needed most to support climate adaptation on tribal lands?” produces narrative or qualitative data and thus omitted from Appendix F frequency count (quantitative data) summary. Furthermore, data from this question was not used in any analysis within this thesis. Coding and grouping this data for quantitative analysis may occur at a later date.

Question 41: What level of risk do you think climate uncertainty poses to tribal resources and communities: (select one best answer)

No risk	Minor risk	Neutral	Major risk	Extreme risk	Valid Total	Missing	Total
0	2	12	53	28	95	3	98

Question 42: The most challenging issue that climate uncertainty poses to tribal resources and communities involves: (select one best answer)

Water supply shortages on tribal lands	Tribal agriculture (farming and ranching)	Tribal fisheries (lakes and/or streams)	Water quality impairment on tribal lands	Wildlife habitat endangered on tribal lands	Tribal economic well being	Human survival on tribal lands	Other	Valid Total	Missing	Total
36	11	3	3	5	5	9	3	75	23	98

Question 42:
The most challenging issue that climate uncertainty poses to tribal resources and communities involves: (select one best answer)

Water supply	Tribal agriculture	Ecological/ environmental health	Tribal economies	Human survival	Valid Total	Missing	Total
36	11	11	5	10	73	25	98

Note: The following variables and response categories were established through the use of grounded theory and the responses to the set of six choices provided for question 42 (above).

Primary sector of climate concern:

Water supply	Environmental health	Economics	Valid Total	Missing	Total
36	33	5	74	24	98

Question 43: In which state do you live or work?

Arizona	California	Georgia	Idaho	Montana	Nevada	New Mexico	Ohio	Utah	Washington	Wisconsin	Valid Total	Missing	Total
27	2	2	3	7	39	6	2	4	1	1	94	4	98

Question 44, "On which reservation(s) do you live [or work]?" response frequency results omitted to protect the anonymity of respondents belonging to or engaged in work with Indigenous communities.
Note: However, the following two (2) variables and response categories were established through grounded theory using responses to question 44.
In which watershed do you live or work?

Great Basin Region	Upper Colorado Region	Lower Colorado Region	Pacific Northwest Region	Rio Grande Region	Missouri Region	Other	Valid Total	Missing	Total
38	15	18	3	2	5	4	85	13	98

In which region do you live or work?

Great Basin Region	Colorado Region	Other	Valid Total	Missing	Total
38	33	14	85	13	98

Note: The following two variables (Questions 45 and 47) and response categories were recoded from scale data to categorical data to facilitate analysis:

Question 45: If applicable, indicate how many years have you lived on a reservation? (years)

30 or less	31-50 years	greater than 50	Valid Total	Missing	Total
23	24	27	74	24	98

Question 47: What is your age?

16-24	25-34	35-44	45-54	55-64	65+	Valid Total	Missin g	Total
8	10	13	16	35	9	91	7	98

Question 46: “If applicable, please indicate whether the reservation land is primarily: (check one)” omitted from Appendix F due to survey error as a result of the overly complex design of this survey question item and fixed set of responses provided.

Question 48: What is your ethnic origin? (check one)

Asian/Pacific Islander	Hispanic/Latino	Native American	Other	White	Valid Total	Missing	Total
6	2	71	1	14	94	4	98

Question 49: What is your gender? (check one)

Female	Male	Valid Total	Missing	Total
26	69	95	3	98

Question 50: My highest level of education completed is: (check one)

Less than high school	High school diploma/GED	Some college/technical	Technical or Associate degree	College degree (BS, BA)	Graduate degree (MS, JD, PhD, MD)	Valid Total	Missing	Total
8	5	17	10	20	34	94	4	98

Appendix G
Cross-Correlation Count Tables

Crosstab

			2. Climate change impacts on tribal lands, water and economies: Very Low Priority	Low Priority	Neutral	High Priority	Very High Priority	Total
23 grouped Data/information use	Implementation	Count	2	0	7	15	18	42
		Expected Count	.9	.5	4.7	14.6	21.2	42.0
	Administration	Count	0	0	2	8	4	14
		Expected Count	.3	.2	1.6	4.9	7.1	14.0
	Analysis	Count	0	1	1	8	23	33
		Expected Count	.7	.4	3.7	11.5	16.7	33.0
Total		Count	2	1	10	31	45	89
		Expected Count	2.0	1.0	10.0	31.0	45.0	89.0

