Climate Change on Arid Lands – A Vulnerability Assessment of Tribal Nations in the American West

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Abstract

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Climate Change on Arid Lands - A Vulnerability Assessment of Tribal Nations in the American West

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Historic marginalization has left many tribal communities in the American West facing a unique set of water resource management challenges associated with climate change. Several approaches have emerged to measure and compare climate vulnerability using techniques from national-level climate vulnerability assessments, applied on a community-level scale to examine and map the relative vulnerability of sovereign tribal territories to climate-induced water challenges. These approaches draw on the literature on integrated vulnerability assessments and can be used to construct a composite index of agricultural vulnerability for 72 western tribal lands. Nineteen empirical indicators were deductively selected and grouped into exposure, sensitivity and adaptive capacity. Exposure indicators include numerous measures of climate variability such as drought and other extreme weather events, temperature and precipitation change. Sensitivity indicators featured three types; human, livelihood, and physical capital. Adaptive capacity examined social, economic and institutional dimensions.

Final results include four vulnerability maps offering a comprehensive picture of how differences in access to resources, class, and other socio-economic factors result in drastically different vulnerabilities across tribes that are located in a similar biophysical context. The discussion addresses both the utility and limitations of traditional climate vulnerability assessments for understanding tribal water challenges. These include the sovereign status of native lands, their connectivity to surrounding regions, nestedness within state and national governance systems, importance of cultural integrity, and evolving legal institutions surrounding water rights. The thesis concludes with a call for a more dynamic approach to understanding the inherent adaptive capacity and resilience of tribal populations, and paths forward for improving water resource management on sovereign tribal territories.

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Chapter 1: Introduction

Climate change has grave implications for water stressed communities in the Southwestern United States (US). Tribal nations[1] in this semi-arid region are on the front lines of confronting several adverse effects of climate change, including extended drought, soil erosion, extreme heat events, flooding, longer dry seasons, decreased snowpack, and less dependable auxiliary water flows from ground and surface water supplies. Negative impacts will be compounded in the coming decades as scientists predict that multi-decadal droughts will emerge in Southwest during the 21st Century unlike anything experienced during the last millennium (Macdonald, 2010; Cook, Ault, & Smerdon, 2015; Barnston, & Lyon, 2016). Drought imposes severe and massive costs to society ranging from economic damages, disruption of livelihoods, infrastructure expenditures and a range of environmental harm. However, any comprehensive accounting of drought should also consider the indirect costs of social malaise and deterioration. Indigenous communities are disproportionately harmed by climate change as they depend more on local natural resources than the US population as a whole. Furthermore, American Indian populations tend to have lower socioeconomic status, making it more challenging for them to prepare for natural hazards such as floods and droughts or to recover from them. By acknowledging the unique challenges that tribes are currently facing, the authors of the third official National Climate Assessment (NCA) asserted that tribal populations living on sovereign territories in the Southwestern US are some of the most vulnerable to the impacts of climate change (Reedster et al., 2013).

Planning for the adverse effects of climate change is essential for policy makers, resource managers, farmers, ranchers and citizens to mitigate its consequences. Vulnerability assessments are increasingly being used by several city, state and nationwide planners and emergency officers to mitigate and adapt to climate change (Wiréhn, Danielsson, & Neset., 2015). Such assessments are effective for identifying sectors, populations and geographic areas that merit particular concern and remedial action. They also are useful for informing decision makers in developing effective policy interventions. To provide a broad overview of tribal vulnerability and to

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1Tribal nations, Native American communities, First Nations, indigenous communities and tribes will be used interchangeably throughout this thesis and refers to American Indian Alaskan/Hawaiian Native communities who are ethnologically similar and also distinguished by historical and cultural differences as well as their legal-political status.

demonstrate the effectiveness of applying vulnerability assessments as a tool to address emerging challenges this thesis presents the first ever large-scale assessment of tribal lands.

The study area includes seventy-two federally recognized American Indian tribes, nations, pueblos, bands, colonies, and reservations located primarily in five Southwestern states Arizona (AZ), New Mexico (NM), Nevada (NV), Utah (UT) and Colorado (CO) (see Figure 1). Vulnerability is measured as a function of: exposure, sensitivity, and adaptive capacity (Adger, 2006). Composite indices were composed to represent these three thematic categories of vulnerability using nineteen sub-indicators. The main outputs of this empirical analysis are composite vulnerability index scores and maps that illustrate differences in biophysical and social characteristics across tribal lands. Results represent the relative agricultural vulnerability of seventy-two tribal nations located across five states.

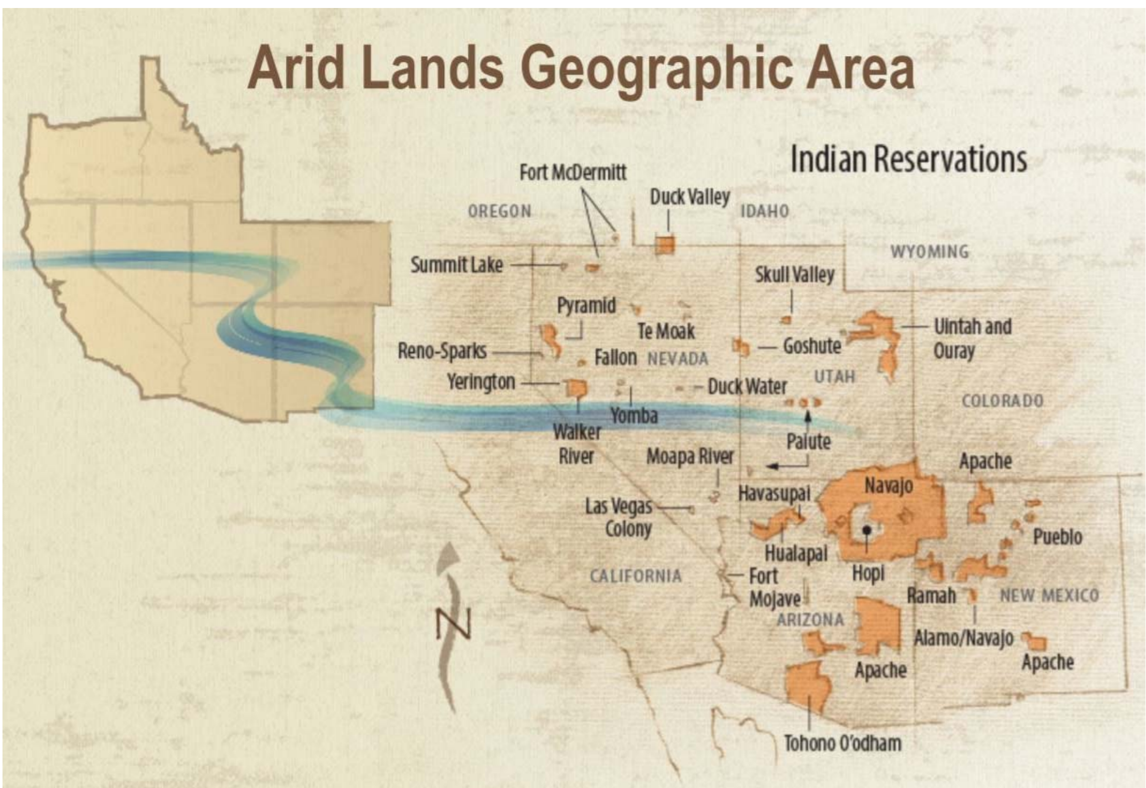


Figure 1. Study Area - Tribal lands concentrated in the American Southwest (Retrieved from Native Waters on Arid Lands, 2017).

