

# Assessing Climate Data and Information Needs of Indigenous Communities in the Arid Southwestern United States

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## Research Article

**Keywords:** Indigenous communities, climate adaptation, water resources, traditional knowledge, needs assessment

**Posted Date:** March 26th, 2021

**DOI:** <https://doi.org/10.21203/rs.3.rs-338122/v1>

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# Abstract

Indigenous communities are actively engaged in interdisciplinary climate adaptation initiatives across the United States making them experienced witnesses to community-based adaptation. This study offers the results of a regional survey of climate information and data needed to enhance the climate resiliency of water resources on reservation lands in the arid southwestern United States. Regional studies of this nature are particularly rare—and reasonably so—due to the place-based nature of Indigenous cultures and the diversity of community experiences. Study participants include tribal government employees, agriculturalists, researchers, and outreach professionals actively engaged in climate adaptation and resiliency efforts on reservation lands. Study respondents prioritize climate information and data that serve to assess local climate change impacts, enhance food security, and integrate the traditional knowledge of their communities into reservation-wide climate adaptation initiatives. In this arid and predominantly rural region, respondents prioritize water quality data as their highest need followed by streamflow data and air temperature data. They most frequently access their respective tribal sources of climate information and data. This research utilizes a participatory approach to identify needs unique to reservation lands in the southwestern United States while illuminating the critical role of Indigenous sovereignty in enhancing climate resiliency.

## 1. Introduction

Water scarcity is a defining feature of southwestern United States ecosystems, and climate projections predict decreasing water availability over time (MacDonald 2010; Seager et al. 2013; Udall and Overpeck 2018). Additional projections include increasing severity and frequency of drought and/or monsoonal flood events, diminished annual snowpack, and earlier snowmelt (Fritze et al. 2011; Knowles et al. 2006; Li et al. 2017; Miller and Piechota 2011). As changing climatic conditions compound aridity issues already associated with this desert region, Indigenous communities face unique adaptation challenges (Draut et al. 2013; Martin et al. 2020). That is, Indigenous communities maintain strong relationships with their natural environment including complex interconnections between human and natural systems that may include place-based interdependencies between cultural, political, spiritual, physical, and environmental resources (Ellis and Perry 2020; Maldonado et al. 2016; Whyte 2018a). Projected changes to climate pose significant threats to these systems, as such changes will not only impact key infrastructure and economic sectors, but also threaten significant cultural resources, and community health and wellbeing (Donatuto 2011; Lemelin et al. 2010). Climatic change threatens traditional agriculture and subsistence practices, as current and projected warming air temperatures impact habitat conditions necessary to sustain culturally important native plants and wildlife of which these communities depend (Jantarasami et al. 2018). Additionally, historically limited economic development opportunities and isolated, rural land bases add to their particular climate vulnerability to changes in water resources (Cozzetto et al. 2013). While limited water availability stymies development of economic industries, such as irrigated agriculture and rural tourism, it may also limit regional capacity to sustainably meet water needs for steady urban population growth (Steele et al. 2018).

Indigenous communities on reservation lands may be uniquely vulnerable to climate change impacts to natural, cultural, and economic resources; however, they may also possess unique opportunities to implement sustainable adaptation measures (Fernald et al. 2015). As compared to non-Indigenous communities, Indigenous communities may be more likely to recognize and acknowledge evidence of climate change impacts (Smith et al. 2014). This may be due—in part—to long-established relational ethics systems linked to the protection of ecological services and strong communal relationships inherent to Indigenous communities (Fillmore 2017). Both attributes provide a strong foundation for successfully carrying out community-based adaptation processes (Maldonado et al. 2016). Indeed, recognition of climate change impacts to communities may inspire and characterize future public policies that aim to mitigate or adapt to climate change impacts (Gurney et al. 2020).

Increasingly, efforts are underway to involve Indigenous communities in climate research in meaningful ways, such as acknowledging a potential role for Indigenous traditional knowledge in climate adaptation initiatives (Robitaille et al. 2017). It follows then that adherence to ethical research protocols are crucial to avoid inadvertent extraction and dissemination of traditional knowledge (Gautam et al. 2013; Klenk et al. 2017). Emerging from participatory research methods and development practices, community-based adaptation (CBA) frameworks have proven particularly successful in this regard (Dodman and Mitlin 2013; Kirkby et al. 2017; McNamara et al. 2020; Reid 2016). Specifically, CBA that empowers Indigenous communities to act locally through their direct involvement in scientific inquiry may be more likely to lead to local action (Westoby et al. 2020). Participatory research methods aim to engage participants in co-identifying research objectives, which help to ensure that subsequent research activities, questions, and findings are ultimately useful to support and potentially improve local decisions to support CBA (Chief et al. 2016; Kirkby et al. 2017; Klenk et al. 2017; Meadow et al. 2015; Reid 2016; Singletary and Sterle 2020). Such research methods may also empower Indigenous communities to identify the role of traditional knowledge in their adaptation efforts, which includes protecting traditional knowledge from inadvertent and unintended uses (Brewer and Kronk Warner 2015; Cochran et al. 2013; Whyte 2018b).

Both local and regional climate action in the U.S. are interconnected by economic and political priorities (Gurney et al. 2020). Therefore, participatory research methods that support CBA at a variety of scales are necessary. Most CBA research efforts focus on an individual community, as they are intended to inform a specific local action; whereas, regional studies of this nature are important to contributing to collective climate adaptation action at a variety of scales (McNamara and Buggy 2017; Nalau et al. 2018). In this regard, this study aims to address an information gap for tribes across the southwestern U.S. by offering a regional assessment of priorities that can inform climate adaptation planning. To date, engagement with Indigenous communities that weave together community priorities, traditional knowledge, and scientific research pursuits have produced mutually beneficial results for both researchers and Indigenous communities (Ford et al. 2018; Ignatowski and Rosales 2013; Lemelin et al. 2010; Maldonado et al. 2016; McNamara et al. 2020; Naulau et al. 2018; Williams and Hardison 2013).

