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Climate Resilient Tribal Waters

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

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This Special Publication reports the results of participatory research to assess the climate information and data needs of Indigenous communities to enhance the climate resiliency of water resources on reservation lands. The work is supported by Agriculture and Food Research Initiative (AFRI) [Water for Agriculture Challenge Area: Enhancing Climate Resiliency & Agriculture on American Indian Land grant no. 2015-69007-23190/project accession no. 1005994] from the USDA National Institute of Food and Agriculture..

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Native Waters on Arid Lands

A partnership of Nevada counties; University of Nevada, Reno; and U.S. Department of Agriculture

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Table of Contents

Executive Summary[1]

The southwestern U.S. is projected to experience dramatic shifts in water resource availability. Indigenous communities in this arid, water-scarce region are highly vulnerable to these changes but are also leading initiatives for community-based climate adaptation. Research can aid and enhance these adaptation initiatives by identifying and assessing the pressing climate data and information needs of Indigenous communities in the southwestern U.S. This publication reports the results of this research, highlighting prioritized climate data and information needs of survey respondents attending annual tribal climate summits in the southwestern U.S.

Summit attendees who volunteered to participate in this survey research included tribal government staff, farmers, ranchers, researchers and outreach professionals interested in and/or pursuing community-based adaptation to increase the climate resiliency of water resources on arid reservation lands. Approximately 75% of the 98 voluntary survey respondents are Native American, and 83% reside in the Great Basin or Colorado River Basin. The majority (85%) of survey respondents indicated that climate uncertainty poses either major or extreme risks to tribal natural resources and communities. Respondents indicated that the greatest threats that climate uncertainty poses are: water supply shortages, agriculture or food security, human survival, tribal economic well-being, wildlife habitat, water quality impairment, and tribal fisheries. Respondents prioritized climate information needs that aid in assessing climate change impacts, enhancing food security, and integrating traditional knowledge into adaptation. In this sparsely populated and comparatively data-scarce region, respondents prioritized water quality data as their highest data need, followed by streamflow and temperature data.

Additional analyses of survey responses suggest that past professional/occupational experience and educational background are associated with participants' perspectives and prioritization of climate information and data needs. Results from this study may clarify ways to support climate adaptation on reservation lands through continued collaborative research and outreach.

A summary discussion emphasizes the importance of ethical collaboration when involving Indigenous communities in participatory research, with special attention to protecting traditional knowledges and data sovereignty of Indigenous communities in their pursuit of community-based climate adaptation. This publication concludes by observing that efforts to increase the numbers of Indigenous scientists, natural resource professionals and students will facilitate such protections as tribes increasingly self-determine their respective paths to enhanced climate resiliency of water resources on reservation lands.

[1]This special publication highlights key findings from a Master Thesis by Helen Fillmore [supported by AFRI grant no. 2015-69007-23190/project accession no. 1005994 from the USDA NIFA] successfully defended in partial fulfillment of the M.S. degree in Hydrology (May 2019). More detailed study findings are available at: Fillmore, H. (2019). *Assessing climate data and information needs to enhance the resiliency of water resources on reservation lands in the southwestern United States.* Master Thesis, University of Nevada, Reno. Graduate Program in Hydrologic Sciences at https://scholarworks.unr.edu/handle/11714/5719.

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1. Introduction

Climate change impacts on water resources are projected to compound water scarcity in already water-stressed regions in the southwestern U.S. (Li et al., 2017). Current water availability limits the capacity of this arid region to sustainably meet water needs for urban 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 available water supply affect everyone living and working in this arid region, these changes may affect Indigenous communities on reservation lands more severely (Gamble et al., 2016). Historically limited economic development opportunities, inadequate water delivery infrastructure, unresolved water rights entitlements (Deol & Colby, 2018), and isolated rural land bases add to the particular vulnerability of Indigenous communities to adapt to projected changes in water resources (Cozzetto et al., 2013). Furthermore, Indigenous communities and cultures are relational to their natural environment (Whyte, 2018a; Maldonado et al., 2016) and inform natural resource management decisions on reservation lands (Azar, Holmberg, & Lindgren, 1996; Maldonado et al., 2016). Climate-induced ecological changes, on or near reservation lands, can result in significant losses to cultural resources and a reduction of subsistence and cultural practices that impact community physical and mental health and social well-being (Jantarasami et al., 2018; Lemelin et al., 2010).

Community-based adaptation has emerged as a cost-effective way forward to adapt to climate change by capitalizing upon the wealth of experience and knowledge communities have with regards to climate variability and climate change (McNamara et al., 2020). It is adaptation that is community-led and based on communities' knowledges, needs, priorities and capacities and fully includes communities in all levels of research, planning and implementation (Reid, 2015; McNamara & Buzzy, 2017).

The extensive socioeconomic, political and cultural diversity that characterizes individual Indigenous communities reinforce the importance of community-based adaptation. Many tribal governments and intertribal organizations are leading the U.S. by providing examples. That is, over the last decade, Indigenous communities across all regions of the U.S. have documented more than 800 climate adaptation activities at the community and/or reservation landscape scale. These include planning and assessment; adaptation and implementation; monitoring and research; governance and capacity-building; youth engagement and cultural continuity. Climate adaptation projects include climate vulnerability assessments, planning and professional development to increase the skills and capacity of tribal staff and natural resource managers, including individual farmers and ranchers (Jantarasami et al., 2018).

To complement the numerous adaptation initiatives already underway on reservation lands, this research aims to assess climate data and information needs and priorities within the southwestern U.S.[2] For this study, our target study population or "stakeholders" include individuals living or working on reservations in the southwestern U.S. and who are interested in pursuing or already engaged in climate adaptation. We use a participatory research framework to engage local stakeholders while preventing the unintended extraction of sensitive or protected cultural information (Whyte, 2018a). 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 wherein research abuses have occurred in the past (Chief, Meadow, & Whyte, 2016; Datta et al., 2015; Klenk et al., 2017). ●

[2]The research presented in this Special Publication is supported by Agriculture and Food Research Initiative [Water for Agriculture Challenge Area: Enhancing Climate Resiliency & Agriculture on American Indian Land grant no. 2015-69007-23190/project accession no. 1005994] from the USDA National Institute of Food and Agriculture.

2. Study Region

We defined our study region boundaries by 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 (see Figure 1). This study region, we refer to here as the "Southwest," includes most of Nevada and Arizona, in addition to portions of California, Colorado, Idaho, New Mexico and Utah. The primary significance of utilizing USGS water resource regions to define the study area boundaries stems from the important role of water law and governance in water use and availability in these regions. That is, typically water rights that serve multiple states are adjudicated through the federal courts at the watershed scale (Colby, Thorson, & Britton, 2005). The Colorado River Basin, for example, is a relatively large watershed spanning several states. While water resources are administered within state jurisdictional boundaries by state officials, federal courts determine water entitlements for states and federally recognized tribes on reservation lands. Similarly, the Great Basin, that includes primarily the state of Nevada, comprises several comparatively smaller terminal river basins, three of which extend into adjacent states where federal courts are involved in water rights adjudication.

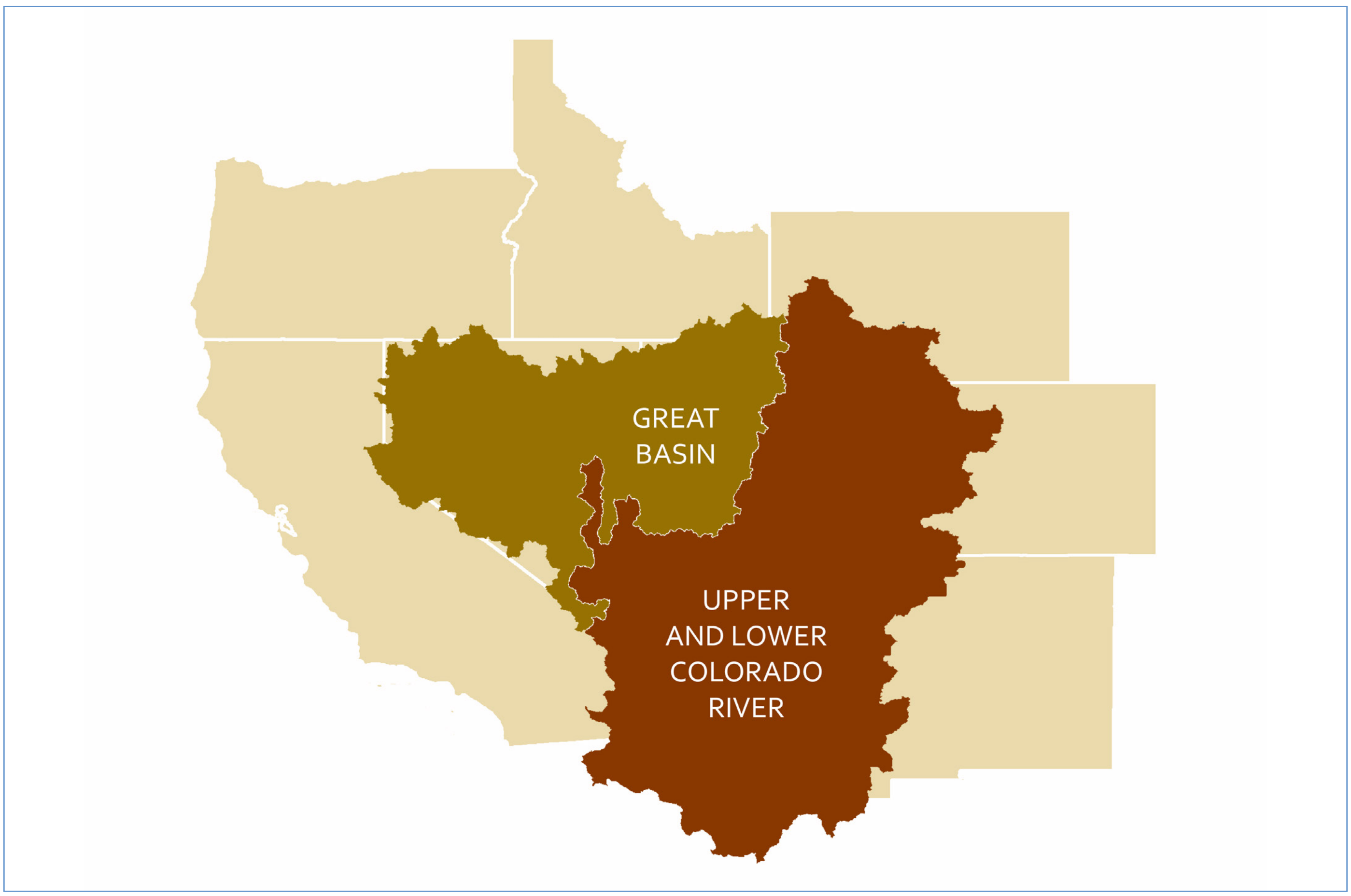

Figure 1. Outline of study area showing Great Basin (light green), Upper Colorado and Lower Colorado (forest green) water resource regions (scaled at USGS 2-digit HUCs).

2.1. Southwest Climate

The Southwest climate is characterized by its aridity, 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. Mountainous terrain across the region forces much of the annual precipitation to fall as snow at higher elevations with nearly 70% of available water originating as snowpack accumulation (Li et al., 2017). In higher elevations of the Sierra Nevada and Rocky Mountain ranges in the region, water is stored as snowpack (Bennett et al., 2018). As spring temperatures warm, melting snowpack releases water into watersheds eventually filling streams and riverbeds. This results in seasonal and variable water availability for large numbers of competing downstream water uses, such as irrigated agriculture, livestock watering, environmental habitat restoration and maintenance, and municipal and industrial usage.

These predominantly snow-fed river systems increasingly demonstrate hydrologic shifts due to climate change (Fritze et al., 2011; Stewart, Cayan, & Dettinger, 2005; Tennant, Crosby, & Godsey, 2015). Stream and river discharge from snowpack runoff is peaking earlier in the spring (Fritze et al., 2011; Hidalgo et al., 2009; Howat & Tulaczyk, 2005; Miller & Piechota, 2011; Stewart et al., 2005; Zampieri et al., 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 influences erosion and 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). Precipitation and evapotranspiration are the most significant factors contributing to available water in a system or watershed (Dingman, 2015). Because the rate of evapotranspiration depends on temperature, as atmospheric temperatures increase, the rate of evapotranspiration also increases, and thus decreases the amount of available water (Dingman, 2015). This impact on water availability is already being observed in the Southwest, as evidenced by declining soil moisture and an expected 10% to 45% decrease in streamflow by the turn of the 21st century (Bennett et al., 2018; Cayan et al., 2010; Rajagopal et al., 2014; Seager et al., 2013; Vano et al., 2014).

With snowpack being the primary source of available water in the Southwest, even small changes in atmospheric temperature can amplify the effects on water resource patterns and compound the effects on the people who rely 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 mountainous topography, climate change adaptation opportunities may be few. Nevertheless, Indigenous communities of the Southwest have a long history of resilience to climate variability (Gautam, Chief, & Smith, 2013; Jones et al., 1999) that precedes colonialism and the establishment of reservations lands.

2.1.1. Great Basin Hydrology

The basin-range topography of the Great Basin contributes to several terminal river basins upon which the surrounding Indigenous populations depend. This unique topography also leads to significant orographic effects, due to rugged mountainous terrain, contributing to the variability of precipitation and temperature from basin to basin (Houghton, 1979). Minimal summer precipitation events result in rivers in this region being nearly entirely snow-fed, making them especially 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 et al., 2014; Dickinson, 2006; Ficklin et al., 2012; Howat & Tulaczyk, 2005; Yu et al., 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 et al., 2011).

2.1.2. Colorado River 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 to 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.

2.2. Indigenous Communities on Reservation Lands in the Southwest

Within the southwestern U.S., as defined for this study, we identified 49 Indigenous communities with federally recognized tribal status inhabiting reservation lands. The status of federal recognition influences the governance structure in which tribes operate and impacts several unique political attributes of tribes and their respective land bases 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 usual and accustomed territories (Singletary et al., 2016).