1.1 Rationale

Problem Statement - Due to geographic exposure, agricultural sensitivity, cultural ties to the natural world and socioeconomic imbalances that occur on Native American reservations, American Indian agriculturalists have been characterized as some of the most vulnerable populations to climate change impacts (Reedster et al., 2013; Bennet et al., 2014). Agricultural vulnerability to drought and climate variability are emerging concerns on tribal lands in the American Southwest, yet to date, there are no published comparative climate change vulnerability studies focusing on tribal nations.

This thesis operationalizes a cutting-edge tool that can help tribal communities overcome modern challenges related to climate change. It also contributes to the growing body of basic and applied research that is needed to support tribal climate adaptation (Cozzetto et al., 2013; Guatam, Chief, & Smith, 2013; Reedster et al., 2013; Singletary et al. 2015). It builds on the recommendations called for by several studies as it translates climate change information and assessment techniques in ways that integrate indigenous perspectives and directly involve tribal communities to inform meaningful action (Maldonado, Bennet, & Chief, 2016).

Gathering data from secondary sources was deemed the most appropriate research design rather than implementing a case study mixed method approach. As Vasquez-Leon, West and Finan's (2003) study illustrated, comparative studies are beneficial for revealing the differential effects of climate on society. Looking beyond the political boundaries of specific tribal nations allows for an examination of how differences in access to resources, infrastructure and institutional capacity contribute to general vulnerabilities that are similar across tribal borders. The hazard potential of current and future droughts in the Southwest is of upmost importance. The general framework and methods operationalized in this thesis can be used to assess vulnerability on several scales and the composite indices applied are flexible and can be customized or swapped to more accurately represent emerging concerns in tribal lands.

Methods and results are transparent and the final products will be distributed to interested Native Waters on Arid Lands project team members, tribal citizens, natural resource managers, government agencies (such as the USDA), non-governmental organizations (NGOs) and other scientists. Relevant basic research regarding long term climate trends in the Southwest are described, filling a gap that is noted in Bennet et al.'s (2014) study:

> There is little available data to establish baseline climatic conditions on tribal lands…without scientific monitoring tribal decision makers lack the data needed to

> quantify and evaluate the current conditions and emerging trends in precipitation, stream flow, and soil moisture, and to plan and manage resources accordingly (pp. 303-304).

Given the lack of existing data on tribal lands, this study also contributes to geographical and scientific debates on the development and application of integrated assessment approaches in geographical areas for which more detailed data is not available (Antwi-Agyei et al., 2012). More detailed information is also provided in Appendix B "Westward Expansion, Climate Change, Drought and Adaptation Planning," which encompasses a longer discussion of: (i) the multi-faceted nature of drought the several definitions and indices for quantifying drought, (ii) publically available climate data sources that can be used for future research, and (iii) the current drought monitoring and mitigation efforts ongoing in the United States.

1.2 Research Questions, Objectives and Organization

This empirical research is intended to answer three primary research questions:

1. How vulnerable are tribal nations in the American Southwest to drought and climate variability?
2. What forms of exposures/sensitivities are faced by tribal nations and what are their adaptive capacities?
3. How can quantitative indicators help identify tribal nations and climate regions where vulnerability is high enough to merit special concern?

In order to address the aforementioned research questions this thesis will achieve five specific research objectives. The objectives of this research are to:

1. Offer an organization of representative literature that enables the reader to better understand the roots of vulnerability assessment methods.
2. Identify and the most appropriate conceptual framework for assessing vulnerability.
3. Operationalize a methodology that combines determinants of drought vulnerability using existing climate data as well as proxy indicators of exposure, sensitivity and adaptive capacity so that accurate cross comparisons of 72 tribal nations can occur.
4. Display final results in the form of vulnerability maps and spider diagrams.
5. Provide insights into the causes of differences in vulnerability status as determined by this assessment.

The remainder of this document assumes the following organization. Chapter 2 identifies the seminal papers in vulnerability research and an organization of representative literature to enable the reader to have a strong understanding and theoretical foundation of vulnerability assessment and methods. Chapter 3 provides an overview of the ecological setting as well as the historical background of America's indigenous people and current socioeconomic conditions. Chapter 4 details the step-by-step methodology applied in this thesis, including: i) the procedures used to select the geographic study area and tribal nations, ii) the hypothesized functional relationship between sub-indicators and vulnerability, iii) the data sources used, iv) the rationale for applying equal weights, and, v) the specific equations involved in normalizing data and aggregating composite indices so that consistent cross-tribal comparisons could be made. Chapter 5 provides the results of the comparative vulnerability assessment for 72 tribal nations, reported as exposure, sensitivity, adaptive capacity and vulnerability index scores and corresponding maps. Followed by the results of relevant statistical analysis that helped validate the results are reported. Concluding the section with, the limitations of this research and areas for future work. Chapter 6 outlines the practical applications of this model. It also presents meaningful examples of current tribal adaptation efforts underway on tribal lands. Finally, the ultimate conclusions are presented.

Chapter 2: A Brief History of America's Indigenous People

Researchers argue that to truly alleviate the effects of natural hazards on a vulnerable population the "root causes" must first be determined. Blaikie et al. (1994) defined root causes as:

> a set of well established, widespread processes… [that] reflect the distribution of power in society. People who are economically marginal or who live in 'marginal environments' tend also to be of marginal importance to those who hold economic and political power. (p. 24)

Identifying root causes is useful for explaining the fundamental drivers of differential vulnerability in human populations. Climate change coupled with a history of aggressive marginalization has led to a series of several serious challenges that tribal nations are confronting today. The root causes of vulnerability are traced over a long history of political-domination that has reproduced vulnerability within American Indian Alaska Natives (AIAN) populations over time. The colonial past of modern day America began 525 years ago when Christopher Columbus landed in the New World. Columbus referred to the aboriginal people he met as *Indios* or Indian when writing back to the King and Queen of Spain as he thought he had landed in India. For lack of a better term, this name stuck. Brown (1970) quoted Columbus' description of America's indigenous people:

> So tractable, so peaceable are these people…. I swear to your Majesties there is not in the world a better nation. They love their neighbors as themselves, and their discourse is ever sweet and gentle, and accompanied with a smile; and though it is true that they are naked, yet their manners are decorous and praiseworthy (p. 1).