Crosstab

			9. Meaning of future climate projections for individual reservations: Very Low Priority	Low Priority	Neutral	High Priority	Very High Priority	Total
23 grouped Data/information use	Implementation	Count	2	1	11	17	11	42
		Expected Count	.9	3.3	9.0	16.5	12.3	42.0
	Administration	Count	0	0	5	8	1	14
		Expected Count	.3	1.1	3.0	5.5	4.1	14.0
	Analysis	Count	0	6	3	10	14	33
		Expected Count	.7	2.6	7.0	13.0	9.6	33.0
Total		Count	2	7	19	35	26	89
		Expected Count	2.0	7.0	19.0	35.0	26.0	89.0

Crosstab

			24. Tribal farmers and ranchers: Never	Rarely	Occasionally	Often	Very Often	Total
23 grouped Data/information use	Implementation	Count	4	2	15	14	6	41
		Expected Count	2.9	9.6	11.1	11.6	5.8	41.0
	Administration	Count	1	4	2	3	3	13
		Expected Count	.9	3.1	3.5	3.7	1.8	13.0
	Analysis	Count	1	14	6	7	3	31
		Expected Count	2.2	7.3	8.4	8.8	4.4	31.0
Total		Count	6	20	23	24	12	85
		Expected Count	6.0	20.0	23.0	24.0	12.0	85.0

Crosstab

			30. Other colleges and universities: Never	Rarely	Occasionally	Often	Very Often	Total
23 grouped Data/information use	Implementation	Count	3	19	7	6	5	40
		Expected Count	2.4	11.1	9.2	11.1	6.3	40.0
	Administration	Count	1	3	2	5	1	12
		Expected Count	.7	3.3	2.7	3.3	1.9	12.0
	Analysis	Count	1	1	10	12	7	31
		Expected Count	1.9	8.6	7.1	8.6	4.9	31.0
Total		Count	5	23	19	23	13	83
		Expected Count	5.0	23.0	19.0	23.0	13.0	83.0

Crosstab

			36. Native Water on Arid Lands Annual Tribal Summits					Total
			Never	Rarely	Occasionally	Often	Very Often	
23 grouped Data/information use	Implementation	Count	4	8	15	5	7	39
		Expected Count	3.3	10.5	10.5	10.0	4.8	39.0
	Administration	Count	1	5	4	3	0	13
		Expected Count	1.1	3.5	3.5	3.3	1.6	13.0
	Analysis	Count	2	9	3	13	3	30
		Expected Count	2.6	8.0	8.0	7.7	3.7	30.0
Total		Count	7	22	22	21	10	82
		Expected Count	7.0	22.0	22.0	21.0	10.0	82.0

Crosstab

			42g1. The most challenging issue that climate uncertainty poses to tribal resources and communities involves:					Total
			Water supply	Tribal agriculture	Ecological/environmental health	Tribal economies	Human survival	
23 grouped Data/information use	Implementation	Count	19	3	3	0	4	29
		Expected Count	13.9	4.8	4.3	1.7	4.3	29.0
	Administration	Count	7	3	2	0	2	14
		Expected Count	6.7	2.3	2.1	.8	2.1	14.0
	Analysis	Count	6	5	5	4	4	24
		Expected Count	11.5	3.9	3.6	1.4	3.6	24.0
Total		Count	32	11	10	4	10	67
		Expected Count	32.0	11.0	10.0	4.0	10.0	67.0

Crosstab

			42g2. The most challenging issue that climate uncertainty poses to tribal resources and communities involves:			Total
			Water supply	Environmental health	Economics	
23 grouped Data/information use	Implementation	Count	19	11	0	30
		Expected Count	14.1	14.1	1.8	30.0
	Administration	Count	7	7	0	14
		Expected Count	6.6	6.6	.8	14.0
	Analysis	Count	6	14	4	24
		Expected Count	11.3	11.3	1.4	24.0
Total		Count	32	32	4	68
		Expected Count	32.0	32.0	4.0	68.0

Crosstab

			1. How to conduct a climate resiliency assessment					Total
			Very Low Priority	Low Priority	Neutral	High Priority	Very High Priority	
44 grouped In which watershed does the majority of your reservation exist?	Great Basin Region	Count	0	2	8	23	5	38
		Expected Count	.5	2.3	5.9	19.9	9.5	38.0
	Colorado Region	Count	1	2	5	16	8	32
		Expected Count	.4	1.9	5.0	16.8	8.0	32.0
	Other	Count	0	1	0	5	8	14
		Expected Count	.2	.8	2.2	7.3	3.5	14.0
Total		Count	1	5	13	44	21	84
		Expected Count	1.0	5.0	13.0	44.0	21.0	84.0