## 2. Methods

## *2.1 Ethical considerations and Indigenous data sovereignty*

As Indigenous communities in the arid southwestern U.S. are expert witnesses to both the challenges and opportunities surrounding climate adaptation of water resources vital to their existence, this study utilizes a participatory research approach to assess, from their perspectives, climate information and data necessary to facilitate adaptation. Specifically, we surveyed stakeholders and practitioners defined for this study as individuals actively participating in climate adaptation initiatives on reservation lands, and as such, have experience with both challenges and opportunities surrounding such efforts. The participatory research method employed and results reported here demonstrate first steps in engaging with Indigenous communities to co-produce new knowledge unique to reservation lands in support of CBA to enhance the climate resiliency of water resources.

Indigenous data sovereignty is an emerging concept used to describe the right of Indigenous communities to determine the collection, analysis, dissemination, and application of data involving their communities (Kukutai and Taylor 2016). Given the historical exploitation of Indigenous culture and homelands, many Indigenous communities are rightfully hesitant to partner with outside agencies, groups, and individuals (Savaresi 2018). To help address these challenges, Indigenous communities and their governance systems increasingly require additional research protocols that honor and protect Indigenous data sovereignty (Lovett et al. 2019). Such research protocols, and the partnerships they may involve, 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 setting research agendas honor the co-production of any resulting new knowledge and information (Chief et al. 2016; Klenk et al. 2017; Maldonado et al. 2016).

This study sought and received approval from the University of Nevada, Reno Office of Research Integrity Internal Review Board. While this study protects the anonymity of each individual research participant, which includes their voluntary consent to participate in this study, it did not acquire official consent from each tribal government located within the study region. This research step was impractical due to the geographic scope of this study and our own limited fiscal resources. For this reason, intentional ethical considerations were taken in the development of this regional study to recognize the data sovereignty of Indigenous communities, to prevent harm, and to ensure that results reported here are meaningful and representative.

Conducting research at a regional scale is a burden of necessity, as it is important to assess needs and priorities at both local and regional scales in order to support collective climate adaptation initiatives. Methodologically, this is a significant challenge due to the complex diversity among Indigenous communities. The reality that we faced in developing this study at a regional scale is that overarching results may appear to homogenize the diverse experiences and perspectives of Indigenous communities reported here. This is the reality of regional assessments in any discipline; however, parsing out data and reporting results by tribal affiliation, for example, makes the inaccurate assumption that tribal affiliation alone without any consideration of cultural, economic, geographical, political, governmental, or other

differences in the makeup of these communities comprises a sufficient basis for comparisons. Additionally, without receiving official consent from the tribal governments located within our study area, we would risk misrepresenting these sovereign entities (Harding et al. 2012). That is, while the significant majority of participants in our study live and work on reservations, they may not be designated representatives of their individual communities. Therefore, our research offers a regional assessment of needs and includes a cross-correlation analysis based on aggregated demographic variables representative of the individuals who participated in this study rather than of their respective communities. Assessing the needs of each individual Indigenous community and reporting results as such would require a different methodology that includes formal consent from the tribal governments participating in the study.

Researchers who implement participatory research methods understand the importance of sharing research processes and findings with participants regularly and in a format that emphasizes transparency, respects local culture and knowledge, and ultimately improves research accountability (Datta et al. 2015; Glass et al. 2018). Preliminary assessment results were reported back to participants attending the 2018 Summit, and final results were presented at the 2019 summit along as part of a capacity-building workshop focused on integrating and protecting traditional knowledge in climate adaptation planning efforts. This workshop was developed in response to the priorities identified through our assessment and was geared towards tribal environmental professionals and elected tribal leaders. Following participatory research principles and best practices, such as these, can enhance the capacity of scientific inquiry to meet the needs of Indigenous communities in pursuit of CBA (Campos et al. 2016; Singletary and Sterle 2020). Future research that involves similar, but more specific community-based assessments, should acquire formal review and consent from each Indigenous community choosing to participate and/or from the tribal governing body of each reservation involved.

## *2.2 Study Area*

To define our study area, we use three U.S. Geologic Survey (USGS) water resource regions delineated at 2-digit hydrologic unit codes as Great Basin, Upper Colorado, and Lower Colorado. We refer to this study area as a whole as the “Southwest,” which spans several states including Arizona, California, Colorado, Idaho, Nevada, New Mexico, and Utah. Utilizing USGS water resource regions to delineate study area boundaries helps to address the complexity associated with water allocated for use through prior appropriation doctrine and water rights are adjudicated at the watershed scale (Colby et al. 2005; Deol 2017). Additionally, the ecological coherence within water resource regions, compared to state or other governmental boundaries, ensures that study participants exist within comparable environmental and climatological conditions.

We identified as study participants 49 federally recognized tribes who inhabit reservation lands located within this region. In the Upper Colorado and Lower Colorado water resource regions, reservation lands comprise nearly 43.6 million acres. In the Great Basin water resource region, reservation lands comprise nearly 2.1 million acres. Figure 1 illustrates the approximate location of these reservations within our

study region noted by names of the 49 federally recognized tribes, referred to herein simply as Indigenous communities.