When American Indians first met Columbus and his men they treated them with honor and presented them with gifts. This generosity was taken as a sign of weakness by European powers. Root causes of vulnerability on tribal lands in North America are attributed to a crippling power dynamic that was re-created as new interactions with European settlers occurred. Geisler (2014) contended that "aboriginal peoples, once tenants-in common …have been dispossessed of their homelands by doctrines of discovery, natural law, conquest, salvation and civilization" (p. 56). Meanwhile, Brown (1970) reported that at the time of early European settlement, North American Indians were unaware that the "intruders from the East were determined to destroy all that was Indian and America itself" (Brown, 1970 p. xiii).

The colonial occupation of North America by Spanish, English and American powers as justified by manifest destiny allowed Euro-Americans to realize their self-determined "right of discovery" at the expense of Native people (Hafen, 2013). Aggression against Indian communities relentlessly used violence against combatants and non-combatants to exterminate Indian nations judged to be acting contrary to American interests. Colwell-Chanthaphonh (2005) asserted that in pursuit of an insatiable greed for land and glory the "genocide" [of American Indians] became the "means to achieve dispossession - the implicit and explicit aims of territorial appropriation" (p.114). Colwell-Chanthaphonh invokes the meaning of genocide as Lemkin (1944) defined it. Lemkin was among the first to define genocide and conceived of such undertakings as the coordinated annihilation of a group of people through a composite of different acts of persecution or destruction. Lemkin's definition includes deadly means as well as non-lethal violence to subvert and destroy the security, autonomy and dignity of a people. Many argue that this definition applies to the coordinated efforts by colonial powers to subjugate Native American existence. Colonial powers perpetuated devastating exposure to disease, violence, extreme hunger, enslavement, displacement from customary food sources, failed alliances and more. All of these factors when considered in aggregate led to the collapse of Native America.

Scholars have concluded that disease was the greatest killer of Native Americans in the colonial period. Euro-American settlers brought several lethal epidemics to the New World including smallpox, measles, diphtheria, typhus and the bubonic plague. "Disease meant a declining population base from which to meet European aggression" (Mullin, 2016). Native American disease known as "virgin soil epidemics" in combination with other factors resulted in the estimated annihilation of between seventy-five and ninety-five percent of the American Indian population that once inhabited North America. During the Sixteenth Century Native population estimates range between 2-20 million. By 1900, American Indian populations were reduced to 530,000. This staggering loss of life and land gave heft to the claim that Native homelands were vacant and awaiting "improvement" by new Euro-American settlers (Geisler, 2014).

Throughout the 18th and early 19th Centuries, American Indians fell victim to the subjugation brought on by warfare, ethnic cleansing, racist policies, exploitation, fraud, dictated displacement and largely uncompensated land enclosures. During the exploratory journey of Lewis and Clark to the Pacific Coast the US government continued to exterminate American Indians perpetuating an "era of violence, greed, audacity, sentimentality, undirected exuberance and an almost reverential attitude toward the ideal of personal freedom for those who already had it" (Brown 1970, xi). One researcher Olster, (2015) noted:

> Faced with the very real possibility that their people would eventually be destroyed utterly, leaders of Indian resistance eventually agreed to US treaties requiring land cessions. The threat of genocide in this very strong sense of the term played a crucial role in allowing the United States to achieve its primary goal of taking Indian lands (p. 11).

Colonization resulted in a staggering loss of land and massive decline of Native populations which effectively extinguished all but the remnants of the aboriginal way of life formed over the millennia. The unjust theft of land upon which the United States is built indisputable as a recent book published historian Saunt (2015) accounts that between 1776 and 1887, the United States seized over 1.5 billion acres from America's indigenous people by treaty and executive order. Colwell-Chanthaphonh, (2005) asserts that the colonial occupation of North America constituted the "greatest known land thefts in human history" (p. 114). Pointing out that to this day in America there is a "ritual telling" of a convoluted narrative which justifies and minimizes the mistreatment of Americans Indians. Common channels of history tend to reinforce beliefs that "Americans are good and those who impede them are evil. [This irony] could explain why so many Americans swim in affluence while Indians suffer on reservations" (Colwell-Chanthaphonh, 2005, p. 117). The miss-accounting of indigenous people being without civilization was debunked by Mann's (2005) book 1491. Mann (2005) gives a detailed accounting of the ongoing archeological scholarship concluding that many of these civilizations were highly advanced. In many cases more advanced than that of Europeans.

The troubling history between tribal nations and the US government "sets the stage for systemic impoverishment and injustice experienced by indigenous peoples across the country" (Maldonado et al. 2016, p. 2). This injustice is now evidenced in the form of decreased adaptive capacity to climate change impacts because any social-ecological system's (SES) ability to absorb and adapt to rapidly changing conditions is directly related to the resources that they have at their disposal. The next section provides an overview of the current federal and socioeconomic status of tribal nations.

2.1 Overview of Current Socioeconomic Conditions

Today, there are 567 federally recognized tribes located across 34 States (BIA, 2017). Tribal lands include approximately 56 million acres (3% of total US lands) within the 48 contiguous states, and an additional 44 million. acres are held by Alaska's Native corporations (Bennet et al., 2014). Today, American Indian Alaska Natives (AIAN) in the US often live in rural communities with smaller populations and frequently experience greater political marginalization and more socio-economic stress than their non-indigenous counterparts (Cozetto et al., 2013, United Nations, 2009). The total AIAN population is roughly 5.3 million, only 2% of the total US population (US Census, 2015), which limits their electoral influence. Furthermore, "American Indians are among the poorest populations in the US" (Singletary et al., 2015 p. 2). Generally, the poorest segments of society are the most vulnerable to climate change because they lack financial, human and institutional capital. Native Americans are twice as likely to live in poverty. In 2010, the poverty rate reported within these reservations was 28.4% compared with the 14.3% of the AIAN population as a whole (Singletary et al., 2015). Moreover, the socioeconomic status and living conditions are often worse on reservations. Several infrastructural cushions that many US populations take for granted, such as piped-in water, easily accessible food sources, and electric power are lacking on reservations. More than 12% of AIAN reservation homes are without access to safe water, as compared to less than 1% of the US population (McSwain, 2012). According to the 2010 US Census, 1.14 million American Indians (roughly 22%) of the total AIAN population, were living on reservations (Cozzetto et al., 2013).