Reservation lands are held in trust by the federal government for the beneficial use of federally recognized tribes (Pevar, 2012). 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 these Indigenous communities, per their federally recognized tribal titles, located within the Great Basin and Colorado River regions.

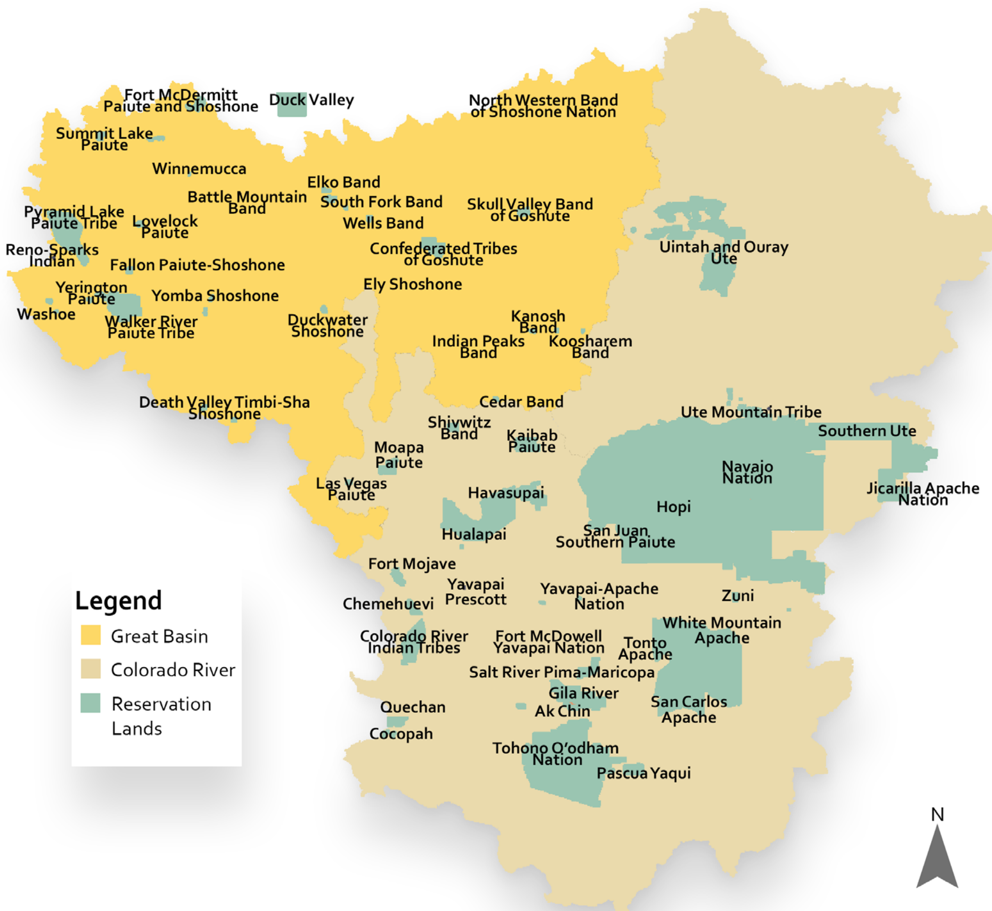

Figure 2. Outline of study area with federally recognized tribal reservations in the Great Basin (light greens) and Colorado River Basin (forest greens).

Federally recognized tribal sovereignty is defined as the inherent ability and right of these Indigenous communities to self-govern within the boundaries of their reservations as domestic dependent nations of the U.S. (Coffey & Tsosie, 2001). These 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. This sovereign status has contributed to the evolution of federal and state land and water use policies unique to reservation lands (Pevar, 2012).

Table 1. Federally Recognized Tribes of the Great Basin and Colorado River Region

Great Basin Tribes	Colorado River Basin 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 (includes Carson Colony, Dresslerville Colony, Woodfords Community, Stewart Community & Washoe Ranches)	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 Ute Tribe
	46. White Mountain Apache Tribe
	47. Yavapai-Apache Nation
	48. Yavapai-Prescott Indian Tribe
	49. Zuni Tribe

* Note. Although the [Shoshone-Paiute Tribes of] Duck Valley Reservation land base is situated outside the Great Basin water resource (HUC) boundary, it is included here due to its close proximity to the northern boundary of the Great Basin study region and its hydrologic characteristics, which align with other reservations located within the Great Basin.

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3. Methods

3.1. Participatory Research

A participatory research approach seeks to harness stakeholder perspectives and knowledge (Datta et al., 2015) to support community-based decisions (Singletary & Sterle, 2020; Singletary & Sterle, 2018; Blodgett et al., 2011). Indigenous communities are expert witnesses to the challenges and opportunities related to how climate change is felt on reservation lands (Chief, 2020; Martin et al., 2020; Ellis & Perry, 2020; Bulltail & Todd Walter, 2020). In this context, participatory research can engage Indigenous community stakeholders in an environment of reciprocity to ensure the co-production of new knowledge that is key to community-based adaptation measures (Singletary & Sterle, 2020; McNamara et al., 2020; McNamara & Buzzy, 2017). This requires that stakeholders help to guide and participate in the research and that research findings are shared with participants in a way that emphasizes transparency, respects local culture and knowledge, and improves research accountability (Singletary & Sterle, 2018; Benham & Daniell, 2016; Datta et al., 2015; Glass et al., 2018).

3.2. Needs Assessment Survey Instrument

We developed a survey instrument to assess a composite of Indigenous communities' climate data and information needs to enhance the climate resilience of water resources on reservation lands in the Southwest. Question items were based primarily on input provided to researchers during facilitated small-group discussions with attendees of the first (2015) of five annual Native Waters on Arid Lands tribal summits held in locations within reasonable travel distance within the study area – Las Vegas and Reno, Nevada. Additional information and data needs included in the survey were determined from guidelines set within the Tribal Climate Change Adaptation Planning Toolkit available through the U.S. Climate Resilience Toolkit and Guidelines for Considering Traditional Knowledges in Climate Change produced by the Climate and Traditional Knowledges Workgroup in 2014. These specific resources are intended to provide Indigenous communities in the U.S. with tools and assistance in the climate change adaptation planning process (Climate and Traditional Knowledges Workgroup, 2014; Institute for Tribal Environmental Professionals, 2020).

Information or knowledge gaps that summit attendees noted during the 2015 summit discussion sessions were used to begin formulating question items related to general climate data and information needs. This listening approach—an important component of participatory research protocol—facilitated development of a first draft of survey question items intended to be meaningful and relevant to the Indigenous communities located within the study region. The authors then cross-referenced these question items with existing research literature related to community-based climate adaptation planning and climate impacts specific to the water resources of Indigenous communities in the U.S. (Bennett et al., 2014; Chief et al., 2014; Chief et al., 2016; Cochran et al., 2013; Cozzetto et al., 2013; Gautam et al., 2013). An interdisciplinary panel of four faculty members with expertise in hydrologic science, atmospheric science, agricultural and applied economics, Extension outreach, and survey methods reviewed drafts of the survey instrument. The purpose of these reviews was to improve the readability and clarity of question items and to identify any missing question items. We revised the question items based on the feedback received from these reviews.

A final 50-question item survey instrument[3] was tested with a random sample of five Indigenous community representatives familiar with the study objectives. These individuals were eliminated from the survey sample (Dillman et al., 2014). 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 deemed necessary.

3.3. Survey Recruitment

Accessing a random sample of the general target population for this study can be extremely cost prohibitive, as such survey research requires formal permission from each tribal council. Because the target population for our assessment comprised individuals directly engaged or interested in being engaged in climate adaptation on reservation lands, we implemented our survey during the second (2016) and third (2017) Native Waters on Arid Lands tribal summits. These summits were organized by land-grant university Extension outreach professionals with decades of experience working with Indigenous communities in the Great Basin and southwestern U.S. Their pragmatic expertise and established social networks facilitated the recruitment of diverse Indigenous communities within the study area to these annual summits. Further, the summits were designed to provide educational outreach and networking opportunities to participants who were either pursuing or interested in community-based climate adaptation on reservation lands. The summit content, which included predominantly speakers reporting on tribal climate challenges and adaptation actions, ensured that summit attendees, and thus recruited survey participants, had some working knowledge or familiarity with the climate information and data items included in the survey. This was paramount to the success of this assessment, given the specificity of the questions asked.

This survey was administered over a period of two consecutive years (2016-2017) during plenary summit sessions. 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 prior to receiving a printed copy of the two-page (front and back) questionnaire. An oral presentation was delivered, using Power Point, that included a review and explanation of the purpose for the data and information needs assessment, question item content, and an explanation of questions that featured a Likert-type scale and a definition of question item choice 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 the spaces provided on the printed survey instrument (Dillman et al., 2014).

[3] Appendix A features the survey instrument used in the assessment.

The presentation clarified the purpose of the assessment and structure of question items. The information presented was designed to mitigate the potential for survey error due to participants' misinterpretation of instructions provided on the printed questionnaire. Participants were instructed also to omit any personal identifying information. Survey administrators were available to repeat or clarify instructions. To ensure survey participants' confidentiality, survey administrators collected the completed questionnaires and immediately placed the documents in an envelope and sealed the envelope (Dillman et al., 2014). Survey participants were reminded that their participation was strictly voluntary and encouraged to discontinue their participation at any time. This administrative protocol was reviewed and approved by the University of Nevada, Reno Office of Research Integrity and Internal Review Board. ●

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4. Results

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. Only de-identified, cumulative results are reported to ensure participant anonymity and confidentiality.

A total of 98 participants completed survey questionnaires. The majority of survey respondents (n=85) live and/or work in the Great Basin (45%) and Colorado River region (39%) region study area, with 16% of respondents representing reservations outside this study region. Also, the majority of respondents (84%, n = 85) represent the watersheds that comprise the study region (e.g., Great Basin (45%), Lower Colorado, (21%), Upper Colorado (18%). Approximately 8% of respondents represent watersheds also located in arid lands that include Missouri (6%), Pacific Northwest (3%), and Rio Grande (2%).

4.1. Survey Respondents

The majority of survey respondents live/work in Nevada and in Arizona, states nearly wholly within the study area boundaries. The remaining respondents mainly live/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. Each of these states include arid reservation lands confronted with water allocation and quantification challenges. Only 6% of the survey respondents represent states outside the study area (Wisconsin, Ohio and Georgia), but they work on reservation lands. To summarize, the majority of respondents live/work within the designated study area, which signifies that the survey recruitment protocol was appropriate to sample a population representing the study area. This outcome ensures that the overall results reported here reasonably represent the target population.

Respondent attributes are characterized additionally 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.

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?”, 32 respondents indicated water supply shortages 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).

Finally, when asked what was needed most to support climate adaptation on tribal lands, nearly 74% of the respondents volunteered suggestions. The majority of these written comments focused on the need to increase public and community education to support climate adaptation planning and implementation on tribal lands, followed by increased funding to support these initiatives. Several comments also referenced the need for more on-the-ground research and decision-support resources, including climate projections and probabilities of climate events (see Figure 3).

Figure 3. Most frequent responses to the survey question: “What is Needed Most to Support Climate Adaptation on Tribal Lands?”.

4.2. Prioritized Climate Information and Data Needs

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. Question items featured equally weighted Likert-type scale choice ratings, from 1 to 5. 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.” 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 items included in this assessment.

Table 2 displays the calculated priority ranking for climate information needs to support community-based adaptation on reservation lands. These needs include those identified as unique to Indigenous 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 on reservation lands." The top-prioritized information need (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 downscaled climate projections and impact assessments as necessary steps to community-based adaptation (McNamara & Bussy, 2017; Jantarasami et al., 2018). This result also aligns with 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 that example, information related to improving food sovereignty and adaptive agriculture on reservation lands was identified by the majority of respondents as necessary to enhance the climate resilience of reservation lands (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 two information needs indicate the highly valued nature of traditional knowledge in Indigenous communities and suggest an important role for traditional knowledge in the respective climate adaptation planning initiatives of tribal nations. Since 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 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 ascertain and integrate Indigenous traditional knowledge into adaptation planning.

If individuals outside these communities are involved in any sharing of traditional knowledge, it must be with the understanding that an outsider cannot 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 (Whyte, 2018b; 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 needs 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 nonpoint source pollutants, and is charged with overseeing water quality monitoring, assessment and reporting (Federal Water Pollution Control Act Amendments, 1972). These water quality data, however, are somewhat difficult to access due to their overlapping nature and complex format (Jones et al., 2020).

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 et al., 2015). From this survey, it is uncertain if respondents 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 respondents' 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), by precipitation ranked fourth (m = 4.03; s.d. = 0.87; n = 94), snowpack data linked 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 notable 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 a 0.18-point difference in mean scores between the two items (see Table 4). This preference may indicate that respondents may require additional 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).

4.3. Sources of Climate Information and Sources Accessed Most Frequently

Table 5 shows mean scores for most frequently accessed climate data and information sources, 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	Need	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. Data needs are ranked by highest mean score (5 = Very High Priority) to lowest mean score (1 = Very Low Priority).

"Tribal natural resource/water/land departments" is the most frequently accessed data and information source (m = 3.74; n = 90). A mean 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 local 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); 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 annual Native Water on Arid Lands 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) (Fillmore et al., 2018).

Additionally, a chronic lack of funding of tribal colleges and universities may also contribute to a comparatively low rating for the role of 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.

4.4. Stakeholders' Role and Perceived Climate Information and Data Needs

Stakeholders' role in climate adaptation on reservation lands in this analysis is determined by responses to survey question 22, which asks respondents to identify their employment or occupation. 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 location. Thus, identifying which stakeholder groups frequently access "traditional knowledge holders" for climate data and information can help to facilitate the integration of this information in planning processes. Responses to the question of employment or occupation were grouped into three categories (see Figure 4).