### *2.3 Target population and survey sample recruitment*

To assess the climate data and information needs of these Indigenous communities, our target population includes tribal members and/or individuals who are engaged in or interested in pursuing climate adaptation specific to water resources associated with these reservation lands. This population of CBA researchers, planners, practitioners, and stakeholders serve as key informants in identifying and prioritizing climate data and information needs of Indigenous communities, as they are uniquely familiar with the types of climate data and information currently accessible as well as information and data gaps that might impede adaptation. For this reason, it was necessary to employ a convenience sampling strategy to represent this population.

Subsequently, we administered the survey during the second (2016) and third (2017) of five annual Native Waters on Arid Lands Tribal Summits conducted within the study area. Recruitment for survey participation targeted voluntary summit attendees during plenary sessions where summit organizers scheduled time on the agenda to allow for participation in this research. We recruited participants to respond to the survey questions based upon their individually-perceived needs, rather than responding on behalf of the Indigenous community in which they live and/or work. This recruitment protocol ensured that survey respondents self-identified as having some role or interest in community-based climate adaptation on reservation lands and acknowledges that only tribal governments can designate representatives to speak about official priorities. Attendees were also encouraged to bring copies of the survey back to their community members and coworkers to submit at a later date in an attempt to encourage participation outside of the summit; these responses make up less than 10% of the total responses. Over the two years of survey administration, a total of 98 participants completed survey questionnaires. Responses to the questions serve as the data sources for the study. Given the challenges in survey recruitment with our target population, due in part to being located over a large, primarily rural region, the convenience sampling strategy—as employed here—was effective (Sandefur et al. 1996).

Of the 98 total respondents, the significant majority (n = 85) self-reported as either living or working on one or more of the reservations within the designated study area. That is, 45% (n = 44) of respondents reported living and/or working in the Great Basin, 21% (n = 21) live in the Lower Colorado River region, 18% (n = 18) live in the Upper Colorado River region. This outcome ensures that the overall results reported here are representative of the target study area.

Additional respondent attributes are characterized by a majority of respondents self-reporting as: Native American (72%, n = 71); male (70%, n = 69); 45 years of age or older (61%, n = 60); having post-secondary education (83%, n = 81), and; 55% specifically holding bachelor or graduate degrees (n = 54). Approximately 87% of respondents reported that they currently live on reservations (n = 85), with 52% (n = 51) for more than 31 years, and 23% having lived on reservations for 30 years or less (n = 23). These results suggest the survey sample may not represent the demographic composition of the general

population of Indigenous communities nationwide. Instead, the surveyed sample in this case represents the target population of researchers, planners, and practitioners in the Southwest. That is, this study required participation from a stakeholder demographic who self-identified as being interested and/or involved in climate adaptation initiatives on reservation lands within the study area. 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.

#### *2.4 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 either Las Vegas or 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 cited 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 protocols—supported the authors' 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 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; Maldonado et al. 2016). 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, and question items were revised based on the feedback received from these reviews.

Demographic information was also collected, and three aggregated variables were produced from these data to cross-analyze participant priorities based on their demographic differences. The aggregated

variables reported here include water resource region (Great Basin, Colorado River Basin, and other) based on geographic location, role in climate adaptation initiatives (administration, implementation, and research) based on occupation, and educational attainment level (high school or less, some college or associates degree, bachelor degree, or professional or doctoral degree) based on highest degree completed, as these are meaningful and defensible demographic characteristics that might influence respondents' prioritized climate data and information needs.

The analysis and results reported here feature 33 Likert-type scale questions that ask respondents to: 1) prioritize their climate data and information needs; and 2) identify their most frequently accessed sources of data and information specific to enhancing the climate resiliency of water resources on reservation lands. Part 1 of the survey includes 20 closed-ended question items intended to identify and prioritize information necessary for Indigenous communities to adapt to and plan for climate uncertainty. Each question provides a 5-point Likert-type rating scale of "1" indicating "very low priority," "2" indicating "low priority," "3" indicating "neutral" priority, "4" indicating "high priority," and a "5" indicating "very high priority." For the 20 question items, the question stem is: "To adapt to and plan for climate uncertainty, tribal communities need information about..." Of these 20 question items, 12 questions identify and prioritize information needs that support climate adaptation on reservation lands, 6 questions identify and prioritize specific data needs, and 2 questions assess individual preference for raw data collected as compared to generalized reports and/or data summaries.

Part 2 of the survey includes 13 question items that ask participants to rate the frequency in which they access climate adaptation planning information from the sources listed. Each closed-ended question provides a 5-point Likert-type scale rating of "1" indicating this resource is "never accessed," "2" indicating "rarely accessed," "3" indicating "occasionally accessed," "4" indicating "often accessed," and a "5" indicating "very often accessed." The stem for these 13 question items is: "In climate adaptation planning, we are currently using information provided by..."

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. Cronbach's coefficient alpha (CCA) was used to estimate internal consistency of the 33 Likert-type scale question items developed to assess climate information and data needs and frequency of access. The CCA score was high for each of three sets of questions (totaling 33 question items). For the 12 question items on climate information needs,  $r = 0.897$ ; for the 6 question items on climate data types,  $r = 0.921$ , and for the 13 questions on frequency of access to climate information sources,  $r = 0.860$ . These scores indicate high internal consistency, or reliability, among these three sets of question items (Carmines and Zeller 1979). For the 2 questions on preference for raw data as compared generalized reports,  $r = 0.754$ . This r-value indicates less internal consistency, but this may be associated with this calculation only being based on two question items.