To escape dire social and economic conditions, some of their most educated and technically trained members leave reservations and assimilate into the general population. This migration of human capital contributes to the overall vulnerability on tribal lands (Rudolph & Adams, 2015). Despite the fact that a large majority (roughly 78%) of AIAN live outside of tribal lands (cities and towns), chronic poverty disproportionately effects this minority population all across the country. About one in four single-race AIAN (29.2 %) lived in poverty in 2013, the highest rate of any racial group (US Census, 2014). American Indians continue to be overrepresented in lower paying jobs and face high unemployment (Swanson, 1996). The average AIAN unemployment rate is nearly double the US average (Austin, 2013). Various studies have tried to explain the pronounced inequities that AIAN populations face. However, even after controlling for various demographic factors such as educational attainment, these differences cannot explain the size of the economic gap (Austin, 2013). A paradoxical finding reported in Swanson's (1996) was that "although the greatest increase in education among rural minority groups was for Native Americans, they also showed the greatest decline in median household income" (p. 2). These struggles can be informed by comprehending the painful legacy of discrimination that Native American's have endured. Tribes have not been appropriately involved in the decisions or setting of priorities that affect their communities. The next section provides important context into a few legal treaties between tribal nations and the federal government which influence the evolving legal status of federal tribes.

2.1.1 The federal trust responsibility. The *Cherokee Nation v. Georgia* (1831) court ruling precipitated the creation of Indian reservations. This court case reinforced US government power to "control tribal economies by holding their lands and assets in trust and treating sovereign Indian nations as government wards" (Singletary et al., 2015 p. 2). In creating reservations, tribes ceded large amounts of land in exchange for a permanent livable homeland with rights to fish, hunt and gather. Under the federal trust responsibility, derived from multiple treaties and defined as "a moral obligation of the highest responsibility and trust" in *Seminole Nation v. United States* (1942), the U.S. government is ethically obligated to "protect tribal self-governance, tribal lands, assets, resources and treaty rights" (NCAI 2015, p. 21). However, treaty rights are not always protected because tribal territory and resources, including water, are held *in trust* by the federal government on behalf of the tribe.

2.1.2 Tribal water rights. Critical to maintaining sovereignty is having access to clean water. The Prior Appropriation Doctrine –famously understood as "first in time, first in right" largely determines the legal system for assigning water rights in the West. In most western states, water is allocated to users based on the order in which water rights were acquired (Stern, 2015). - This allocation system assigns priority of use to the first person or entity to put the water to "beneficial use." Granting upstream senior appropriators the right to the full amount from available supplies before a junior appropriator (one who came later). These rights are largely granted by state governments. Increasing water demand by upstream jurisdictions and states creates constant water conflict with downstream users. In recent years, water demand has far exceeded water supply. The impact of changing water availability seriously threatens water-dependent tribal communities on arid and semiarid lands.

The water law applying to tribal governments is distinct from the water law that dominates the American West. According to US federal law, tribal nations have priority water rights superseding those rights of the States due to the Federal status of treaty rights and trust responsibilities which the Supreme Court has defined as "a moral obligation of the highest responsibility and trust" (NCAI, 2015). *Winters v. United States* (1908), is a key decision that acknowledged the inherent rights all federally recognized tribes have to "reserved" water rights that provide sufficient access to fulfill the purpose of the reservation (Stern, 2015). The intention of government policy under The Winters Doctrine was "to change the Indians from nomadic and uncivilized people to pastoral and civilized people" (Henderson 2011, p. 129). By having a tribe cede large tracts of land for a smaller reservation they would have a reserved water right and "have command" of water for their beneficial use. Neglecting marginal lands without providing irrigation is to leave the tracts practically valueless for the intended purpose of the policy. The "reserved" water rights implied in Winters were mainly for irrigation and farming, otherwise known as *new uses.* These came in addition to the existing water rights that were granted to the tribes by *United States v. Winans* (1905). This decision recognized all tribes' "aboriginal rights" to *existing uses* of water and land including fishing and hunting rights both in- and outside of reservation boundaries. It allowed tribes to maintain elements of their long-established traditional subsistence lifestyles. *Winans* and *Winters* distinguished water rights as "reserved" or "aboriginal*"* and together these doctrines carry immense moral and legal force (Henderson, 2011).

Though many tribal governments are inherently senior water resource users with legal precedent for adequate water rights, several tribes have gone through a separate adjudication process quantifying an amount they are eligible to receive under a settlement. Since 1978, 33 innovative settlements have been approved benefitting 36 distinct tribes (Stern, 2015). However, even tribes that have succeeded with legal settlements and received water rights on paper do not receive the "wet water" that is promised in their adjudicated amount. For example, in 2015 four reservations discussed in this paper (the Cocopah, Yuma, Colorado River and Fort Mohave) received 20% or 161,000 acre feet (afa) less "wet water" than the rights[2] assured on paper (MacDonnell, 2016). An acre foot is a quantity of water needed to cover: one acre (a) one-foot-deep (f) annually (a). Going forward with increased evapotranspiration, it is likely that existing water rights settlements will have to be re-negotiated to ensure there is enough water to make up for this discrepancy.

2 Another reservation also included in the settlement, and the shortage is the Chemeheuvi of California (not discussed in this paper). Their legal entitlement was determined by Arizona v. California 1963.

Chapter 3: Concepts & Analytical Framework

3.1 Overview of Vulnerability Assessment

Due to the relative sluggishness of climate change policy responses there is a critical need for society to adapt with new and improved approaches for understanding, measuring and coping with long-term environmental changes. On pace with a mounting acknowledgement and apparent necessity for innovative ways of approaching sustainability, vulnerability research has grown in recognition over the past thirty years across several academic disciplines. Patt, Klein & Vega-Leinert, (2005) noted that "there are currently hundreds of vulnerability studies underway in countries and regions around the globe, delivering a variety of information packages" (p. 412). Policy makers are eagerly consuming vulnerability assessments to develop plans informed by science that enhance adaptation efforts. The vulnerability concept is used extensively in various fields, including engineering, psychology, economics, ecology, public health, poverty and development, livelihood and food security, sustainability, land use change, and foremost among them global climate change (Patt et al., 2005; Adger, 2006; Zharafshani et al., 2016).

Patt, et al., (2005) noted that the growing popularity of vulnerability research in the global change community is due to the fact that: "on its face, the use of vulnerability assessment to inform policy-making seems like the perfect integration of knowledge and action and a necessary ingredient in fostering a transition to a more sustainable future" (p. 412). However, an unintended consequence of its broad application is resulting confusion surrounding the informality of assessment methods and associated terminology. To avoid ambiguity, the following chapter provides an overview of representative literature for vulnerability assessment. It begins with the basic elements required for valid vulnerability research across disciplines. Followed by the key definitions for transdisciplinary climate change research which are applied in this thesis. Subsequently the roots of vulnerability assessment in three diverging research camps are described. As well as a summary of, two opposing worldviews and two contrasting approaches for collecting data. Finally, the chapter concludes with common challenges to be aware of when beginning the process of conducting a vulnerability assessment.