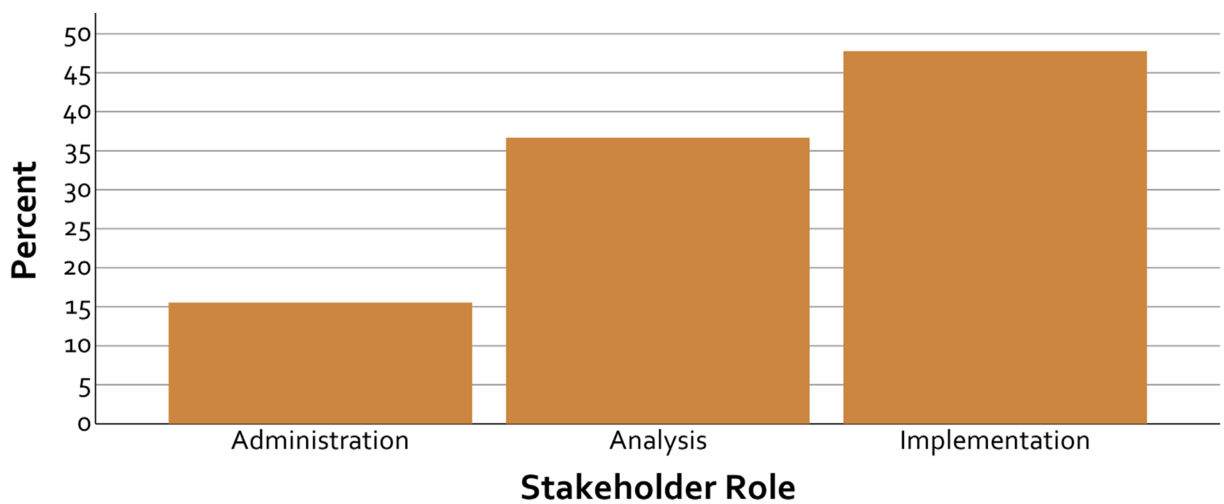


Figure 4. Distribution of responses grouped into three categories representing **stakeholder role** in climate adaptation initiatives.

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 scales. These include land managers, farmers and 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 socioeconomic, 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.

Table 6. Needs Associated with Stakeholder Role in Climate Adaptation on Reservation Lands

Overall Rank	Climate 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	Climate Information and Data 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.

A cross-correlation analysis was conducted using this stakeholder role 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). That is, a Pearson Chi-square test for association was employed for each pair of variables to test for the statistical significance of cross-correlated responses. Only the cross-correlated data with statistically significant associations are presented here since cross-correlated data without such statistically significant association indicates that respondents agreed in overall ranked mean results for those question items. Table 6 displays those results that are statistically significant for association between stakeholder role in climate adaptation initiatives on reservation lands and responses to data and information need priorities and frequently accessed sources of climate information.

Two climate information needs with statistically significant associations listed in Table 6 are similar in scope. Both identify the need for a better understanding of climate impacts and future climate projections on reservation lands. Figures 5-7 display 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." An interpretation of the cross-tabulated results of the statistically significant correlations yielded the following result: respondents assigned to the "analysis" stakeholder role category were more likely to value the "Climate change impacts on tribal lands, water and economies" information need relative to respondents in administration and implementation roles (see Figure 5).

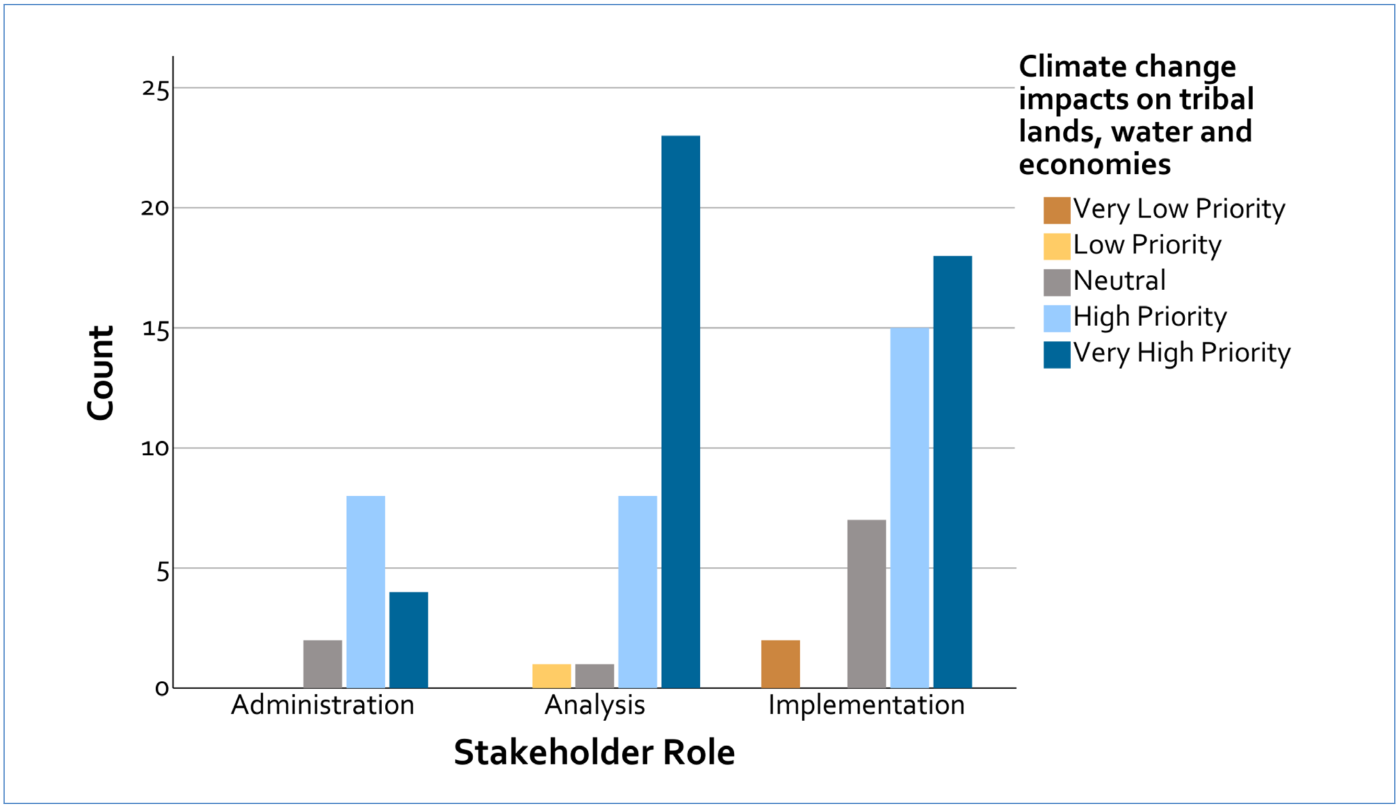


Figure 5. Cross-tabulation counts from a statistically significant association between **stakeholder role** and **climate information** need, "Climate change impacts on tribal lands, water and economies."

The cross-tabulated results between the stakeholder role variable and the climate information need variable, "Meaning of future climate projections for individual reservations" has a statistically significant association (see Table 6). Responses of individuals who self-identified as stakeholders with "implementation" and "administrative" roles did not prioritize this variable as highly as expected. Respondents grouped in the "analysis" role category, however, rated this climate projection variable higher than expected, but lower than expected relative to respondents in implementation and administration stakeholder roles (see Figure 6).

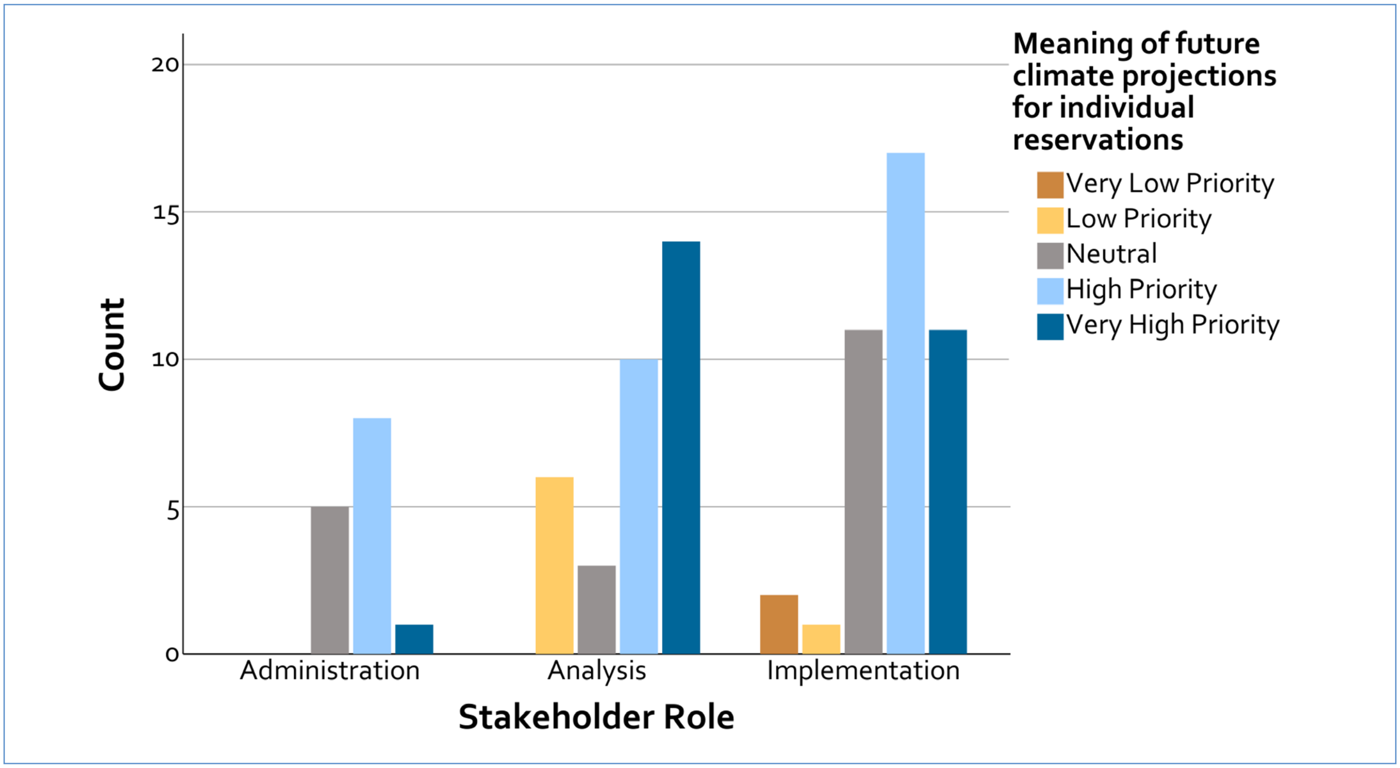


Figure 6. Cross-tabulation counts from statistically significant association between **stakeholder role** and **climate information** need, "Meaning of future climate projections for individual reservations."

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 (see Figure 7). The opposite is true for accessing climate data and information from colleges and universities, with respondents in implementation roles accessing this source less frequently. There is a split among those in analysis roles in terms of their access of climate data and information through annual Native Waters on Arid Lands tribal summits. The majority indicated that they often access this information source, while a lesser but relatively large percentage indicate that they access this source rarely. This split appears contradictory but may indicate the potential for distinct sub-groups within the analysis stakeholder role. Further research using a larger sample size is needed to better understand this division in access.

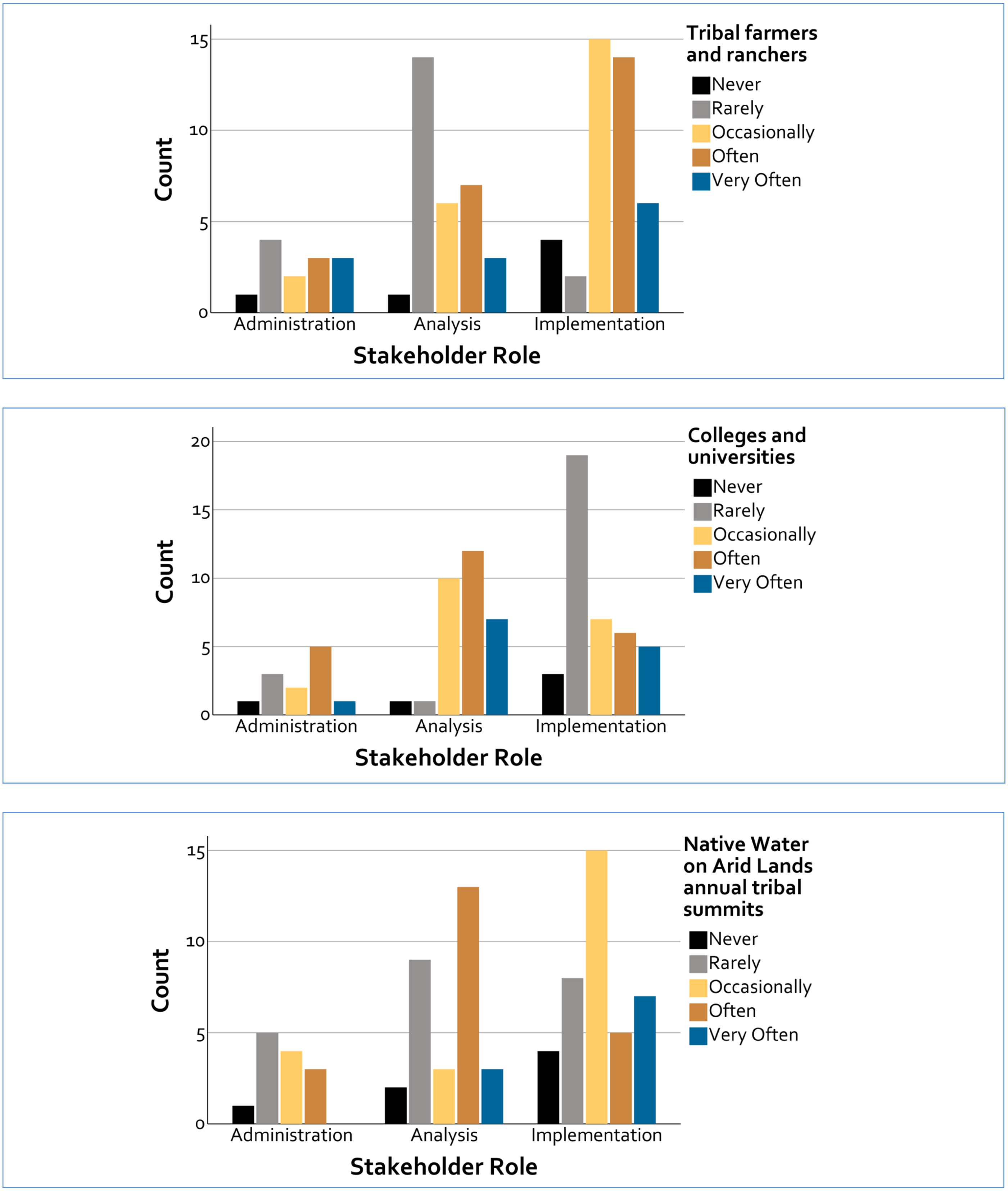


Figure 7. Cross-tabulation counts from statistically significant associations between **stakeholder role** and climate **data/information sources**, "Tribal farmers, and ranchers," "Colleges and universities," and "Native Water on Arid Lands annual tribal summits."