## 3. Results

### *3.1 Information and data needs*

In order to identify and prioritize survey participants' data and information needs, mean scores were calculated and ranked from highest to lowest priority. A ranking of mean scores reveals respondents' prioritized climate data and information needs relative to others. That is, the lowest ranked climate information item does not necessarily indicate an overall "very low priority" rating for that item, but rather indicates its priority standing relative to other climate information and data items identified for this assessment. Table 1 displays the calculated ranked mean scores of prioritized climate information needs to support adaptation on reservation lands while Figure 2 depicts response frequencies for each question item. In addition to calculating and ranking mean scores, survey responses were cross-correlated with aggregated variables based on self-identified demographics using a Chi-square test for statistical significance. Correlated variables with a 95% or greater confidence interval (a p-value less than or equal to 0.05) are noted along with the ranked mean scores in Table 1 and Table 2. Overall, the priority rankings assigned by respondents held regardless of demographic characteristics.

<b>Table 1</b> Prioritized Climate Information/Data Needs.					
	<u>Rank</u>	<u>Need</u>	<u>N</u>	<u>Mean</u>	<u>Std. Dev.</u>
Information Needs	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 <sup>abc</sup>	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
Data Needs	1	Water quality data	93	4.22	0.81
	2	Streamflow data	92	4.07	0.81
	3	Air 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
Reports	1	Generalized reports of summaries on water resources and climate information data	93	4.02	0.82
	2	Raw data collected from monitoring instruments <sup>ac</sup>	94	3.84	0.92
<p>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).</p> <p>Superscripts represent priorities with statistically-significant association to one of the following aggregated demographic variables determined using a 95% confidence interval (p-value of less than or equal to 0.05):</p> <p><sup>a</sup> Water resource region (based on geographic location): Great Basin, Colorado River Basin, or other;</p> <p><sup>b</sup> Stakeholder role (based on occupation): administration, implementation, or research;</p> <p><sup>c</sup> Educational attainment level: high school or less, some college or associates degree, bachelor degree, professional degree or doctorate;</p>					

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 have repeatedly voiced the need for climate impact assessments as a critical first step to resiliency planning for their communities (National Congress of American Indians 2017). Of the 49 Indigenous communities

included in the study area, nearly half (44.89%) are undertaking efforts to assess climate impacts and develop climate adaptation plans for their communities, lands, and/or resources (Jantarasami et al. 2018).

The second ranked information need ( $m = 4.28$ ;  $n = 96$ ) is, “Enhancing tribal food security and sovereignty.” This finding is not surprising as water scarcity characterizes and has posed a chronic threat to the viability of conventional irrigated agriculture in the region. Most reservations in the region have suffered these effects in part as a result of inadequate water delivery infrastructure and unresolved water rights claims (Cosens 2012; Cosens and Chaffin 2016). Both of which must be addressed to sustain water conserving agricultural production, which is paramount to attaining both food security as well as providing economic stability.

While the third and fourth ranked information needs have equivalent mean scores ( $m = 4.16$ ;  $n = 97$  respectively), the item with a smaller standard deviation (0.76 as compared with 0.91) is ranked higher. These information needs include the “Role of traditional knowledge in climate adaptation on tribal lands” and “How to protect traditional knowledge that tribes incorporate into their adaptation strategies.” The high priority ratings assigned to these topics indicate that survey respondents highly value the role of Indigenous traditional knowledge in climate adaptation. This response may also demonstrate the need to enhance tribal efforts to apply this knowledge in climate adaptation planning. To appropriately apply traditional knowledge to climate adaptation efforts requires the leadership of Indigenous community members who are both familiar with the knowledge itself, its level of sensitivity to outside exposure, and its relationship to climate adaptation (Klenk et al. 2017; Kovach 2010). Using and sharing this knowledge typically requires securing prior and informed consent from the pertinent tribal governing body to permit the use of such knowledge, and therefore, its potential dissemination (Maldonado et al. 2016). This step is imperative as tribes increasingly develop, and many already possess, legal protections to address the misappropriation and abuse of traditional knowledge (Brewer et al. 2015; Harding et al. 2012; Savaresi 2018).

As previously mentioned, the remaining information topics listed maintain high overall priority ratings. That is, mean scores range from 3.71 to 4.08. In general, these topics include information to assist with building the fiscal and professional capacity of Indigenous communities to carry out climate adaptation activities. Due to the high standard deviation values, these topics may very well be higher in priority. Future partnering efforts to assist with capacity building of Indigenous communities should encourage collaboration and maintain space for Indigenous partners to co-identify project goals and priorities.

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 ( $m = 4.07$ ;  $n = 92$ ). For the remaining data types featured here, temperature ranked third ( $m = 4.05$ ;  $n = 92$ ), followed by precipitation ranked as fourth ( $m = 4.03$ ;  $s.d. = 0.87$ ;  $n = 94$ ), snowpack data as fifth ( $m = 4.03$ ;  $s.d. = 0.91$ ;  $n = 91$ ), and soil moisture data ranked last comparatively ( $m = 3.93$ ;  $n = 94$ ).

The cross-correlation analysis between the three demographic variables—water resource region, stakeholder role, and educational attainment level—and information and data needs resulted in statistically significant correlations of only two priorities. Participant groups within all three variables disproportionately prioritized the information need, “Meaning of future climate projects for individual reservations.” Participants in different water resource regions and in educational attainment level groups disproportionately prioritized the report need, “raw data collected from monitoring instruments,”

### 3.2 Accessing data/information resources

We followed a similar procedure to identify and rank the most frequently accessed climate data/information resources. Mean scores were calculated and ranked for each of the 13 Likert-type questions on data/information resources from most frequently accessed to least frequently accessed. These results are reported in Table 2. For mean scores that are the same, we use the standard deviation, or variance from the mean, to determine the higher ranked item. Response frequencies to each question item are depicted in Figure 3.