3.1.1 Four basic criteria for vulnerability assessments. Certain concepts in vulnerability research are contradictory to one another. Alcamo et al., (2008) noted a clear drawback in that assessments are: "based on a wide range of non-standardized methods which produce heterogeneous results" (p.137). Füssel (2007) identified four basic pre-requisites for all vulnerability research: 1) the system analysis, 2) the attribute of concern, 3) the hazard, and 4) the temporal reference. By explicitly defining these four elements it is easier to align the scope of the vulnerability assessment and provide consistency between knowledge domains.

1) The System of Analysis - refers to the unit/scale of analysis that is being analyzed. The term "system" can refer to a variety of geographic scales: household, community, landscape, region, nation, and global. It can also refer to spatially disaggregated systems such as economic sectors, cultural groups, governments, and biomes. The generally applicable Intergovernmental Panel for Climate Change (IPCC) vulnerability framework can be used to carry out assessments at global, continental, sub-national, regional or local scales. Different tools and indicators will be applied depending on the scale and research tradition. Some research traditions can be narrow in scope, while other research focuses on complex human-coupled systems at a variety of scales which can either be international (Brooks, Adger, & Kelly, 2005), national (O'Brien et al. 2004), regional (Carter, 2010; Ravintranath et al., 2011), watershed (Adger, 1999) or household (Esteves, 2016). The other commonly applied scale in climate change vulnerability studies is the local scale, which identifies the vulnerability of systems such as coastline, community, ecosystem niche or agricultural region (examples include: Adger,1999; Ford, Smit, & Wandel, 2006; Klein & Nicholls, 1999). The system of analysis for this thesis is tribal level, which is most easily compared to a local community-level approach. Community level analysis refers to a specific municipal/provincial/political district boundary. A tribal community, in this context, refers to seventy-two tribal nations, bands, pueblos, colonies and communities on distinct reservation lands.

2) The Attribute of Concern - Füssel (2007) defines the attribute of concern as: "the valued attribute(s) of the vulnerable system that is/are threatened by its exposure to the hazard" (p. 157). These attributes of concern can be organized into four categories which are either in socioeconomic or biophysical knowledge domains, and classified into two spheres, internal or external. Vulnerability to climate variability and change is a regional and local phenomenon that must be taken into account by federal and tribal governments and an understanding of the internal and external forces that modify or contribute to vulnerability. For example, drought has both internal and external dimensions that can be used to assess vulnerability among tribal communities. The factors described in Table 1 are examples of factors considered in this assessment, demonstrating complexity of considering dynamic forces operating across spheres and knowledge domains. Other leading researchers in the field have found that even after extensive research, confusion still exists about assessing the multi-dimensionality of vulnerability

in a comprehensive form. Even the most cutting-edge assessments are unable to capture the linkages between local, national and global processes (Leichenko & O'Brien, 2002).

Table 1

Classification scheme for vulnerability factors

	Knowledge Domain	
Sphere	Socioeconomic	Biophysical
Internal	Poverty	Local environmental conditions
	Social Networks	Land cover
External	National Policies	Drought
	Federal Aid	Extreme Weather Events

Examples of the four categories of vulnerability factors according to the dimension's sphere and knowledge domain. Adapted from (Füssel, 2007 p. 158).

The main internal attributes of concern for tribal systems are socioeconomic factors, including prominence of primary sector economic activity and the internal capacity of tribal institutions to adapt. Concerns that are internal and biophysical include local geography and environmental conditions. Within the external sphere concerns that are socioeconomic include: national policy; power relations with regional stakeholders; and external support. The external socioeconomic attributes of concern considered in this research are the larger political dynamics that determine Indian water rights. Finally, external biophysical concerns are brought about by forces of nature such as: floods; droughts; temperature rise; etc.

Füssel (2007) highlights the motivation for considering internal biophysical factors because a "community can be threatened by hazardous business activities or by unsustainable land management practices within this community" (p. 157). It was beyond the scope of this study to assess internal biophysical attributes of concern in detail. However, a deeper exploration into internal biophysical areas of concern on tribal lands is an area for future research (see Section 5.4)

3) The Hazard - Vulnerability is always linked to a hazard or specific set of hazards. Most often the hazard represents external attributes of concern. The United Nations International Strategy for Disaster Reduction (UN/ISDR) (2004) defines hazard as "a potentially damaging physical event, phenomenon or human activity that may cause the loss of life, property damage,

social and economic disruption or environmental degradation" (p.17). Hazards often encompass vulnerability to flooding, variability in climate parameters, sea level rise, storm surges, long term climate conditions, drought, and frequency of extreme events or from the social side, vulnerability to poverty. The hazards explicitly accounted for in this thesis are external biophysical areas of concern, including drought and climatic variability.

4) Temporal reference – Defining a specific temporal reference is important for vulnerability assessments. The temporal reference can either be current, future or dynamic. Future assessments estimate vulnerability based on climate scenarios in relation to a specific tipping point within a particular time frame. This thesis uses a snapshot of current vulnerability, based on the most up to date data available. Exposure reflects current vulnerability as a cumulative phenomenon reflected by climate reports of current conditions, variability from 20th Century historical averages and a running total of extreme weather events. This assessment also includes two dynamic variables representing economic vitality on tribal lands and there are no future temporal references included.

3.2 Key Definitions

3.2.1 Vulnerability. The term "vulnerability," has no universally accepted definition. Liverman (1990) as cited by Füssel (2007) noted that vulnerability "has been equated to concepts such as resilience, marginality, susceptibility, adaptability, fragility and risk." Füssel (2007) goes on to add "exposure, sensitivity, coping capacity, criticality, and robustness" to the list (p.155). This thesis assumes the heavily relied upon conceptualization of climate change vulnerability as was introduced by the IPCC'S Third Assessment Report (TAR) where vulnerability is defined as:

> the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity' (McCarthy et al., 2001: 995).

The most recent Fifth Assessment report of the IPCC defines it as "the propensity or predisposition to be adversely affected" (IPCC, 2014). In this conception, a system is most vulnerable to climate change if it has a high sensitivity and exposure to the effects of climate change impacts and if it has an inadequate capacity to adapt. The susceptible system discussed in this thesis is agriculture on tribal lands and the IPCC framework is applied. Wiréhn, Opach and Neset's (2017) clarification of the assessment process is helpful, stating that "assessing agricultural vulnerability to climate change is a process of studying the propensity of a system to be adversely affected while also taking into account dimensions of exposure, sensitivity and adaptive capacity” (p.1). While there is no single conceptual framework that fits all assessment contexts, these three key dimensions are often considered as being the main determinants of vulnerability in climate change research (IPCC, 2007).