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." That is, responses to this question were grouped into 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 at the 90% (or $p < .10$) confidence interval ($p = 0.084$) (see Figure 8). This means that, based on the results for this sample, we can be 90% confident that this association holds for the population.

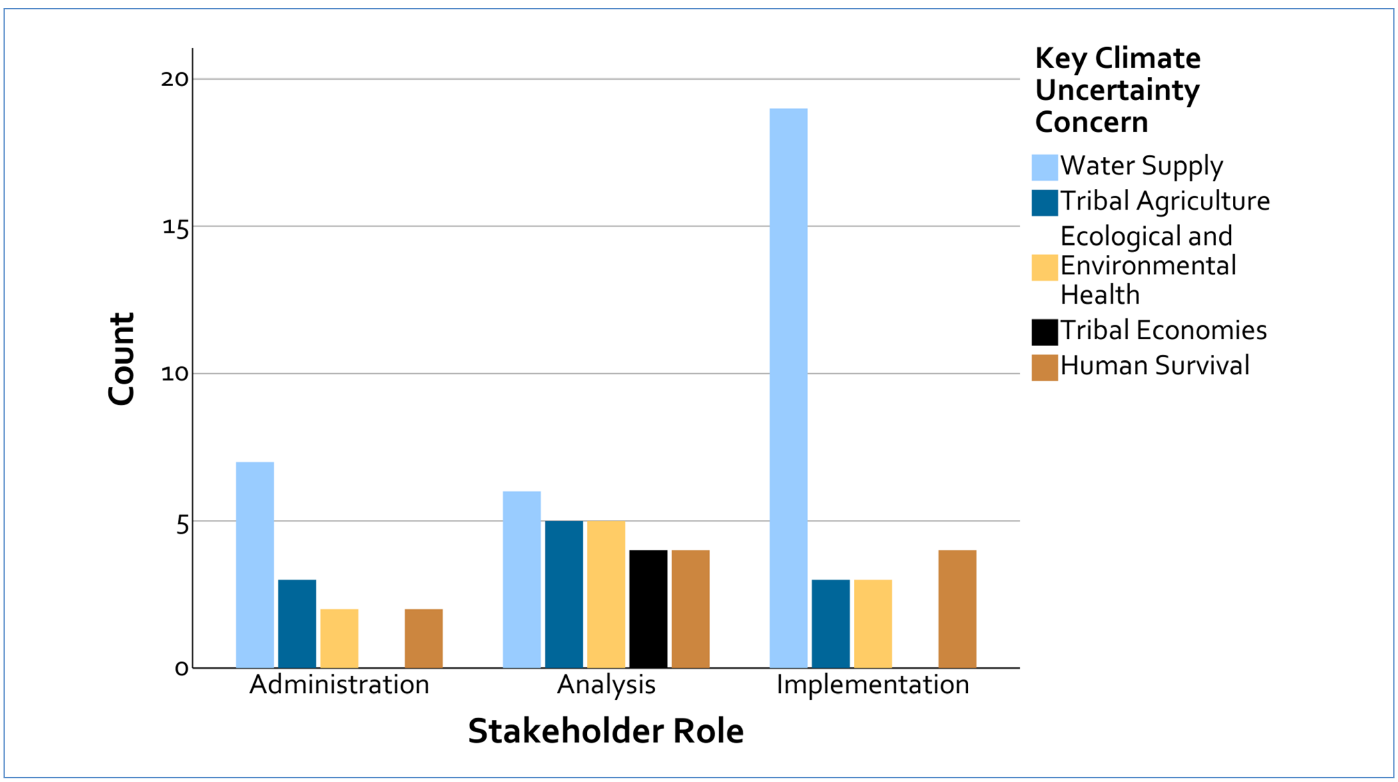


Figure 8. Cross-tabulation counts from statistically significant associations between **stakeholder role** and the three key climate uncertainty concern.

This result suggests that stakeholders in implementation roles are primarily and significantly concerned about available 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 the education sector. That is, respondents who comprise this stakeholder category include researchers, educators and outreach professionals. Their occupational priorities concerning climate adaptation initiatives are presumed to involve them in the analysis of the various threats that climate change poses to Indigenous communities. 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.

4.5. Stakeholders' Location and Perceived Climate Information and Data Needs

This section reports differences in stakeholders' regional priorities for climate data and information needs based on respondents' location. Grouping data based on the location of respondents' reservations within a larger watershed region ensures that no Indigenous community is compared with another. Differences in responses by stakeholders' location may provide important insight to inform efforts to more effectively direct and improve climate information and data resources and accessibility to Indigenous communities.

The significant majority of survey respondents live or work in the Great Basin region and the Colorado River region (see Figure 9). 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. 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 focus on the southwestern U.S., as we define the region for this study. Cross-tabulation results of association with statistical significance reveal climate data and information priorities that may have been skewed due to respondents grouped in the "other" category.

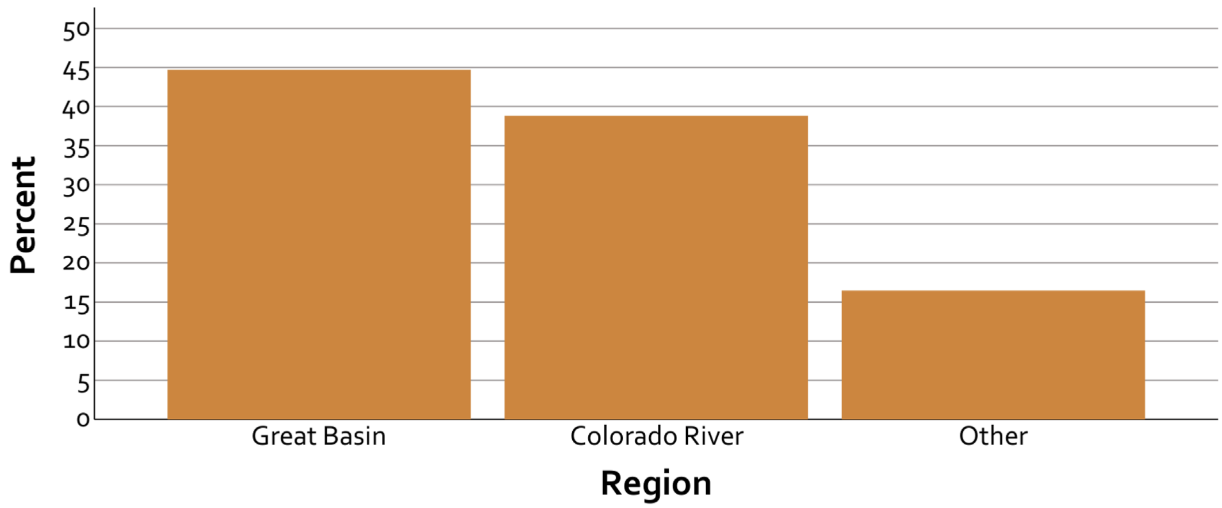


Figure 9. Percentage of respondents living or working within the study region - an aggregated variable used in cross-correlation analysis of **stakeholder region** with climate data and information priorities.

The 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 in Table 7 along with the associated significance value (p-value). The cross-correlation results are discussed for each association and are reported in Figures.

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
n/a	Scale of precipitation data (hourly vs. daily vs. monthly)	0.091
n/a	Scale of streamflow data (hourly vs. daily vs. 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	Tribal natural resource/water/land departments	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, while respondents living or working in the Great Basin region rated this need comparatively lower (see Figure 10).

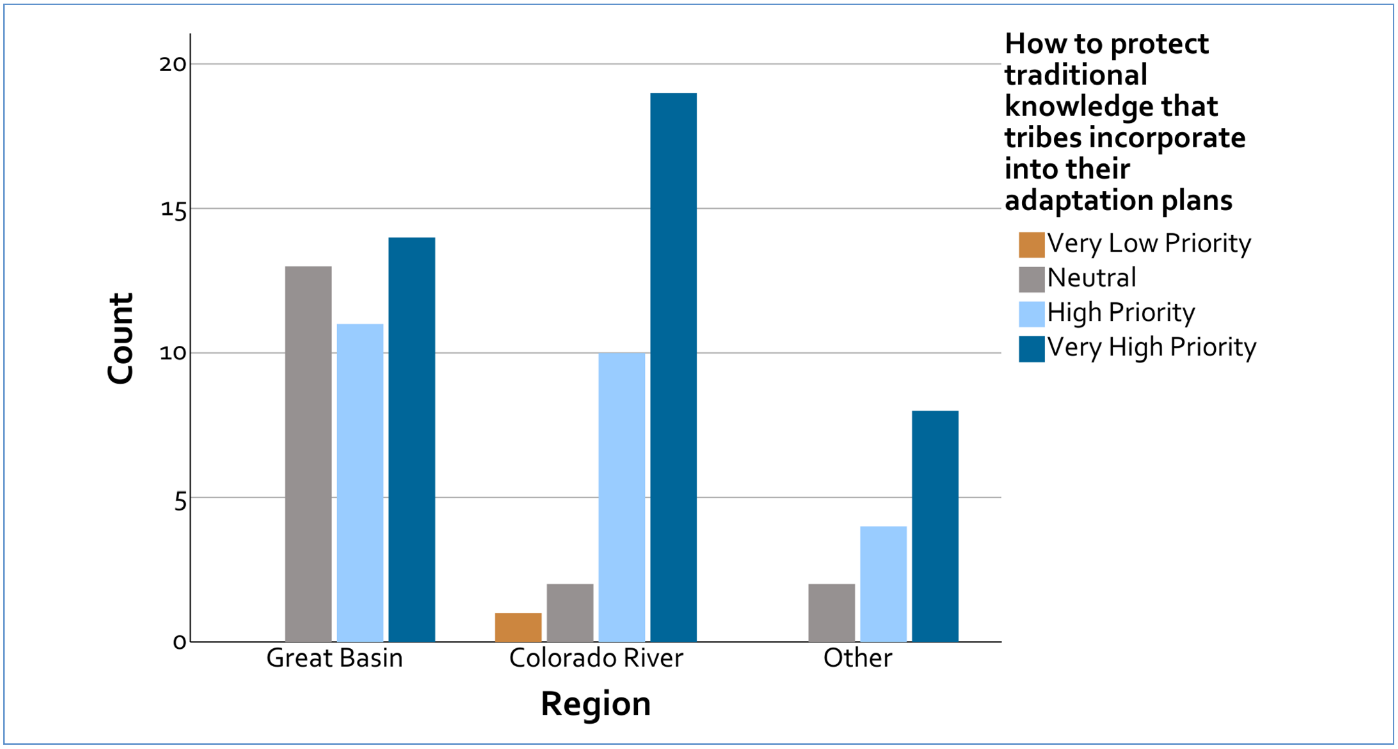


Figure 10. Cross-tabulation counts with a statistically significant association between the stakeholder region variable and the climate information variable, "How to protect traditional knowledge that tribes incorporate into their adaptation plans."

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 11). Respondents in the Great Basin region rated this variable comparatively lower, with more "neutral" responses.