<u>Rank</u>	<u>Source</u>	<u>N</u>	<u>Mean</u>	<u>Std. Dev.</u>
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 <sup>b</sup>	92	3.20	1.14
7	Colleges and universities <sup>abc</sup>	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 <sup>b</sup>	89	3.12	1.19
10	USDA Climate Hubs	91	2.99	1.13
11	The Weather Channel; Weather.com; local news and radio	91	2.96	1.17
12	Bureau of Indian Affairs climate planning program	90	2.90	1.18
13	Tribal colleges and universities	90	2.64	1.26

Note. Topics are ranked by highest mean score (5=Very Often Accessed) to lowest mean score (1=Never Accessed). Verbiage reported here is taken directly from survey instrument. Sources specified as “tribal” here are referenced as “Indigenous” in the body of this study. Superscripts represent priorities with statistically-significant association to one of the following aggregated demographic variables determined using a 95% confidence interval (p-value of less than or equal to 0.05):

<sup>a</sup> Water resource region (based on geographic location): Great Basin, Colorado River Basin, or other;

<sup>b</sup> Stakeholder role (based on occupation): administration, implementation, or research;

<sup>c</sup> Educational attainment level: high school or less, some college or associates degree, bachelor degree, professional degree or doctorate;

Understanding respondents' sources for climate data and information is an important component in assessing climate adaptation needs. Results can help to identify ways to improve tribes' access to and use of information sources commonly used by other organizations to support their adaptation initiatives. Our survey results indicate that respondents accessed most frequently ( $m = 3.74$ ;  $n = 90$ ) their respective "Tribal natural resource/water/land departments" for climate data and information. This result may demonstrate the important role that local resources are for Indigenous communities.

The second ranked resource currently accessed is "USGS stream gauges" ( $m = 3.41$ ;  $n = 91$ ). This result supports previous findings reported for climate data needs (see Table 2) where the second most prioritized item is streamflow data. The next information source ranked closely together is: National Oceanic Atmospheric Administration/National Weather Service/National Resources Conservation Service (NOAA/NWS/NRCS) ( $m = 3.36$ ;  $n = 91$ ). This source includes climate data collected and reported by the National Oceanic and Atmospheric Administration, National Weather Service, and Natural Resources Conservation Service and includes daily, monthly, and annual records for air temperature, precipitation amounts and types, and snow water estimates. While specific data types for water, climate, and environmental data and information may vary by individual use, the items featured in the survey instrument are verified as publicly available and can be used to help conduct climate assessments and/or informing adaptation initiatives.

Respondents also ranked informal information exchanges highly, which include sources such as tribal oral histories ( $m = 3.30$ ,  $n = 91$ ), traditional knowledge holders ( $m = 3.29$ ,  $n = 90$ ), and tribal farmers and ranchers ( $m = 3.20$ ;  $n = 92$ ). Oral histories can include both local knowledge such as family history and environmental observations over an individual's lifetime. Traditional knowledge, such as traditional land use practices, and can inform and/or support climate adaptation. Indigenous community members transfer information regularly, usually through informal conversations, and this information is relatively easy for Indigenous community members to obtain. Some cite conversations over morning coffee as opportunities for learning and sharing (Kovach 2010). While such information may not always be documented formally, it remains readily available, and based on these results, it appears to be used regularly. It is imperative, however, that adaptation efforts on reservation lands develop and recognize local protocols for integrating traditional knowledge within formal adaptation frameworks.

By descending order of mean scores, the next cluster of frequently accessed information and data sources include: colleges and universities ( $m = 3.19$ ;  $n = 90$ ); tribally-owned and operated weather monitoring equipment ( $m = 3.18$ ,  $n = 88$ ); and Native Water on Arid Lands Annual Tribal Summits ( $m = 3.12$ ;  $n = 89$ ). 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 ( $m = 2.64$ ;  $n = 90$ ). These mean scores indicate that respondents only "rarely" to "occasionally" access these sources of climate data and information.

The cross-correlation analysis between the three demographic variables and frequently accessed climate data and information sources resulted in statistically significant correlations between only three sources. Participant groups within all three variables disproportionately access, “colleges and universities.” Participants in different stakeholder roles disproportionately access, “Tribal farmers and ranchers,” and the “Native Waters on Arid Lands Tribal Summits.”

## 4. Discussion

Water quality being the highest rated data need was initially a surprising result. This finding being of such a high priority may be attributed to the disproportionate rate of water quality disparities impacting Indigenous communities in comparison to non-Indigenous populations in the U.S. (Conroy-Ben and Richard 2018). Compared to the other data types featured in this assessment, water quality data are the least readily available through the USGS online data portal for the Southwest. The U.S. Environmental Protection Agency (EPA) is tasked with enforcing provisions of the Clean Water Act, to monitor point source pollutants and non-point source pollutants, and is charged with overseeing water quality monitoring, assessment, and reporting in waterbodies that impact human health (Federal Water Pollution Control Act Amendments 1972). These water quality data, however, are limited in scope to inform water management decisions. That is, water quality data collection and analysis is labor intensive, and due to the multitude of external influences on water quality, it is unreasonable to extrapolate single point collections as being representative of regional conditions.

Furthermore, quantifying climate impacts on water quality at a regional scale is a complex process, as no single accepted method yet exists (Senhorst and Zwolsman 2005). Unlike climate data, such as temperature and precipitation, which have regional and even global relationships, water quality can be particularly site specific. This is why water quality standards are defined differently for different bodies of water. Standards are typically dependent on the location, purpose, use, and/or accessibility of the water to the public, and are often re-evaluated and changed over time (Xia et al. 2015). In much of the western U.S., water quality standards are set by regional water quality control boards to remain in compliance with federal EPA standards, but there are still rural watersheds that lack the baseline data needed to set standards. Without baseline data, or data collected throughout time, it’s challenging to understand relationships between water quality and climate, yet alone predict changes.