3.2.2 Exposure. Exposure refers to ‘the amount of external stress or change a community is likely to be affected by’ (ABARE – BRS, 2010, p.vi). In a climate context, it is defined as “the nature and degree to which a system is exposed to significant climatic variations” (McCarthy et al., 2001) or the degree of climate stress upon a particular unit of analysis (Smit et al., 2000). Exposure is most often used to measure the biophysical forces of nature or “disturbances” that impact a system. The Resilience Alliance (2010) elaborated that disturbances can be divided into “pulse” or “press” disturbances. Pulse disturbances are intermittent and potentially catastrophic. Examples of pulse disturbances likely to impact tribal nations are extreme precipitation events, increased intensity and frequency of floods and flash floods. It is understood that human beings have little control over pulse disturbances and as they occur “the predictability and manageability of singular phenomena is low” (McCarthy et al., 2001, p 951). Press disturbances are ongoing threats to the system that gradually degrade the resilience of that system due to the cumulative impact. The Exposure Index developed for this thesis identifies which climate regions are likely to be impacted by a change in climate by measuring the extent communities have experienced ongoing press disturbances (droughts, and variability in temperature and precipitation) in the past, and the frequency of pulse disturbances (extreme climate events) on tribal nations. These past conditions represent how severely deteriorated the tribal lands are, and gives some insight into the likelihood that disturbances will continue to pose a threat to specific tribal lands.

3.2.3 Sensitivity. Sensitivity is “a measure of how dependent a community is upon the resource that is changing” (ABARE – BRS, 2010, p.vi). It is defined by the IPCC as “the degree to which a system is affected either positively or negatively by climate-related stimuli. “The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea level rise) (McCarthy et al., 2001). The presupposition of this thesis assumes that some tribal nations that are highly sensitive due to their heavy dependence on agriculture. The Sensitivity Index was developed to explore which tribal nations are the most dependent on agriculture for their livelihoods in an attempt to identify which communities are most likely to be impacted.

3.2.4 Adaptive capacity. This is defined as 'the ability of a system to adjust to climate change (including climate variability and extreme) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences' (McCarthy et al. 2001, p. 21). The adaptive capacity usually refers to the longer term capacity (Smit & Wandel, 2006). It is dependent on socioeconomic conditions and human decisions, and has the capability to provide immediate benefits through a reduction in sensitivity to potential climatic risks on varying temporal scales (Ford et al., 2010). The IPCC asserts that adaptive capacity is facilitated through adjustment in behavior, resources, and technology (IPCC, 2007). The Adaptive Capacity Index reflected in this thesis highlights several institutional, economic and social factors which effect a tribal nation's ability to cope with or recover from the effects of hazardous climate conditions.

3.3 The Roots of Vulnerability Assessment

Vulnerability assessments are mainly a product of three streams of research that are discussed in the following section. Careful examination of the roots and application of each of these views is important for choosing the most appropriate knowledge domain that fits the needs of the researcher conducting a vulnerability assessment. Adger (2004) recognized that definitions of climate change vulnerability can be grouped into two categories, either "(i) in terms of the amount of (potential) damage caused to a system by a particular climate related event or hazard or (ii) as a state that exists within a system prior to the occurrence of a hazard event" (p.29). The former research stream analyzes the physical manifestation of vulnerability and most often appears in risk/hazard literature utilizing outcome/end-point approaches. The latter category is most often applied in political economy/ecology and transdisciplinary integrated assessment literature and includes the contextual/starting-point research stream. Each of the knowledge domains mentioned below are intended to provide a background into the theoretical underpinnings of vulnerability research. This thesis does not place a value judgment on the 'best' conceptualization of the term, however, the nature, purpose, methods and policy implications of vulnerability assessments will vary based on the epistemological underpinnings found the approaches mentioned below.

3.3.1 Risk/hazard approach (RHA). Geography and natural-hazards were the first scientific disciplines to focus on 'vulnerability' as a topic of study (Zarafshani et al., 2016). Today, the RHA is used in several disciplines including engineering, economics, epidemiology and technical literature on disasters. The focus of this research is to understand the ultimate impacts of climate change and assess the biophysical vulnerability on physical systems and built infrastructure. It is useful for understanding the risks associated with 'various biological, physical, meteorological and geotectonic processes. This view understands vulnerability as status of valued elements or "exposure units" in relation to hazards of a particular type and magnitude. Füssel (2007) highlighted some important terminology associated with this approach, stating that "the vulnerability relationship is understood as a 'hazard-loss relationship' in natural hazard research, a 'dose-response or exposure relationship' in epidemiology and a 'damage function' in macroeconomics" (p. 161). Results disproportionately heighten the most precarious physical environments that are likely to undergo dramatic or expensive physical changes in the event of a rare hazard event.

A major limitation of the RHA is that it treats people as assets and assumes that the vulnerability of people is simply a matter of "being in the wrong place at the wrong time" (Liverman 1990 as cited by Füssel, 2007 p. 160). This approach explicitly focuses on the quantitative biophysical impacts rather than the human role in mediating the outcomes of hazard events. The limitations inherent in the RHA were noted by Blaikie's (1994) Pressure and Release Model which argued that biophysical vulnerability as well as the social characteristics of a group must be considered together to adequately determine risk. The RHA formulation has often been slated as hegemonic and insufficient for dealing with the complexity associated with the multiple mutually reinforcing shocks of climate change. This approach does not analyze the underlying social dynamics that are perpetuating vulnerability before the hazard occurs. To define vulnerability to hazards as only caused by "natural triggers" is to ignore the underlying political and economic factors that make rebuilding lives that are shattered by hazards impossible. The RHA disregards the ability for populations to cope with hazards once they manifest, and neglects vulnerable populations that have been found to experience a spectrum of vulnerabilities throughout their lives, both before and after a hazard occurs. Due to this narrow focus Füssel and Klein (2006) would argue that this type of study would fall into the "first generational" category of vulnerability studies which rely mainly on quantitative data and fall under the Act of God paradigm in which "nature' and 'society" are two distinct entities. It targets physical conditions and rarely connects to the experiences of the affected community.

3.3.2 Political economy/ecology approach (PEA). This approach explicitly analyzes the s*ocial vulnerability* of a system and is rooted in "poverty and development literature" (Füssel, 2007 p. 160). Traditionally determinants of social vulnerability include "poverty, inequality, marginalization, access to insurance, and housing quality" (Adger, 2004 p. 30). It is extremely helpful to trace the linguistic roots of vulnerability when understanding its relevance in this type of discussion surrounding climate variability and change. Kelly and Adger (2000) noted that the word "vulnerability" is rooted in the Latin *vulnus* meaning "a wound." The Latin term *vulnerabilis* was used by the Romans to describe the state of a wounded soldier lying on a battlefield, already injured, and therefore susceptible to future attacks. Vulnerability (the existing wound) is defined as a current state of being, and not by the future stress (any further attack). This framework addresses the cumulative effects of prior damage, arguing that underlying inequities must be addressed in order to reduce the risk for those most exposed members of society.