Crosstab

			4. Adaptation strategies unique to tribal lands					
			Very Low Priority	Low Priority	Neutral	High Priority	Very High Priority	Total
44 grouped In which watershed does the majority of your reservation exist?	Great Basin Region	Count	0	0	14	15	9	38
		Expected Count	.9	.5	8.1	15.4	13.1	38.0
	Colorado Region	Count	1	1	2	13	15	32
		Expected Count	.8	.4	6.9	13.0	11.0	32.0
	Other	Count	1	0	2	6	5	14
		Expected Count	.3	.2	3.0	5.7	4.8	14.0
Total		Count	2	1	18	34	29	84
		Expected Count	2.0	1.0	18.0	34.0	29.0	84.0

Crosstab

			6. How to protect traditional knowledge that tribes incorporate into their adaptation plans				
			Very Low Priority	Neutral	High Priority	Very High Priority	Total
44 grouped In which watershed does the majority of your reservation exist?	Great Basin Region	Count	0	13	11	14	38
		Expected Count	.5	7.7	11.3	18.5	38.0
	Colorado Region	Count	1	2	10	19	32
		Expected Count	.4	6.5	9.5	15.6	32.0
	Other	Count	0	2	4	8	14
		Expected Count	.2	2.8	4.2	6.8	14.0
Total		Count	1	17	25	41	84
		Expected Count	1.0	17.0	25.0	41.0	84.0

Crosstab

			9. Meaning of future climate projections for individual reservations					
			Very Low Priority	Low Priority	Neutral	High Priority	Very High Priority	Total
44 grouped . In which watershed does the majority of your reservation exist?	Great Basin Region	Count	0	2	12	16	8	38
		Expected Count	.9	2.7	7.7	15.4	11.3	38.0
	Colorado Region	Count	2	1	2	14	13	32
		Expected Count	.8	2.3	6.5	13.0	9.5	32.0
	Other	Count	0	3	3	4	4	14
		Expected Count	.3	1.0	2.8	5.7	4.2	14.0
Total		Count	2	6	17	34	25	84
		Expected Count	2.0	6.0	17.0	34.0	25.0	84.0

Crosstab

			13b. Precipitation data (daily_, hourly_, monthly_)			
			Daily	Hourly	Monthly	Total
44 grouped In which watershed does the majority of your reservation exist?	Great Basin Region	Count	10	0	24	34
		Expected Count	13.1	1.0	19.9	34.0
	Colorado Region	Count	14	1	10	25
		Expected Count	9.6	.7	14.6	25.0
	Other	Count	3	1	7	11
		Expected Count	4.2	.3	6.4	11.0
Total		Count	27	2	41	70
		Expected Count	27.0	2.0	41.0	70.0

Crosstab

			14b. Temperature data (daily_, hourly_, monthly_)			
			Daily	Hourly	Monthly	Total
44 grouped In which watershed does the majority of your reservation exist?	Great Basin Region	Count	15	0	18	33
		Expected Count	15.3	2.9	14.8	33.0
	Colorado Region	Count	13	5	7	25
		Expected Count	11.6	2.2	11.2	25.0
	Other	Count	4	1	6	11
		Expected Count	5.1	1.0	4.9	11.0
Total		Count	32	6	31	69
		Expected Count	32.0	6.0	31.0	69.0

Crosstab

			15b. Streamflow data (daily_, hourly_, monthly_)			
			Daily	Hourly	Monthly	Total
44 grouped In which watershed does the majority of your reservation exist?	Great Basin Region	Count	16	2	15	33
		Expected Count	13.5	6.0	13.5	33.0
	Colorado Region	Count	8	8	6	22
		Expected Count	9.0	4.0	9.0	22.0
	Other	Count	3	2	6	11
		Expected Count	4.5	2.0	4.5	11.0
Total		Count	27	12	27	66
		Expected Count	27.0	12.0	27.0	66.0