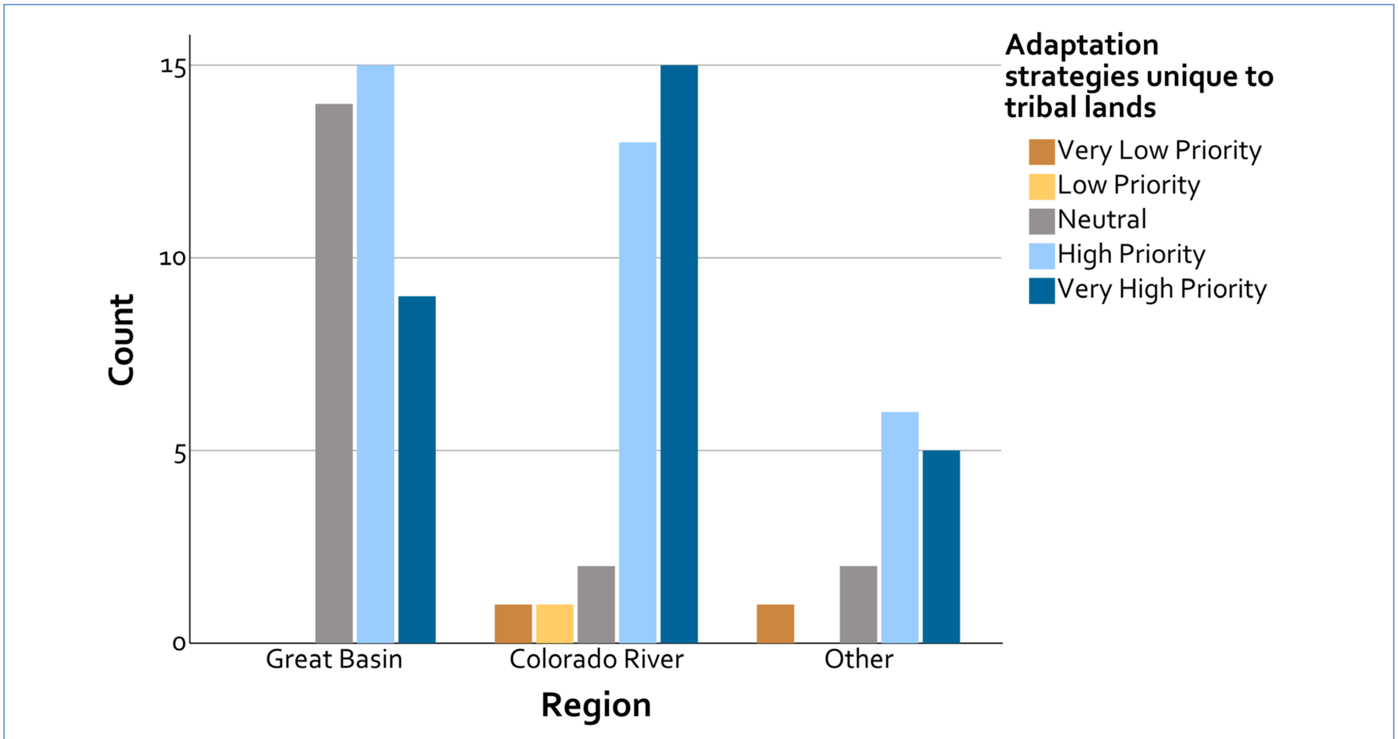


Figure 11. Cross-tabulation counts with a statistically significant association between the stakeholder **region** variable and the **climate information** variable, "Adaptation strategies unique to tribal lands."

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 12 and indicates that stakeholders in both the Colorado River and the Great Basin region consider this information need to be of "high priority." Respondents in the Great Basin region, however, had 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. Priority response counts of stakeholders in the Colorado River region were in line with the expected distribution of counts.

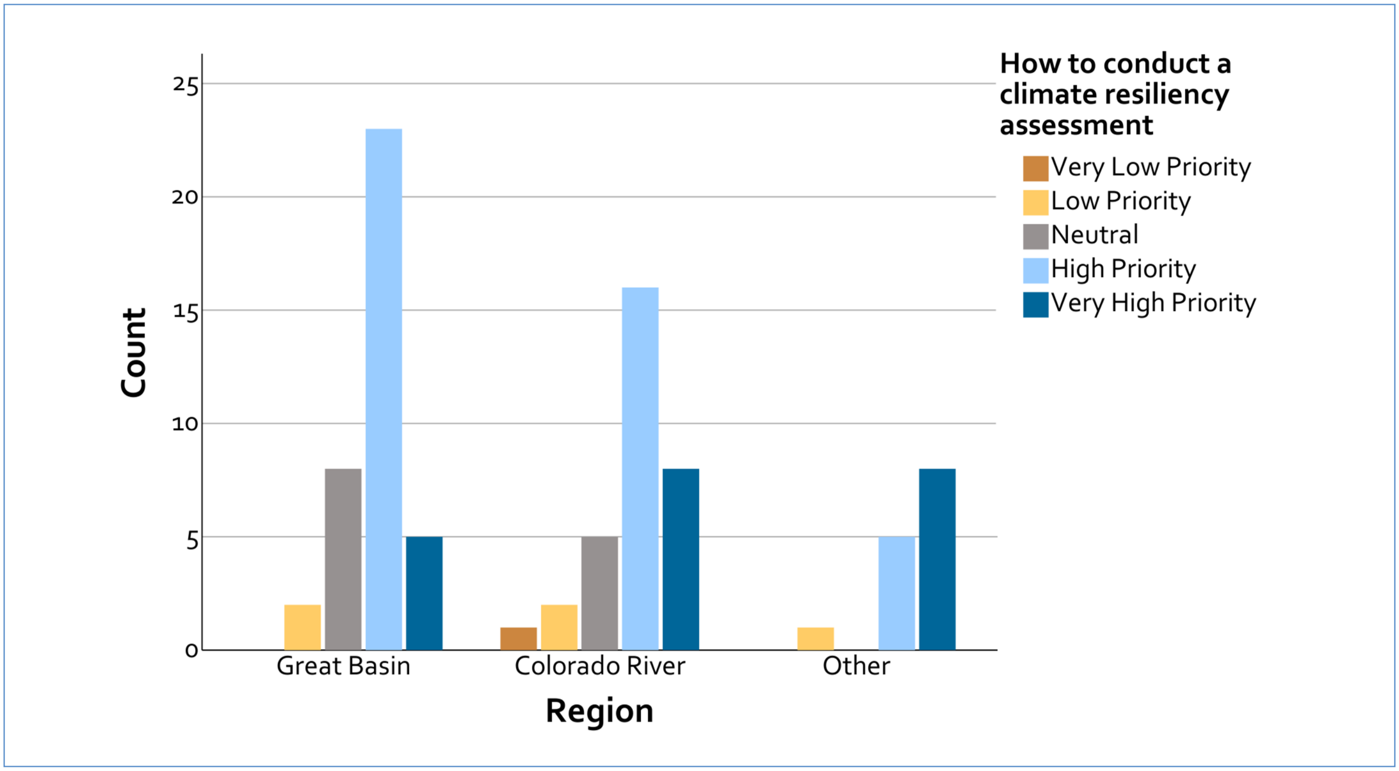


Figure 12. Cross-tabulation counts with a statistically significant association between the stakeholder **region** variable and the **climate information** variable, "How to conduct a climate resiliency assessment."

"Meaning of future climate projections for individual reservations" is the final climate information need variable with statistically significant association with the stakeholder region variable, at the 95% confidence interval or $p < .05$ ($p = 0.035$). The distribution of responses indicates that stakeholders in the Colorado River region are more likely to highly prioritize this information need compared to stakeholders in the Great Basin region (see Figure 13).

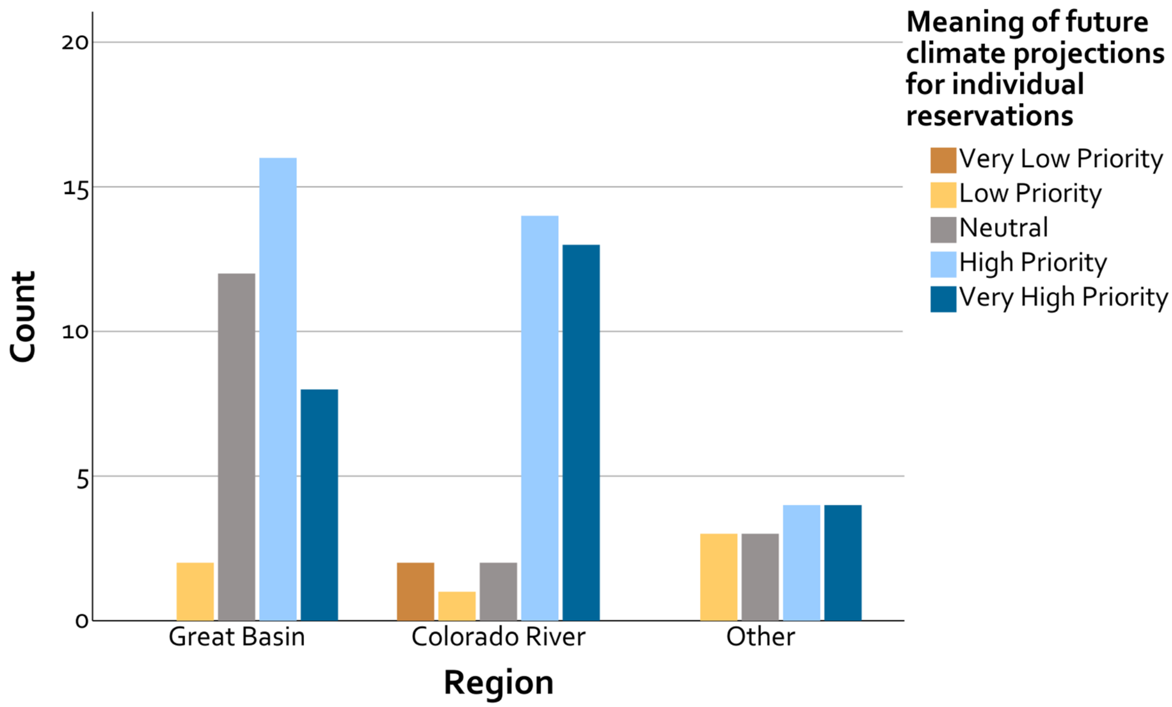


Figure 13. Cross-tabulation counts with a statistically significant association between the stakeholder **region** variable and the **climate information** variable, "Meaning of future climate projections for individual reservations."

The relationship between stakeholder region and the climate data variable, “Raw data collected from monitoring equipment,” is statistically significant at the 95% confidence interval ($p = 0.045$). The cross-correlation analysis results reported in Figure 14 indicate that stakeholders in the Great Basin region may perceive these data as less a priority than do stakeholders in the Colorado River region.

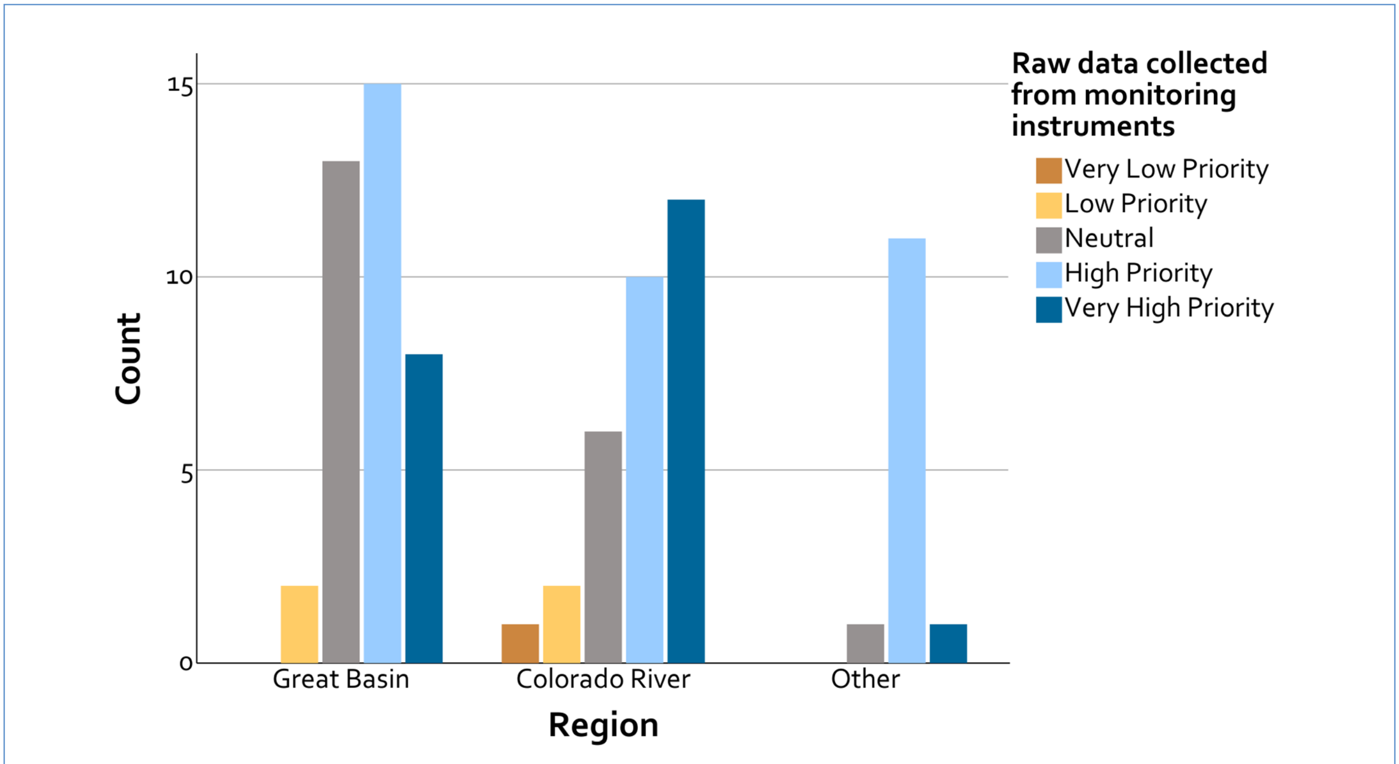


Figure 14. Cross-tabulation counts with a statistically significant association between the stakeholder **region** variable and the **climate data** variable, “Raw data collected from monitoring equipment.”

Survey respondents were asked to indicate their priorities for climate data, and to indicate the scale of data: daily, hourly or monthly. Mean scores were not calculated for these responses because response categories did not use a Likert-type scale. While these more detailed data question items were not included in an overall ranking of data need priorities, we include them here to test responses for association with stakeholders’ location within the study region.

Three climate data scale needs 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 15). Respondents in the Colorado River region, however, indicate that they are more likely to prioritize daily data for these two types.