Vulnerability assessments in the PEA reflect the state of a system that is effected by systemic political, and socio-economic factors that affect a community's capacity to adapt to rapidly changing climate conditions. The main purpose this type of research is to confront hard-hitting questions by asking who is most vulnerable and why? (Adger & Kelly 1999). It asserts that poverty, inequality, isolation and marginalization can all undermine the entitlements of individuals and groups which enhances vulnerability. In this formulation, Adger and Kelly (1999) argue that "the vulnerability or security of any group is determined by the availability of resources and, crucially, by the entitlement of individuals and groups to call on these resources" (p. 253). This research builds on the work of Sen (1981), who argues that famines result not from insufficient food stocks, but from the lack of coordination for food access, through legal and customary means, in periods of political or climatic stress. Entitlements are a principal determinant of a society's capacity to adapt, and are extremely relevant factors in determining the climate change vulnerability of Native American agricultural producers. According to a recent survey *availability of water for agricultural purposes* ranked as a top concern of tribal agricultural and natural resource managers (Singletary et al., 2015). Therefore, PEA is useful for describing systemic inequities that are hurting tribal nations. For example, Taylor (2014) noted that:

> In wet years as well as dry, many American Indians live in chronic drought like conditions, thanks to decades' worth of dams that hold water back or divert it from reservations which were usually sited on already marginal land.

A commonality between PEA and IAA is an understanding of vulnerability as a relative measure that does not exist as something that is observable or measureable, but rather, as a state or condition of being that is constantly evolving and typically moderated by existing inequities in resource distribution and access (Nguyen et al., 2016).

3.3.3 Integrated assessment approach (IAA). The final approach is the IAA which is rooted in human ecology and resilience literature. The IAA was derived in recognition that the interactions between biophysical and social determinates are almost inseparable when studying human systems. There is a growing consensus that these two approaches must considered in tandem to comprehensively assess the vulnerability of different social groups or sectors to climate change. This approach accounts for multiple stressors i.e. social, political, economic and historical factors, that significantly contribute to existing vulnerability but have been inadequately handled in climate change policy to date. This formulation analyzes the differential effects of climate change based on biophysical factors such as geography, in conjunction with several non-climatic social determinants, such as local institutions. When assessing these two diverging vulnerabilities inclusively, a complex web of interrelating factors creates a more dynamic and accurate representation of vulnerability phenomena.

A key strength of the IAA is its ability to incorporate "internal" factors of a vulnerability system with its exposure to "external" hazards (see Table 1). The IAA would be categorized within the second generation of vulnerability studies according to Füssel and Klein, (2006) because it includes non-climatic variables, such as socio-political and economic factors. Second-generational IAA understand that underlying climate vulnerability is often caused by unequal opportunity and distribution of resources. Second generation vulnerability studies more often focus on the local scale and try to achieve a win-win situation by enhancing local capacity in the face of unavoidable changes. They recognize that the vulnerability of the community is based on its ability to carry out adaptation measures, not merely on the hypothetical availability of adaptation measures alone. Therefore, it often relies on qualitative studies, such as interviews with stakeholders. This thesis is an example of a second generation vulnerability studying following the IAA. Relevant non-climatic variables, such as socio-economic and institutional factors, are considered for each unique tribe, as well as, biophysical data representing regional climate conditions. Opportunities and constraints are identified and the differential effects that drought and climate change have on tribal communities is communicated. Although social factors were included to develop macro-profiles for this thesis, future research using qualitative data would be beneficial for identifying how policies and initiatives originating at different scales interact to shape vulnerability.

3.4 Distinction Between Two Frameworks Interpreting Climate Change Vulnerability

Researchers have both highlighted the need for climate change vulnerability assessments and discussed particular ways of conducting them. O'Brien and her colleagues distinguished between two worldviews or frameworks for characterizing vulnerability to climate change. These frameworks can be distinguished as 'outcome vulnerability' vs. 'contextual vulnerability' (see O'Brien et al., 2007) and take on corresponding "end-point" vs. "starting point" assessment methods (Kelly & Adger, 2000). Ultimately, outcome and contextual approaches represent two different world views. The outcome/end-point approach produces technical scientific studies to identify how the climate will change under different scenarios, and the crucial focal point is climate change. Compared with context-based approaches where climate change is only part of the process that affects the society as a whole. The following section reviews these two contrasting approaches.

3.4.1 Outcome vulnerability/end-point assessment methods. The "outcome" lens can be used by researchers utilizing either the RHA, or IAA for vulnerability assessment. This lens focuses on broad scale geographic characteristics to answer the questions (a) "vulnerable to what?" (O'Brien et al., 2007 p. 84), "(b) what consequences might be expected, and (c) where and when might those impacts occur" (Eakin & Leurs, 2006 p. 369). A discussion framed around these questions will utilize "end-point" assessment methods to predict the nature and severity of biophysical vulnerabilities. The end-point approach measures vulnerability as a simple cause-and-effect relationship determined by the severity of the hazard, its frequency of occurrence, and the system's sensitivity to its impact.

Methods involve projecting future emission trends based on climate models such as General Circulation Models (GCMs) and Single-Column Models (SCMs) to simulate the possible climate change scenarios and associated biophysical impacts. Vulnerability is then determined as the end result of a sequence of analyses (Kelly & Adger 2000). Finally, climate change adaptation measures are suggested to limit the anticipated negative outcomes based on a suite of possible scenarios. The outcome/end-point vulnerability assessments are helpful for engineers and social leaders to understand the degree of climate change impacts that are likely to occur. The outcome research lens results in mitigation policy at the national and international level and stresses policy recommendations that involve reducing the potential impact of climate change by controlling the emission of greenhouse gases mainly through technological and engineering interventions. A couple of examples representing the outcome/endpoint approach are: i) the international goal of mitigating global warming to 1.5° above 20th Century averages based on the Conference of Parties (COP) 21 Paris Agreements, and ii) the downscaled climate models created by the New York City (NYC) #ONENYC climate plan. To reduce potential loss, NASA scientists projected a range of climate scenarios one-hundred years into the future. Climate scenarios were downscaled to a city block level and made publically available to engineers. This will enable engineers to have a better understanding of future climate conditions that their buildings will endure and help them to voluntarily incorporate resilient designs into their infrastructure plans to mitigate future loss.