Crosstab

			19. Raw data collected from monitoring instruments (check one below and rate priority)					
			Very Low Priority	Low Priority	Neutral	High Priority	Very High Priority	Total
44 grouped In which watershed does the majority of your reservation exist?	Great Basin Region	Count	0	2	13	15	8	38
		Expected Count	.5	1.9	9.3	16.7	9.7	38.0
	Colorado Region	Count	1	2	6	10	12	31
		Expected Count	.4	1.5	7.6	13.6	7.9	31.0
	Other	Count	0	0	1	11	1	13
		Expected Count	.2	.6	3.2	5.7	3.3	13.0
Total		Count	1	4	20	36	21	82
		Expected Count	1.0	4.0	20.0	36.0	21.0	82.0

Crosstab

			27. Tribal natural resource/water/land departments					Total
			Never	Rarely	Occasionally	Often	Very Often	
44 grouped In which watershed does the majority of your reservation exist?	Great Basin Region	Count	0	1	10	15	8	34
		Expected Count	.9	3.8	7.2	11.9	10.2	34.0
	Colorado Region	Count	1	5	7	7	13	33
		Expected Count	.8	3.7	7.0	11.5	9.9	33.0
	Other	Count	1	3	0	6	3	13
		Expected Count	.3	1.5	2.8	4.6	3.9	13.0
Total		Count	2	9	17	28	24	80
		Expected Count	2.0	9.0	17.0	28.0	24.0	80.0

Crosstab

			28. Tribally owned and operated monitoring equipment					Total
			Never	Rarely	Occasionally	Often	Very Often	
44 grouped In which watershed does the majority of your reservation exist?	Great Basin Region	Count	2	5	12	12	3	34
		Expected Count	3.4	7.3	9.9	7.7	5.6	34.0
	Colorado Region	Count	6	9	7	3	7	32
		Expected Count	3.2	6.9	9.3	7.3	5.3	32.0
	Other	Count	0	3	4	3	3	13
		Expected Count	1.3	2.8	3.8	3.0	2.1	13.0
Total		Count	8	17	23	18	13	79
		Expected Count	8.0	17.0	23.0	18.0	13.0	79.0

Crosstab

			30. Other colleges and universities					Total
			Never	Rarely	Occasionally	Often	Very Often	
44 grouped In which watershed does the majority of your reservation exist?	Great Basin Region	Count	2	15	10	7	2	36
		Expected Count	2.3	10.4	9.5	9.9	4.1	36.0
	Colorado Region	Count	2	4	10	8	7	31
		Expected Count	1.9	8.9	8.1	8.5	3.5	31.0
	Other	Count	1	4	1	7	0	13
		Expected Count	.8	3.7	3.4	3.6	1.5	13.0
Total		Count	5	23	21	22	9	80
		Expected Count	5.0	23.0	21.0	22.0	9.0	80.0

Crosstab

			31. The Weather Channel; Weather.com; local news and radio					Total
			Never	Rarely	Occasionally	Often	Very Often	
44 grouped In which watershed does the majority of your reservation exist?	Great Basin Region	Count	3	10	10	12	0	35
		Expected Count	3.9	7.8	8.6	12.5	2.2	35.0
	Colorado Region	Count	2	5	8	13	5	33
		Expected Count	3.7	7.3	8.1	11.8	2.0	33.0
	Other	Count	4	3	2	4	0	13
		Expected Count	1.4	2.9	3.2	4.7	.8	13.0
Total		Count	9	18	20	29	5	81
		Expected Count	9.0	18.0	20.0	29.0	5.0	81.0

Crosstab

			4. Adaptation strategies unique to tribal lands					
			Very Low Priority	Low Priority	Neutral	High Priority	Very High Priority	Total
50 grouped My highest level of education completed is:	High school or less	Count	0	1	6	3	3	13
		Expected Count	.3	.1	2.7	5.5	4.4	13.0
	Some college/technical or associates degree	Count	0	0	3	10	14	27
		Expected Count	.6	.3	5.6	11.4	9.1	27.0
	College degree (BS/BA)	Count	1	0	4	8	6	19
		Expected Count	.4	.2	3.9	8.1	6.4	19.0
	Graduate degree (MS, JD, PhD, MD, etc.)	Count	1	0	6	18	8	33
		Expected Count	.7	.4	6.8	14.0	11.1	33.0
Total		Count	2	1	19	39	31	92
		Expected Count	2.0	1.0	19.0	39.0	31.0	92.0