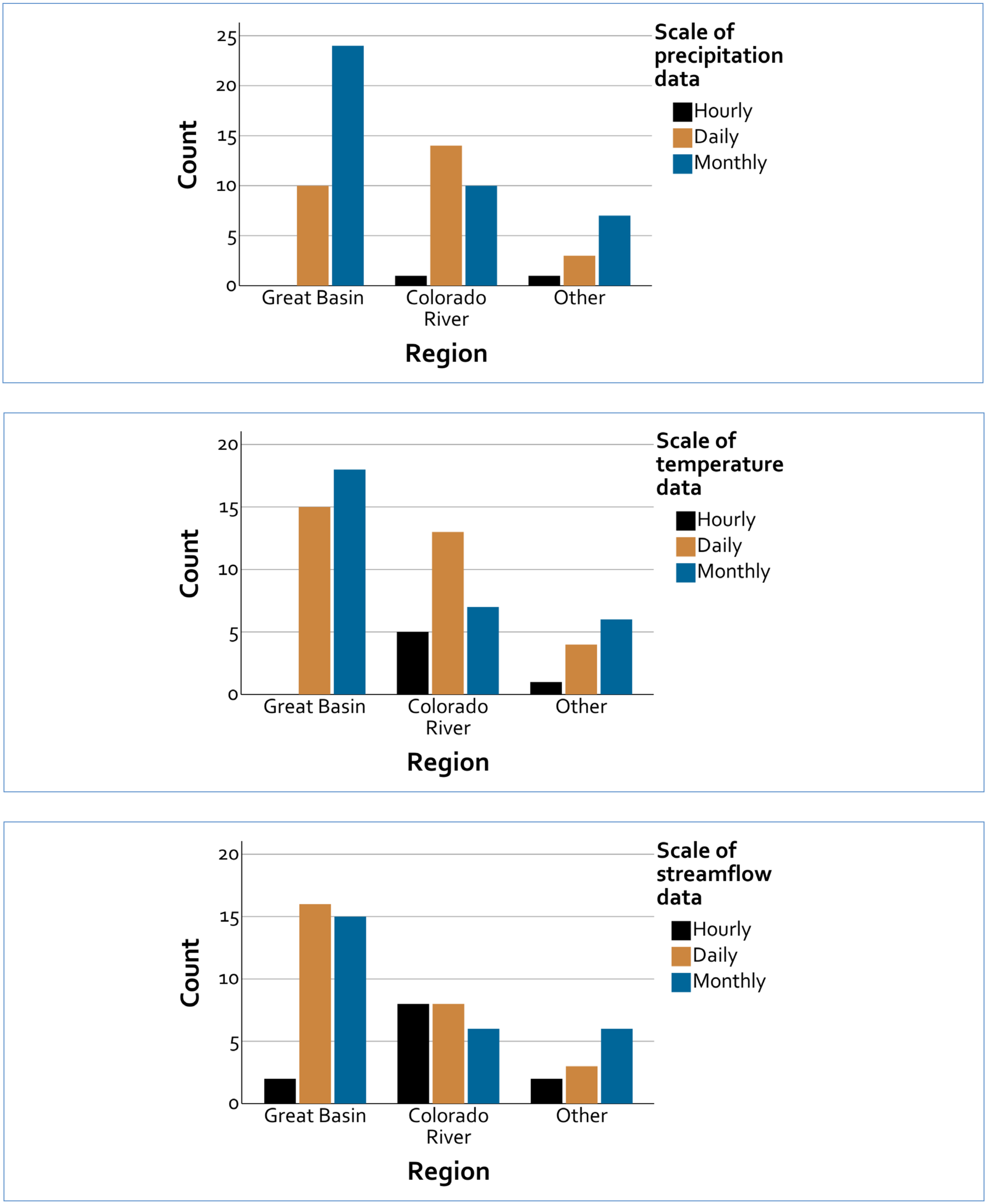
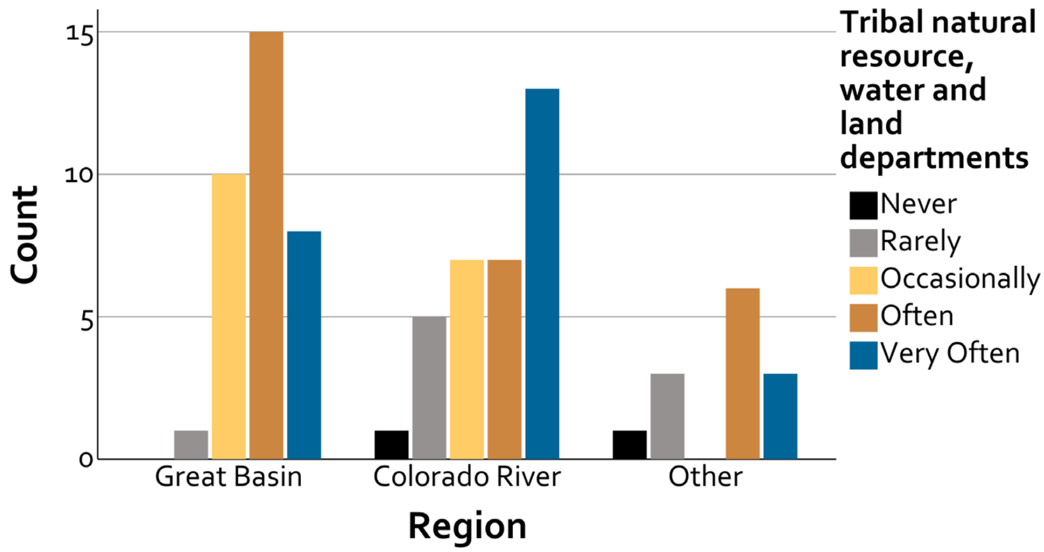


Figure 15. Cross-tabulation counts with statistically significant associations between the stakeholder **region** variable and the **scale of climate data** variables.

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.

Cross-correlation analysis results between the stakeholder region variable and participant responses to climate data/information source variables are reported together in Figure 16 and Figure 17. Four associations have statistical significance at 90% ($p < .10$) and 95% ($p < .05$ confidence intervals: “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” ($p = 0.058$). 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 acknowledging the extensive cultural diversity of Indigenous communities. Also, due to the relative remoteness of reservations in the Great Basin region, stakeholders may be working on climate adaptation more independently at the local or community level and with less outside influence.



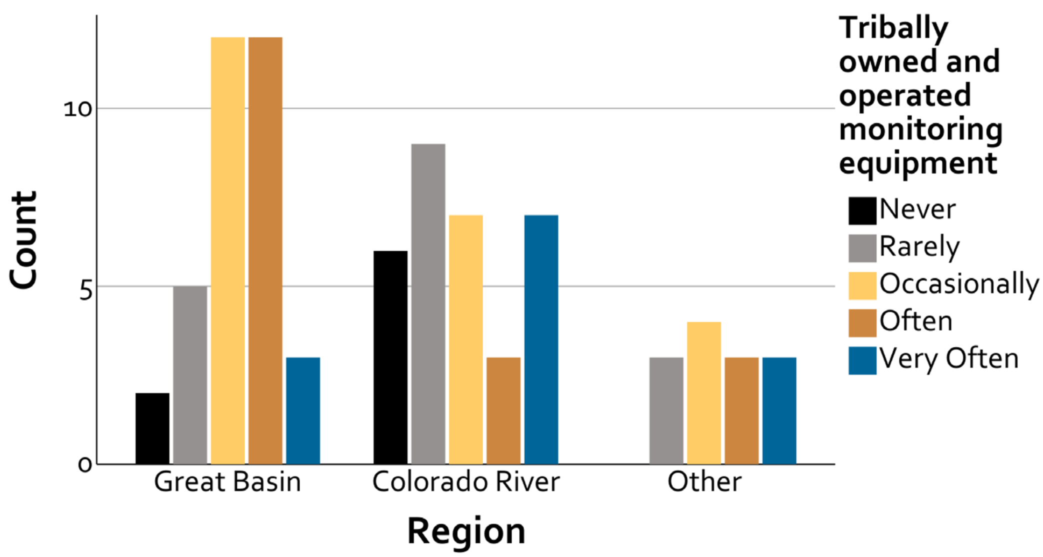
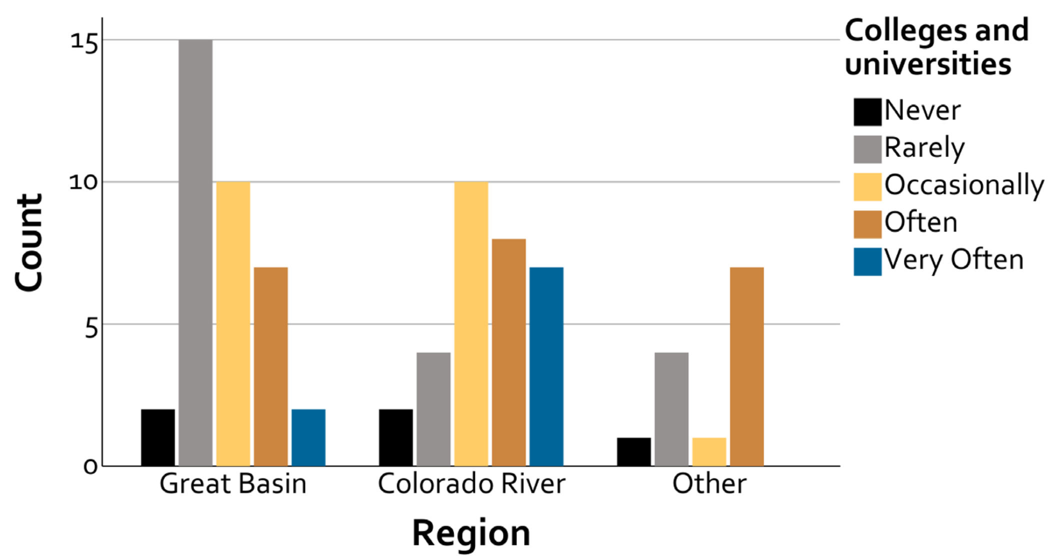


Figure 16. Cross-tabulation counts with statistically significant associations between the stakeholder **region** variable and the **data/information source** variables, "Tribal natural resource/water/land departments," and "Tribally owned and operated monitoring equipment." Note. These graphs do not have an equally distributed y-axis, meaning that count frequencies cannot be compared across climate data/information source.



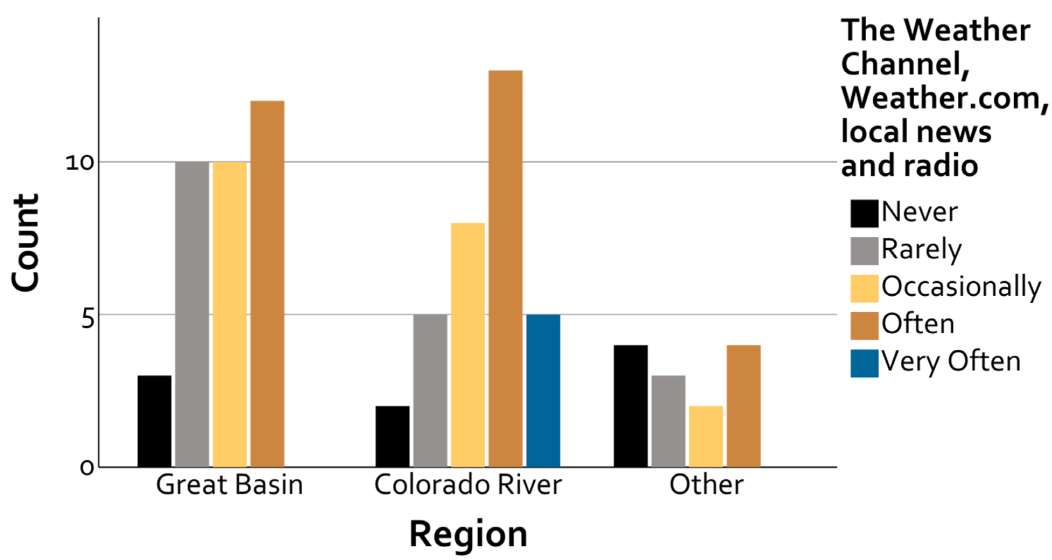


Figure 17. Cross-tabulation counts with statistically significant associations between the stakeholder region variable and the data/information source variables, "Colleges and universities," and "The Weather Channel; Weather.com; local news and radio." Note. These graphs do not have an equally distributed y-axis, meaning that count frequencies cannot be compared across climate data/information source.

It is important to note that the results reported here may not illustrate the numerous and diverse reasons behind regional differences in prioritized climate data and information needs. That is, the results highlighted here may suggest more generally that data at the desired scales in this region are simply less available. 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.

4.6. Educational Attainment Level and Perceived Climate Information and Data Needs

This next set of analyses is included to test for differences in responses based on respondents' educational attainment levels. Educational background may include prior experience working with multiple sources of climate data and information, and so has implications for information and data needs and access.

Four levels of educational attainment are used to test for statistically significant correlations. These include: 1) high school or less; 2) some college/technical or associate degree; 3) college degree (i.e., B.S./B.A.), and 4) graduate degree (i.e., M.S., J.D., Ph.D., M.D., etc.). The distribution of responses across these levels of educational attainment is depicted in Figure 18. These delineations are reasonably representative of the different levels of educational attainment characteristic of respondents in the study area.