Based on these survey results, it is uncertain if respondents are primarily concerned with the general limited availability of water quality data or the impacts of climate change on water quality. A more in-depth follow-up survey would be required to better assess priorities related to this question. That is, priorities may range from climate impacts on baseline water quality standards, drinking water quality, water quality for agriculture, groundwater quality, and/or riparian water quality needed to support ecosystem services. Increasingly, Indigenous communities request future research focus on the effects of climate change specific to water quality (Chief 2020; Jantarasami et al. 2018).

Another surprising finding from this analysis (see Table 2) 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 (Fritz and Pebesma 2011; Oubeidillah et al. 2011; Seager et al. 2013). A comparatively lower ranking for this item may indicate a need for education and outreach on the use of snowpack data to predict summer water availability. In contrast, it may also suggest that respondents recognize that this annual water supply predictor is increasingly variable or in decline.

Another informative finding here is that survey respondents revealed a clear preference for “Generalized reports of summaries on water resources and climate information data” ( $m = 4.02$ ,  $n = 93$ ) as compared to “Raw data collected from monitoring instruments” ( $m = 3.84$ ,  $n = 94$ ) as evidenced by 0.18-point difference in mean scores between the two items (see Table 4). This preference may indicate lack of time and/or available human resources necessary to collect, process, and summarize raw data, and report it in a timely and consistent manner so as to be useful to CBA planning and implementation. Additionally, this finding may speak to an issue of data and information accessibility. That is, publicly funded climatological research typically makes data publicly available through online databases; however, if publicly available data are not in a format that practitioners and general members of the public can easily use to inform their decisions, then it is not publicly *accessible*. Researchers aiming to support CBA for local climate action should factor in these limitations and incorporate more accessible modes of communicating critical data, results, and findings to Indigenous communities.

## 5. Conclusion

This study assesses and reports the climate information and data needs of Indigenous communities in the Southwest through the lens of individuals engaged in or interested in climate adaptation. Statistical analyses of primary data collected through this survey produce a hierarchy of climate data and information priorities that highlight the unique needs of survey participants. Results from this assessment were shared with attendees of the 2019 tribal summit and will also be disseminated to tribal nations within the study area via Extension resources in an effort to further inform and potentially enhance climate adaptation initiatives on reservation lands.

The persistence of Indigenous communities in a region characterized by historical climate extremes and water scarcity implies that climate resilience is an inherent part of the culture and economies of these communities, which should encourage locally led community-based adaptation efforts (Chief 2020; McNamara et al. 2020). Integrating traditional knowledge and values into adaptation strategies may be particularly advantageous, and perhaps a continuance of sustainable practices that have persisted and endured for thousands of years (Chief et al. 2016; Guatam et al. 2012; Robitaille et al. 2017; Whyte 2018a, b). Findings from this study demonstrate this strategy as a high priority. Coupling this finding with the result that Tribal natural resource departments are the most readily accessed source of data and information suggests that Indigenous communities already have many tools to lead CBA initiatives at local levels without the need of outside resources. Outside researchers may still assist efforts to enhance

the climate resiliency of Indigenous communities, as results from this study suggest that climate information and data are not universally available and accessible to all communities. Results also suggest there may be a need to more effectively communicate and disseminate climate data and information, which may increase the coherence of climate research and adaptation priorities across local, regional, and national scales. Specifically, these assessment results can inform applied climate adaptation research and educational outreach.

### *5.1 Study limitations*

We maintain that our survey sample reasonably represents our target population given that it includes practitioners from multiple universities, federal agencies, and the Indigenous communities within the study region (Fowler 2014). With respect to CBA initiatives, however, our surveyed population only includes a subset of community members primarily composed of professionals. While surveying an expert population is helpful for identifying climate data and information needs, expanding this study to include a more diverse and intergenerational range of community members may yield important findings. A larger sample size will also improve this study as a small sample size makes it challenging to identify statistical significance or to determine causal relationships using these survey data (Dillman 1978). For example, ranking information and data needs using mean scores produces a list of priorities, but most mean scores are associated with sizeable standard deviations. A larger number of survey respondents is necessary to test the extent to which the current mean-score rankings are upheld.

While primary data collection via a regional tribal climate summit setting facilitated a convenience sampling strategy, the sampled population may not be entirely representative of community-based climate adaptation practitioners working on reservation lands in the region. That is, summit attendance required funding for registration and travel, which may have limited the participation of early-career tribal professionals, students, and/or other Indigenous community members interested or active in climate adaptation on their respective lands. We attempted to overcome this by requesting that participants bring surveys back to their communities, but those responses represented less than 10% of the overall sample. Considering this study is focused specifically on climate data and information needs on reservations in the region, having a target population of practitioners representing Indigenous communities within the region was reasonable. And results from this study represent a focused subset of priorities for climate adaptation planning on these reservation lands. Additional research at more localized scales is needed to assess a broader scope of climate impacts, priorities, and opportunities for Indigenous communities in this region.

### *5.2 Future research*

Replication of this assessment, combining both face-to-face and e-survey administration, may inform the potential study limitations cited here. Such additional research may ensure that assessment results more accurately represent a future generation of climate scientists and planners working on reservation lands, which can better capture localized Indigenous community needs. Nevertheless, this exploratory study comprises a critical first step in building a better understanding of information and data needs that, if

effectively addressed, may enhance climate resiliency on reservation lands in the Southwest. Methods and results reported here may help guide scientists interested in engaging with Indigenous communities to support their ongoing climate adaptation research, planning, and action efforts.