Crosstab

			5. Incorporating traditional knowledge in climate adaptation planning for tribal lands				
			Low Priority	Neutral	High Priority	Very High Priority	Total
50 grouped My highest level of education completed is:	High school or less	Count	1	5	5	2	13
		Expected Count	.1	2.2	5.6	5.0	13.0
	Some college/technical or associates degree	Count	0	2	11	14	27
		Expected Count	.3	4.6	11.6	10.5	27.0
	College degree (BS/BA)	Count	0	6	6	8	20
		Expected Count	.2	3.4	8.6	7.7	20.0
	Graduate degree (MS, JD, PhD, MD, etc.)	Count	0	3	18	12	33
		Expected Count	.4	5.7	14.2	12.8	33.0
Total		Count	1	16	40	36	93
		Expected Count	1.0	16.0	40.0	36.0	93.0

Crosstab

			15b. Streamflow data (daily_, hourly_, monthly_)			
			Daily	Hourly	Monthly	Total
50 grouped My highest level of education completed is:	High school or less	Count	3	0	8	11
		Expected Count	4.8	1.9	4.3	11.0
	Some college/technical or associates degree	Count	7	2	11	20
		Expected Count	8.6	3.5	7.8	20.0
	College degree (BS/BA)	Count	9	4	3	16
		Expected Count	6.9	2.8	6.3	16.0
	Graduate degree (MS, JD, PhD, MD, etc.)	Count	13	7	7	27
		Expected Count	11.7	4.7	10.6	27.0
Total		Count	32	13	29	74
		Expected Count	32.0	13.0	29.0	74.0

Crosstab

			16b. Soil moisture data (daily_, hourly_, monthly_)			
			Daily	Hourly	Monthly	Total
50 grouped My highest level of education completed is:	High school or less	Count	2	1	7	10
		Expected Count	3.2	.5	6.3	10.0
	Some college/technical or associates degree	Count	5	0	15	20
		Expected Count	6.3	1.1	12.6	20.0
	College degree (BS/BA)	Count	4	3	9	16
		Expected Count	5.0	.9	10.1	16.0
	Graduate degree (MS, JD, PhD, MD, etc.)	Count	12	0	15	27
		Expected Count	8.5	1.5	17.0	27.0
Total		Count	23	4	46	73
		Expected Count	23.0	4.0	46.0	73.0

Crosstab

			19b. Raw data collected from monitoring instruments (daily_, hourly_, monthly_)			
			Daily	Hourly	Monthly	Total
50 grouped My highest level of education completed is:	High school or less	Count	5	3	3	11
		Expected Count	4.5	1.2	5.3	11.0
	Some college/technical or associates degree	Count	6	0	16	22
		Expected Count	9.1	2.3	10.6	22.0
	College degree (BS/BA)	Count	5	3	8	16
		Expected Count	6.6	1.7	7.7	16.0
	Graduate degree (MS, JD, PhD, MD, etc.)	Count	15	2	9	26
		Expected Count	10.7	2.8	12.5	26.0
Total		Count	31	8	36	75
		Expected Count	31.0	8.0	36.0	75.0

Crosstab

			20. Generalized reports or summaries on water resources and climate information (check one below and rate priority)				
			Very Low Priority	Neutral	High Priority	Very High Priority	Total
50 grouped My highest level of education completed is:	High school or less	Count	0	7	3	2	12
		Expected Count	.3	2.3	6.1	3.4	12.0
	Some college/technical or associates degree	Count	1	2	17	7	27
		Expected Count	.6	5.2	13.7	7.6	27.0
	College degree (BS/BA)	Count	1	2	9	7	19
		Expected Count	.4	3.6	9.6	5.3	19.0
	Graduate degree (MS, JD, PhD, MD, etc.)	Count	0	6	16	9	31
		Expected Count	.7	5.9	15.7	8.7	31.0
Total		Count	2	17	45	25	89
		Expected Count	2.0	17.0	45.0	25.0	89.0

Crosstab

			20b. Generalized reports or summaries on water resources and climate information (daily_, hourly_, monthly_)			
			Daily	Hourly	Monthly	Total
50 grouped My highest level of education completed is:	High school or less	Count	2	0	9	11
		Expected Count	1.9	.3	8.8	11.0
	Some college/technical or associates degree	Count	2	0	20	22
		Expected Count	3.9	.6	17.5	22.0
	College degree (BS/BA)	Count	2	2	11	15
		Expected Count	2.6	.4	12.0	15.0
	Graduate degree (MS, JD, PhD, MD, etc.)	Count	7	0	19	26
		Expected Count	4.6	.7	20.7	26.0
Total		Count	13	2	59	74
		Expected Count	13.0	2.0	59.0	74.0