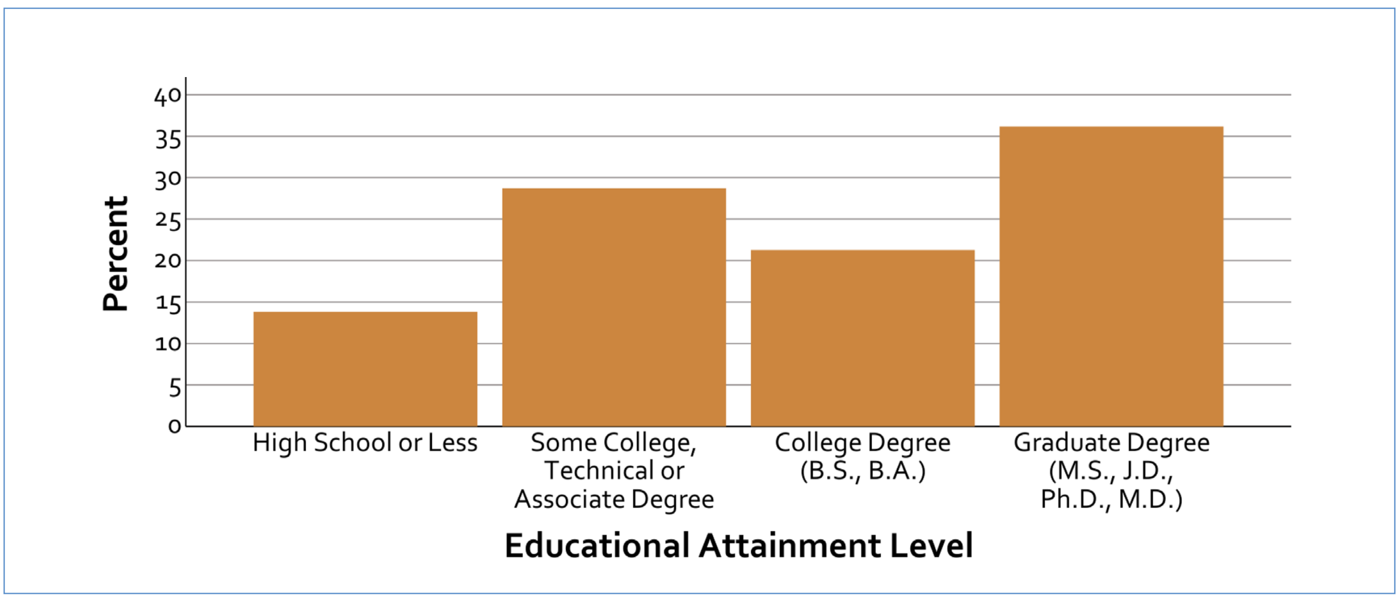


Figure 18. Percentage of respondents grouped into highest educational attainment level, based on responses to survey question 50.

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 Figures 19-23. 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

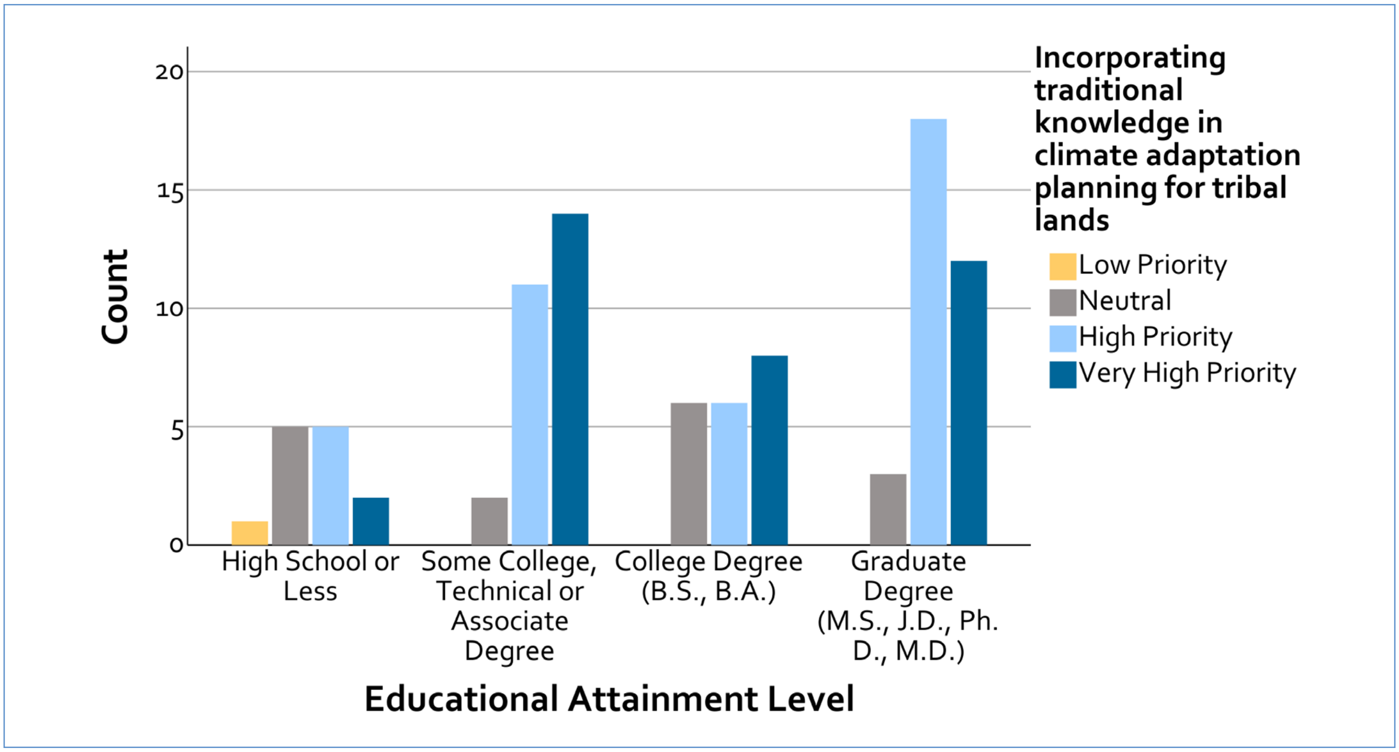
Overall Rank	Information Needs	P-value
3	Role of traditional knowledge in climate adaptation planning for tribal lands	0.023
7	Adaptation strategies unique to tribal lands	0.072

Overall Rank	Climate Data Needs	P-value
n/a	Scale of streamflow data (hourly v. daily v. monthly)	0.039
n/a	Scale of soil moisture data (hourly v. daily v. monthly)	0.079

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 19). Respondents who indicated high school as their highest level of educational attainment were more likely to rate both climate information variables as being of a more "neutral" (neither low nor high) priority than the expected count for these variables. 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. Respondents with graduate education degrees 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 are not particularly related. Respondents with undergraduate college degrees 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.



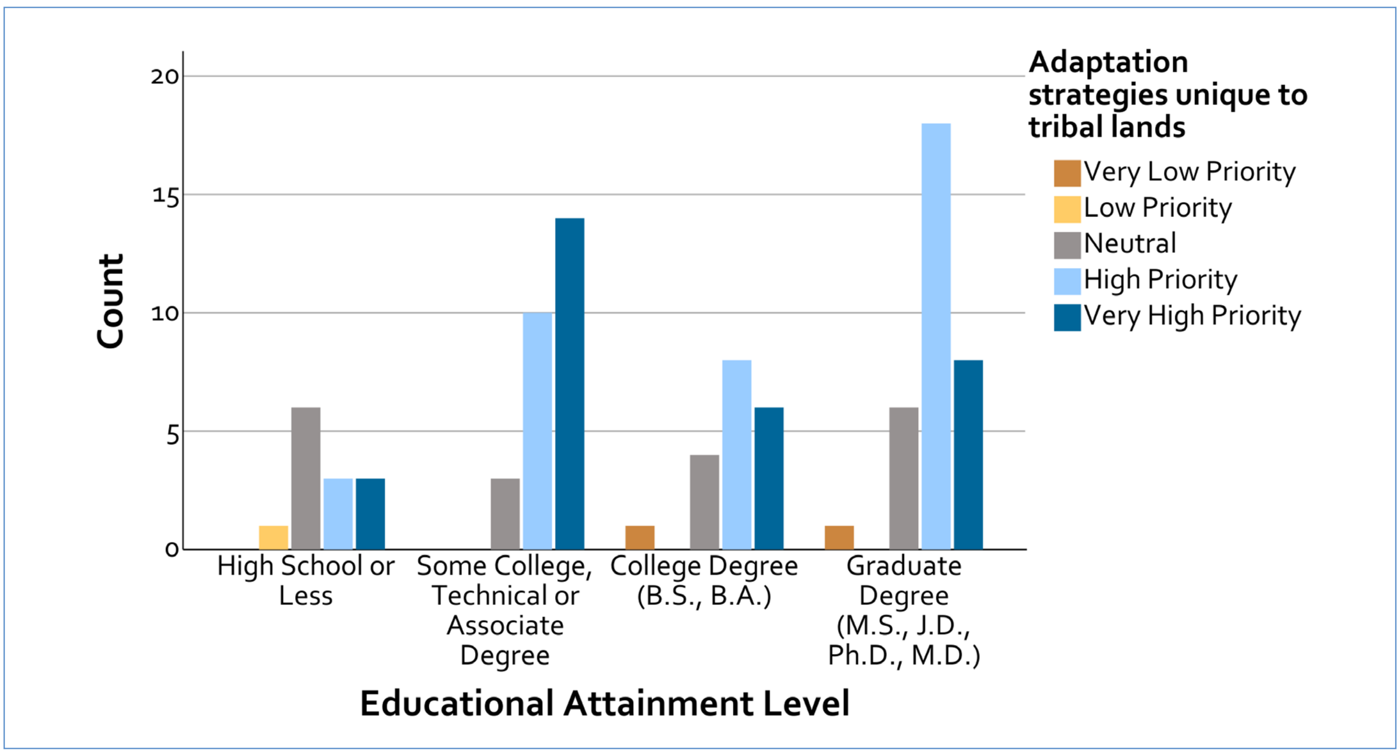


Figure 19. Cross-tabulation counts with statistically significant associations between the stakeholder **educational attainment level** variable and the **climate information** variables, "Incorporating traditional knowledge in climate adaptation planning for tribal lands," and "Adaptation strategies 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 20 shows the distribution of responses in this cross-tabulation. Respondents with undergraduate and graduate degrees prioritize this variable similarly (i.e., majority indicating that this variable is of a “high priority”). 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 20).

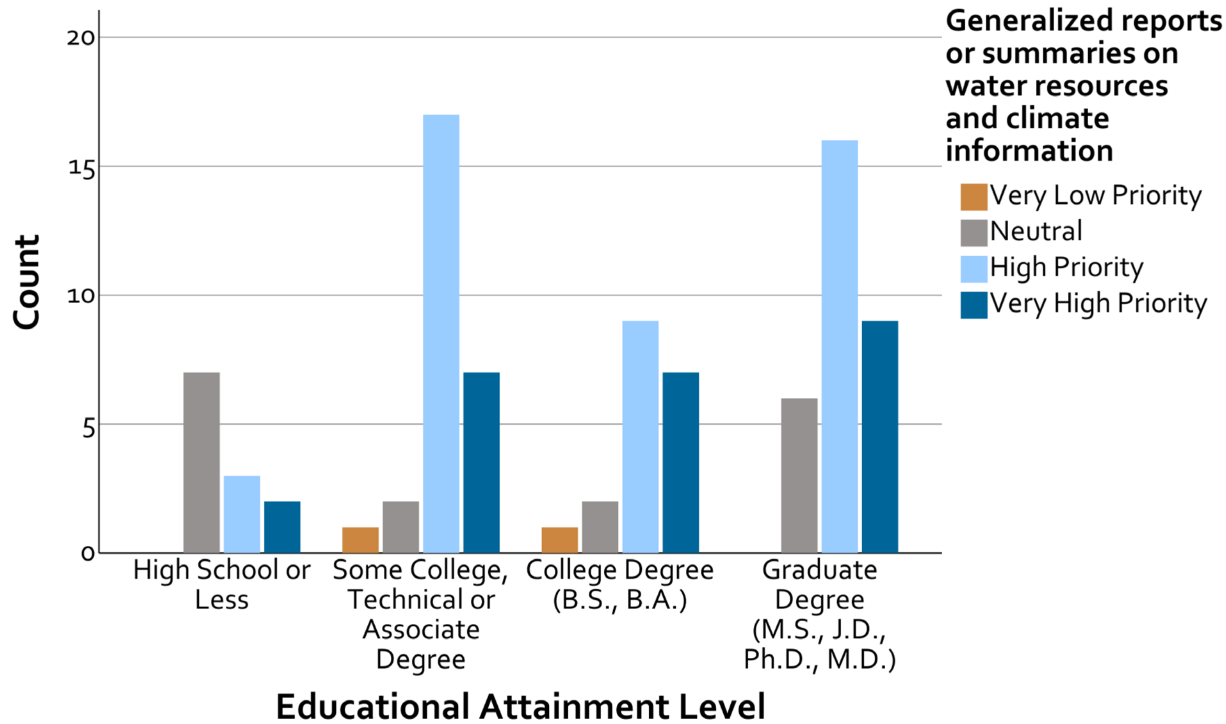
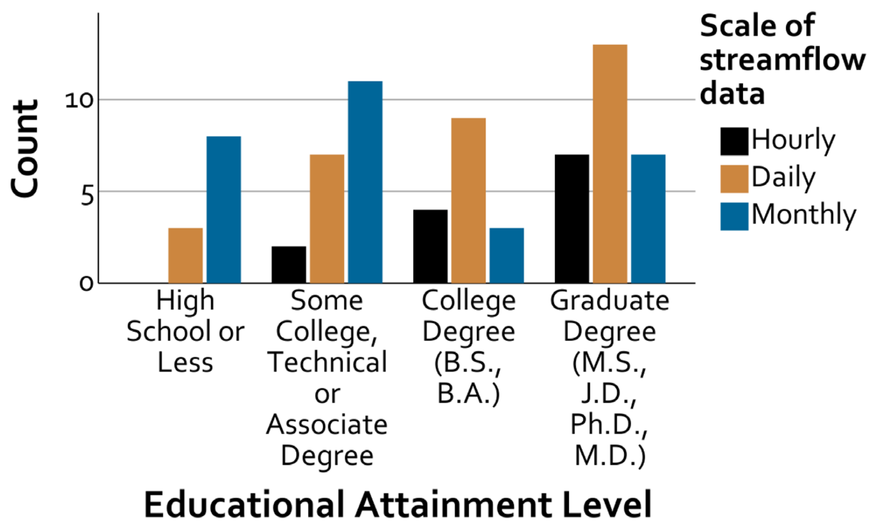


Figure 20. Cross-tabulation counts with statistically significant association between the stakeholder **educational attainment level** variable and the **climate data** variable, “Generalized reports or summaries on water resources and climate information.”

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 21 and 22).