The very purpose for conducting this needs assessment is to help Indigenous communities to identify and prioritize such resource needs, which may include ongoing climate science research, increased allocation of fiscal resources, and increased outreach education, among other forms of capacity-building on reservation lands. Results from this needs assessment suggest that those individuals who responded to this survey and who are engaged in community-based adaptation initiatives on reservation lands in the Southwest perceive that climate information and data resources are currently limited despite having many tools and resources to support adaptation efforts such as access to traditional knowledge holders. As such limitations may hinder comprehensive assessments of local climate impacts on reservation lands, Indigenous communities may likewise wish to increase collaborative partnerships with federal and state government agencies, universities, and non-profit organizations to bolster, at least in the short run, tribal self-determination efforts to realize their respective community-based adaptation goals. These collaborative efforts should empower Indigenous communities to lead their own CBA initiatives respective to their communities and mutually-respect the various roles that different practitioners and knowledge holders may have in these processes to ensure beneficial outcomes.

In the long run, increasing the numbers of Indigenous students and subsequently scholars (Martin et al. 2020) pursuing climate science research and outreach with Indigenous communities will organically enhance the tribal self-determination of climate resiliency on reservation lands and such knowledge will likely extend beyond the borders of reservations to enhance the climate resiliency of communities elsewhere (Chief 2020; Kozich et al. 2020). At the same time, Indigenous communities should continue to take necessary steps to ensure data sovereignty, including voluntary participation in CBA research and adaptation projects. This includes ongoing efforts to establish research protocols when working with tribes and the protection of sensitive traditional knowledge from misuse that could inadvertently harm tribal nations (Ellis and Perry 2020; Whyte 2018a, b). Finally, future research must continue to evaluate the impacts of participatory research and development practices at local, regional, national, and international scales and should aim to support locally-led community-based adaptation efforts rather than extract knowledge or resources from historically marginalized populations including Indigenous communities (McNamara et al. 2020; McNamara and Buggy 2017; Dodman and Mitlin 2013).

## **Declarations**

### *Funding*

This research is funded by the U.S. Department of Agriculture National Institute of Food and Agriculture Water for Agriculture Challenge Area Award Number 2015-69007-23190 “Enhancing climate resiliency and agriculture on American Indian lands.”

### *Conflicts of interest/Competing interests*

Not applicable

### *Ethics approval*

This research protocol was reviewed and approved by the University of Nevada, Reno Office of Research Integrity Internal Review Board.

### *Consent to participate*

Voluntary completion of survey questionnaire indicated consent to participate as part of the approved survey recruitment protocol.

### *Consent for publication*

Voluntary completion of survey questionnaire indicated consent to publish research findings as part of the approved survey recruitment protocol.

### *Availability of data and material*

As this research involves surveying the opinions of human subjects, data will be kept and stored following the University of Nevada, Reno Institutional Review Board guidelines for which this research was approved.

### *Code availability*

Not applicable

### *Author's contributions*

Helen Fillmore and Loretta Singletary contributed equally to the study conception, design, and material preparation. Helen Fillmore led in the data collection and analysis. Both authors contributed equally to the first draft of the manuscript and all subsequent versions and revisions. Both authors read and approved the final manuscript.

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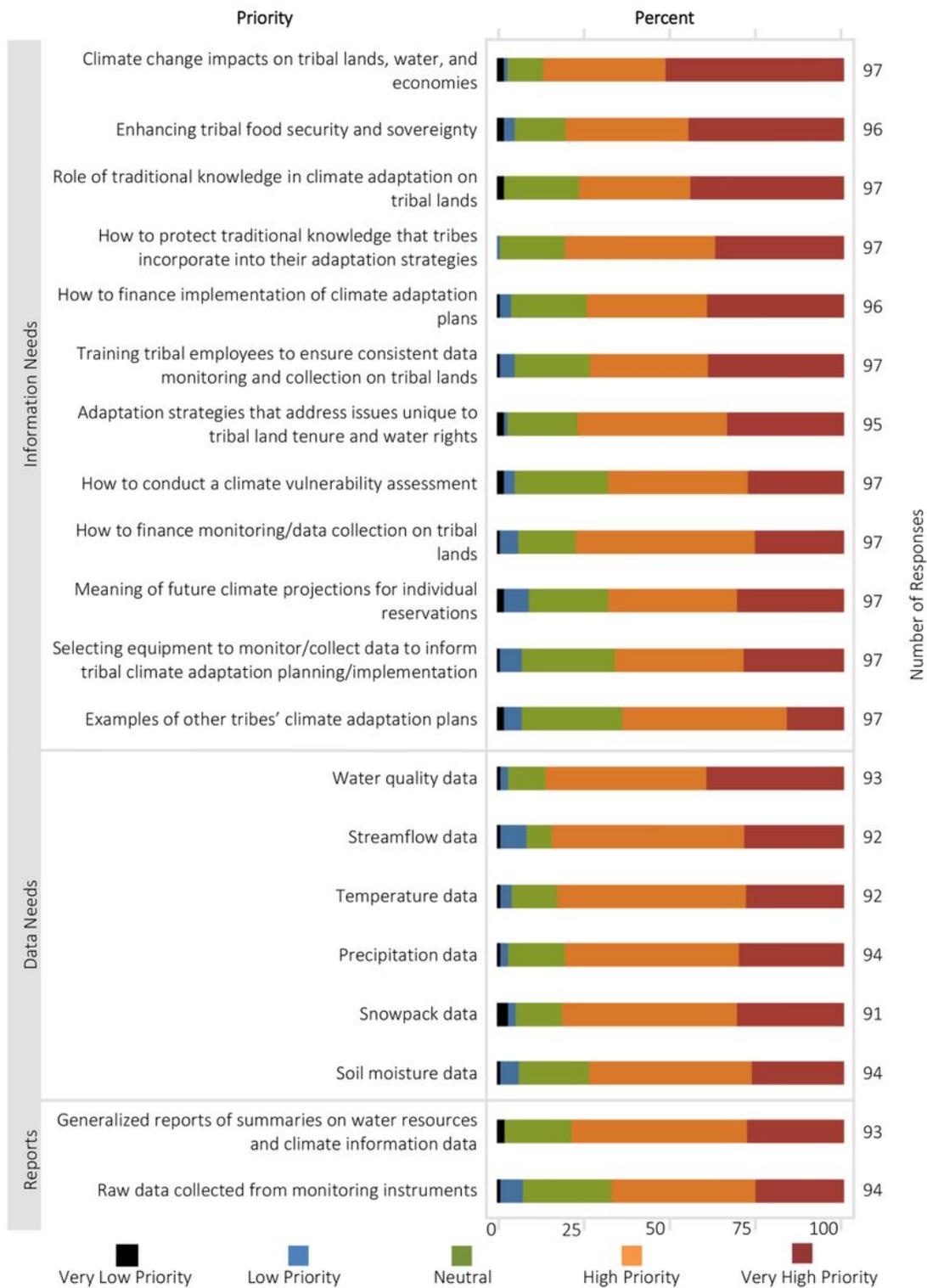
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## Figures