Crosstab

			36. Native Water on Arid Lands Annual Tribal Summits					Total
			Never	Rarely	Occasionally	Often	Very Often	
50 grouped My highest level of education completed is:	High school or less	Count	2	4	4	1	1	12
		Expected Count	.8	3.2	3.3	2.8	1.8	12.0
	Some college/technical or associates degree	Count	2	4	8	5	7	26
		Expected Count	1.8	7.0	7.3	6.0	3.9	26.0
	College degree (BS/BA)	Count	0	4	6	7	1	18
		Expected Count	1.3	4.8	5.0	4.2	2.7	18.0
	Graduate degree (MS, JD, PhD, MD, etc.)	Count	2	11	6	7	4	30
		Expected Count	2.1	8.0	8.4	7.0	4.5	30.0
Total		Count	6	23	24	20	13	86
		Expected Count	6.0	23.0	24.0	20.0	13.0	86.0

Crosstab

			13. Precipitation data (check one below and rate priority)					Total
			Very Low Priority	Low Priority	Neutral	High Priority	Very High Priority	
49 What is your gender? (check one)	Female	Count	0	0	3	9	12	24
		Expected Count	.3	1.8	1.8	12.9	7.1	24.0
	Male	Count	1	7	4	40	15	67
		Expected Count	.7	5.2	5.2	36.1	19.9	67.0
Total		Count	1	7	7	49	27	91
		Expected Count	1.0	7.0	7.0	49.0	27.0	91.0

Crosstab

			20. Generalized reports or summaries on water resources and climate information (check one below and rate priority)				Total
			Very Low Priority	Neutral	High Priority	Very High Priority	
49 What is your gender? (check one)	Female	Count	0	1	12	11	24
		Expected Count	.5	4.5	12.3	6.7	24.0
	Male	Count	2	16	34	14	66
		Expected Count	1.5	12.5	33.7	18.3	66.0
Total		Count	2	17	46	25	90
		Expected Count	2.0	17.0	46.0	25.0	90.0

Crosstab

			31. The Weather Channel; Weather.com; local news and radio					Total
			Never	Rarely	Occasionally	Often	Very Often	
49 What is your gender? (check one)	Female	Count	8	5	4	7	0	24
		Expected Count	3.5	4.9	6.3	7.9	1.4	24.0
	Male	Count	5	13	19	22	5	64
		Expected Count	9.5	13.1	16.7	21.1	3.6	64.0
Total		Count	13	18	23	29	5	88
		Expected Count	13.0	18.0	23.0	29.0	5.0	88.0

Crosstab

			13b. Precipitation data (daily_, hourly_, monthly_)			
			Daily	Hourly	Monthly	Total
47 grouped What is your age?	16-24	Count	3	0	3	6
		Expected Count	2.5	.2	3.3	6.0
	25-34	Count	3	1	3	7
		Expected Count	2.9	.2	3.9	7.0
	35-44	Count	6	0	5	11
		Expected Count	4.6	.3	6.1	11.0
	45-54	Count	10	1	3	14
		Expected Count	5.9	.4	7.7	14.0
	55-64	Count	9	0	23	32
		Expected Count	13.5	.8	17.7	32.0
	65+	Count	1	0	5	6
		Expected Count	2.5	.2	3.3	6.0
Total		Count	32	2	42	76
		Expected Count	32.0	2.0	42.0	76.0

Crosstab

			18b. Water quality data (daily_, hourly_, monthly_)			
			Daily	Hourly	Monthly	Total
47 grouped What is your age?	16-24	Count	5	0	1	6
		Expected Count	1.8	.3	3.8	6.0
	25-34	Count	3	1	3	7
		Expected Count	2.1	.4	4.5	7.0
	35-44	Count	4	1	5	10
		Expected Count	3.1	.6	6.4	10.0
	45-54	Count	5	1	7	13
		Expected Count	4.0	.7	8.3	13.0
	55-64	Count	5	1	24	30
		Expected Count	9.2	1.7	19.2	30.0
	65+	Count	0	0	6	6
		Expected Count	1.8	.3	3.8	6.0
Total		Count	22	4	46	72
		Expected Count	22.0	4.0	46.0	72.0