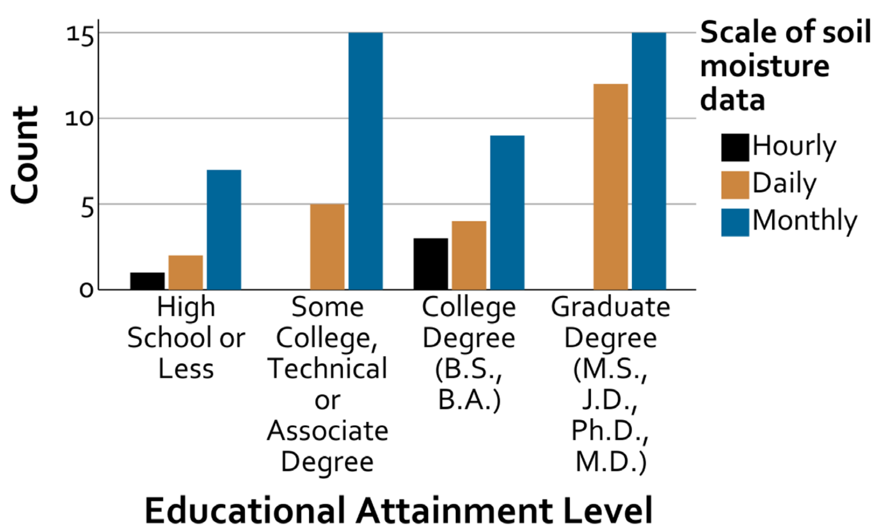
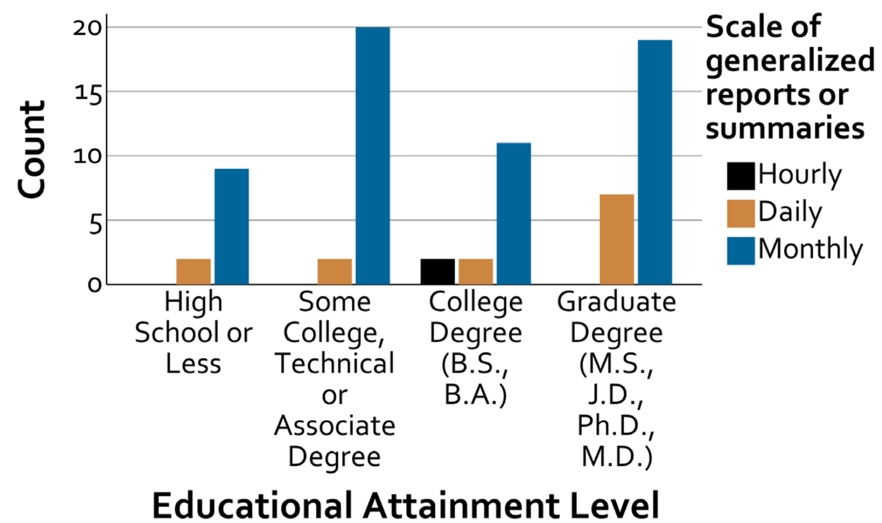


Figure 21. Cross-tabulation counts with statistically significant associations between the stakeholder **educational attainment level** variable and the **scale of climate data**, "Scale of streamflow data," and "Scale of soil moisture data." Note. These graphs do not have an equally distributed y-axis, meaning that Count frequencies cannot be compared across here.

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. In regard to general climate summaries, respondents with high school educations did not vary from the expected distribution of response counts to each scale category. Respondents with some college education had significantly higher counts in the monthly category than the expected distribution, while respondents with undergraduate and graduate degrees required coarser scale data (see Figure 22).



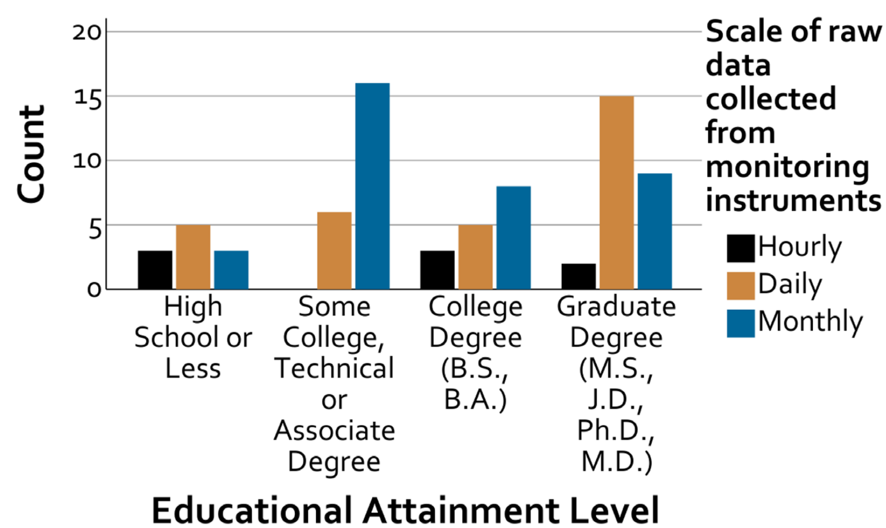


Figure 22. Cross-tabulation counts with statistically significant associations between the stakeholder **educational attainment level** variable and the **scale of climate data**, "Scale of streamflow data," and "Scale of soil moisture data." Note. These graphs do not have an equally distributed y-axis, meaning that Count frequencies cannot be compared across here.

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 23). In contrast, respondents with graduate degrees indicate that they "rarely" access this source with the highest count frequency.

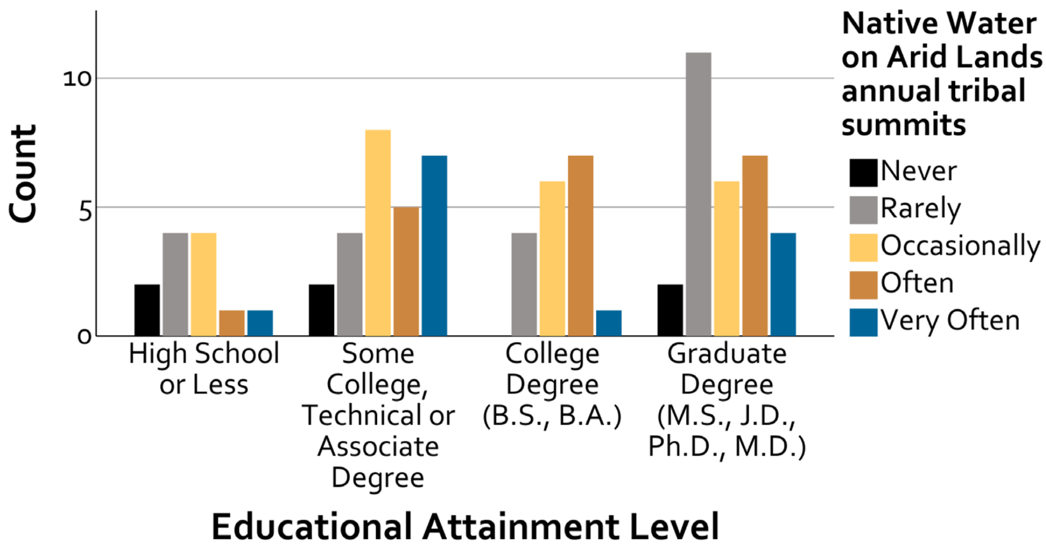


Figure 23. Cross-tabulation counts with statistically significant associations between the stakeholder **educational attainment level** variable and the **climate data/information source** variable, "Native Water on Arid Lands annual tribal summits."

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 on 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. ●

5. Conclusions

This study assessed and reported the climate information and data needs of Indigenous communities in the southwestern U.S. through the lens of individuals who self-identified as being engaged in or interested in climate adaptation on reservation lands. Study area boundaries depicted an arid snow-fed dependent region that includes a significant number of federally recognized tribes on reservation lands. A 50-question item survey was developed to examine human needs and interaction with pertinent climate information and data resources that can inform water management and community-based climate adaptation on reservation lands. Using purposeful and convenience sampling strategies (Fowler, 2014), the survey was administered to attendees of two annual tribal outreach summits (2016, 2017) held within the study area and focused on community-based adaptation of water resources on reservation lands within the study area.

Survey respondents prioritized as their highest information/data need "Assessing climate impacts on tribal lands, water and economies." When land, water and economic impacts are considered separately, respondents indicated climate impacts on water resources as their greatest concern. Survey respondents ranked water quality data as the highest priority need followed by streamflow data. These results suggest that Indigenous communities in these arid, snow-fed dependent regions maintain strong interrelationships with the snow-fed river systems and water supplies on which they depend. While water quality data collection across the southwestern U.S. has intensified and is available to the public, these databases are presented in impracticable formats to facilitate broad access (Jones et al., 2020).

Respondents also prioritized food security on reservation lands and incorporating traditional knowledge into climate adaptation initiatives, while protecting the use of traditional knowledge in adaptation planning and action. The perseverance 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 long-held cultural practices values into community-based adaptation strategies may be particularly advantageous, and perhaps a continuance of sustainable practices that have persisted and endured for thousands of years (Whyte, 2018b; Chief et al., 2016; Guatam et al., 2012).

Respondents indicate that tribal natural resource departments are their most frequently accessed resource for climate data and information. This suggests that directing resources and support to increase the technical capacity of these departments to monitor, research, assess and disseminate climate impact information may be particularly beneficial to the adaptation initiatives of Indigenous communities (Whyte, 2018a). Such 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 (McNamara et al., 2020; 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 collaborative 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 total number of observations was just under 100, which 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 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.

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. Ethical Participatory Research 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 nations and incorporates well-rounded climate vulnerability and resiliency assessments that address potential governance, cultural 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).

Indigenous communities already have the ability to conduct this work independently, but results from this needs assessment suggest that those engaged in climate adaptation initiatives may have limited human and fiscal capacity and resources necessary to assess climate impacts on their reservations and/or within their 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; Lacey et al., 2015). 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 (Martin et al., 2020; Klenk et al., 2017; Maldonado et al., 2016).

This study 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 and unethical 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 study attempts to overcome this paradox by using community-based research methodologies, such as participatory research (Lacey et al., 2015).

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 required 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. 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 their natural resources (Kukutai & Taylor, 2016). This principle, however, contrasts with Western science research frameworks that have been relied upon heavily to 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.

Therefore, while this study sought and received approval from the University of Nevada, Reno Office of Research Integrity, Internal Review Board, additional analytical 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 and primary data to characterize and assess the climate information and data needs of Indigenous communities. We take an extra precautionary step by reporting results categorically by geographic region, rather than by individual Indigenous community, to ensure the protection of these communities from unintended harm.

Similarly, community-specific data obtained through secondary sources have been disseminated in the past (see Tiller, 2005). This study, however, recognizes that some published secondary data, specifically historical data, may not have been collected through the use of evolving ethical research protocols being established by individual Indigenous communities (Harding et al., 2012). 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 via seeking permission from tribal councils or similar representative bodies. Sharing community-specific data, under these ethical considerations specific to Indigenous communities, would therefore require official consent from the representative body tasked with such decisions for each individual 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 (Singletary & Sterle, 2020; Singletary & Sterle, 2018; Wall, Meadow, & Horganic, 2017), otherwise such information may not be useful, as it may not fit into local decision-making contexts (Lacey et al., 2015; Kalafatis et al., 2015). Overcoming these barriers will require creative collaborative research tailored to specific community characteristics and researchers skilled in these approaches. Efforts to increase the numbers of Indigenous scientists, natural resource professionals and students will facilitate the protection of local and potentially sensitive information as tribes increasingly self-determine their respective paths to enhanced climate resiliency of water resources on reservation lands (Chief, 2020).

5.3. Recommendations for Future Research

Additional investigations into the relationships between Indigenous communities in the southwestern U.S. and the hydrologic systems upon which they rely 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 that delivers water entitlements from the Colorado River to enhance water security in Arizona, and which includes Arizona's more densely populated cities, such as Phoenix (Central Arizona Project, 2016).

In addition to the needs assessment survey and results reported here, future research with Indigenous communities can be conducted through focus groups and face-to-face interviews as ways to include community input directly into climate resiliency and adaptation studies. Future research should also explore the relationships between collaborative partners engaged in this work and potential opportunities and barriers associated with these collaborations. This challenging yet necessary work can help to improve decision-making support tools for land and water managers by making such tools more applicable to Indigenous community priorities to inform climate policy and enhance the climate resiliency of reservation lands while sustaining tribal economies (Nusser, 2017; Deol & Colby, 2018).

Photo by ***Loretta Singletary***

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Appendix A. Survey instrument

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% ☐ 1-5% ☐ 6-10% ☐ 11-15% ☐ 16-20% ☐ 21-25% ☐ Greater then 25%

22. I work for:
- ☐ Tribal government (which department) ________________
- ☐ Tribal college/universities
- ☐ Other college/universities
- ☐ Cooperative Education FRTEP
- ☐ Self employed ________________
- ☐ Local/County government
- ☐ State government
- ☐ Federal government
- ☐ Private sector business

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

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); National Weather Service; NRCS Snotel	1	2	3	4	5
33. USDA Climate Hubs	1	2	3	4	5
34. U.S. 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
- ☐ Radio and TV
- ☐ Annual tribal summit
- ☐ Webinars
- ☐ Online information or data portal
- ☐ 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 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
- ☐ White
- ☐ Hispanic/Latino
- ☐ Asian/Pacific Island
- ☐ Black
- ☐ 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 (B.S., B.A.)
- ☐ Graduate degree (M.S., J.D., Ph.D., M.D.)

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Photo by ***Loretta Singletary***

EXTENSION
College of Agriculture,
Biotechnology & Natural Resources

Climate Resilient Tribal Waters

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

This Special Publication reports the results of participatory research to assess the climate information and data needs of Indigenous communities to enhance the climate resiliency of water resources on reservation lands. The work is supported by Agriculture and Food Research Initiative (AFRI) [Water for Agriculture Challenge Area: Enhancing Climate Resiliency & Agriculture on American Indian Land grant no. 2015-69007-23190/project accession no. 1005994] from the USDA National Institute of Food and Agriculture.

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