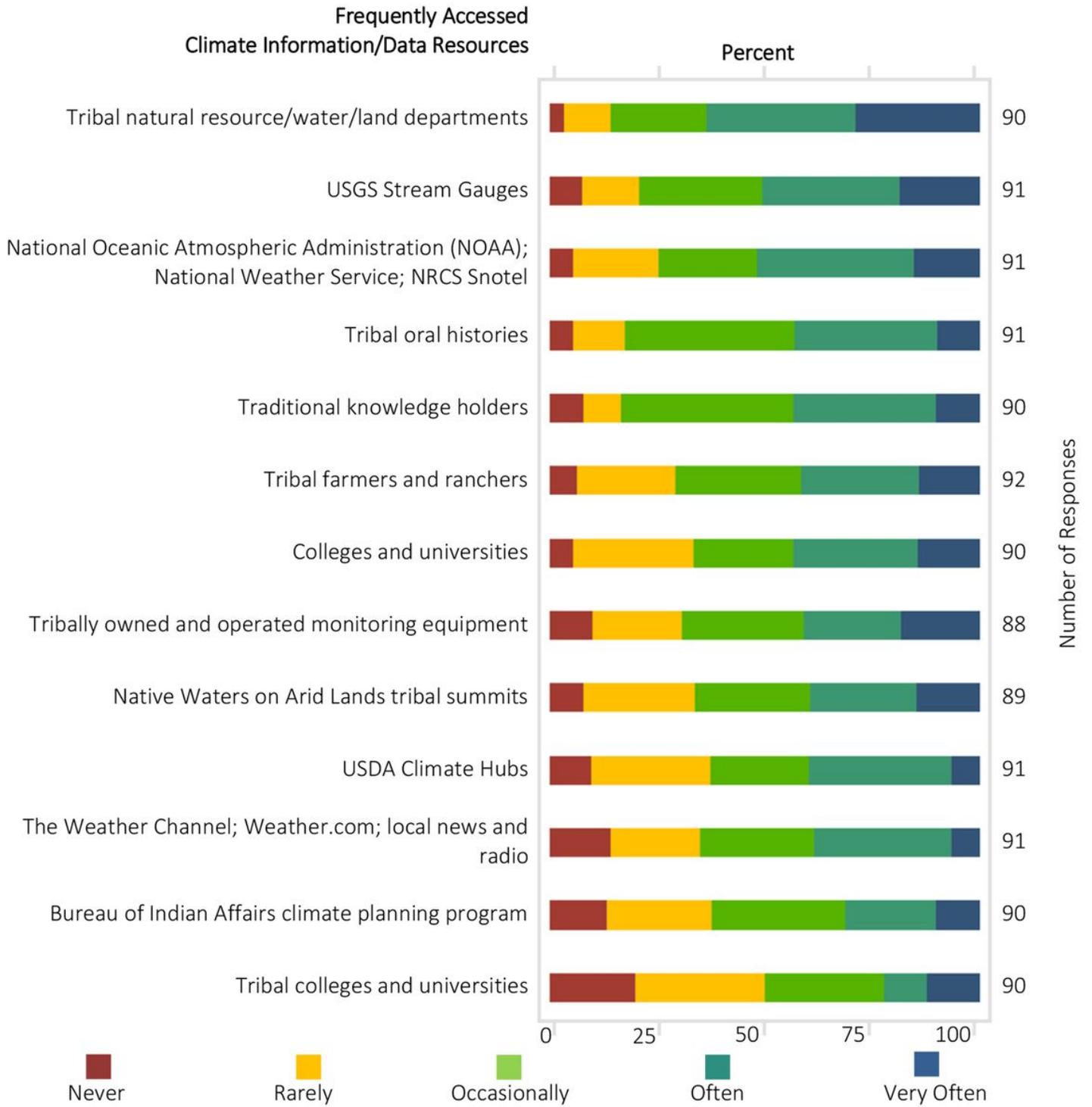
**Figure 1**

Approximate location of reservation lands of the 49 federally recognized tribes [Indigenous communities] within the study region.



**Figure 2**

Climate information and data ranked priorities.



**Figure 3**

Frequently accessed climate information and data sources.