Large scale climate scenarios can also be coupled with dynamic crop growth models to predict outcomes such as: "percent change in land suitability, crop yields, and/or farmer incomes" (Eakin & Leurs, p. 369). Additional examples of indicators from the outcome/end-point framework include: monetary cost, human mortality, production costs, ecosystem damage, crop yield, farm income, human mortality, [or] food and water availability (Adger et al., 2004; Füssel & Klein, 2006). These index examples can both be estimated into the future to project potential future loss, but they can also be used to enhance the validity of vulnerability assessments after the hazard event once the potential loss is realized. For example, the state of Colorado developed a Drought Mitigation and Response Plan in 2010 that estimated drought vulnerability for all sixty-four counties in CO. Between 2011-2013 CO experienced a devastating drought. In 2013 the state published a Drought Vulnerability Assessment which used reports on damages to property and infrastructure to validate the results of the initial study conducted in 2010 (Colorado Water Conservation Board, 2013).

Criticisms of the outcome/end-point world view are two-fold. First, the inherent technical uncertainties associated with simulated climate models. Second, the requirement for highly advanced technical science to downscale several GCMs and SCMs to predict future effects. Also, the adaptation suggestions resulting from this worldview are largely GHG reductions or technical solutions. While, there is no doubt that engineering interventions such as resilient building design, dykes, seawalls, and drought-resistant seeds will continue to be important innovations that lessen the degree of harm felt by society, they are insufficient responses to combat climate change. Finally, one must acknowledge that assessments and warnings produced by this worldview since the early 1990's have not adequately motivated a paradigm shift among leaders to persevere and take common action towards achieving a radical social transformation that ensures the sustainability of all beings.

3.4.2 Contextual vulnerability/starting-point assessment methods. The alternative lens for vulnerability assessments is 'contextual' which utilizes 'starting-point' assessment methods. The vulnerability research framework in this lens first asks the question: "*whether* climate change is a relevant problem for a particular region, community, sector or social group" (O'Brien et al., 2007, p.78). If it is a problem, then, contextual vulnerability studies go a step further to ask "*why* some regions and social groups are more vulnerable than others" (Ibid. p. 79). The contextual framework takes a holistic approach in understanding the multi-faceted complexities of climate change vulnerability. The policy question in starting-point assessments is: "How can the vulnerability of societies to climatic hazards be reduced?" (Füssel, 2007, p.163). Starting-point assessment begin the process by examining several social factors that constrain or facilitate adaptation strategies at several scales. This 'camp' of research stresses that it is crucial to and to focus on the social, economic, and political process that will mitigate the impacts of climate change. This thesis frames vulnerability through the lens of context-based approach. The contextual worldview was identified as the best approach because as Reedster et al.'s (2013) chapter in the National Climatic Assessment (NCA) noted:

> Vulnerability of Southwestern tribes is higher than that for most groups because it is closely linked to endangered cultural practices, history, water rights, and socio-economic and political marginalization, characteristics that most Indigenous people share (high confidence) (p. 385).

In order to effectively communicate the severity of vulnerability on tribal lands it is crucial that the social vulnerability is represented. Context-based assessments centralize social vulnerability and incorporate several other factors aside from climate change, such as physical, economic and social capital, entitlements, institutional capacity and socio-economic constraints to local responses. Another strength of this framework is that it takes a much wider boundary and rejects that vulnerability is caused by a rare stochastic climatic hazard events with discrete impacts that can be quantified by distant scientists. Conversely, scientists conducting this research argue that vulnerability is not predominantly a climate based condition, but rather a human-environment coupled interaction driven by a set of socio-economic and political variables at several scales.

Starting-point assessments take the stance that the vulnerability assessment should not be an end in itself, but rather the first step for identifying opportunities and prioritizing adaptation strategies through an iterative process. In this worldview, vulnerability can be reduced by altering contextual factors that influence the decision making environment where climate change occur. Contextual vulnerability attempts to identify and address what factors facilitate or constrain adaptation in local communities, and aims to recommend solutions that will alter the context in which adaptation occurs (O'Brien et al., 2007). Factors often include the community's physical exposure, the availability of resources, past exposures and institutional policies (Kelly & Adger, 2000; O'Brien et al., 2004; Smit & Wandel, 2006). Once a holistic diagnosis of vulnerability is reached, adaptation measures can be integrated within existing management strategies.

3.5 Contrasting Approaches for Selecting Indicators and Collecting Data

Each assessment can be viewed as both a process and product, where the process used determines the product. Therefore, it is important to determine the appropriate definitions, methods and indicators when developing robust vulnerability assessments. Composite-indicators are a widely used approach in vulnerability research. The index approach is useful for reducing the complex phenomena of vulnerability into a few comparable scores so accurate cross comparisons can occur. If case specific data is not available national or sub-national proxy statistics can be used. Wirehn & Nesset (2015) stress that "any vulnerability assessment process must be transparent" (p. 79). The following section briefly describes the two main approaches for selecting indicators and two main methods for collecting data.

3.5.1 Deductive indicator selection method. The first widely used approach for selecting indicators is the theory driven deductive approach. This approach involves proposing relationships derived from a conceptual framework and selecting indicators on the basis of these relationships. Adger et al., (2004) noted:

> In deductive research, a hypothesis is tested by operationalising the concepts in the hypothesis and collecting the appropriate data to explore the relationship between the measures of these concepts. A strong conceptual framework can form the basis for identifying vulnerability indicators (p. 17).

In other words, indicators are chosen to measure a theoretical concept and produce data on it. A deductive approach for indicator selection was applied in this thesis, and the first two phases seen in Figure 12 represent the deductive method for indicator selection. Because indices chosen in this method are strictly based on theoretical understandings many subjective factors influence indicator selection and weight determination in this method. Thus, it is essential for researchers to refer to the conceptual framework which ensures that a logical and valid assessment will be produced. The significance of findings in this method is assessed on the basis of the validity of the theoretical approach and assumptions, the appropriateness of the selected indicators and the reliability of data.

3.5.2 Inductive indicator selection method. The second approach for indicator selection is the more formal inductive data driven method. Researchers applying an inductive method must examine alot of data, look for patterns and examine correlations and other statistical relationships. Most often a Principal Component Analysis (PCA) is used to select the statistically optimized indicators that will ultimately be included in the assessment. The methodological differences for selecting indicators using inductive approaches are that indicators are narrowed down with a reductionist technique and empirical generalizations can be used to develop conceptual models and theories. However, a challenge of this apporach is the difficulty of finding meaningful explanatory statistical relationships between variables at the national level (Adger et al., 2004). One impressive example of a well-known inductive vulnerability assessment is the Social Vulnerability Index (SOVI) developed by Cutter (1996). Cutter began by collecting over two hundred and fifty variables for 3,141 counties in the United States. Several statistical relationships were examined and multi-collinearity tests were run until eventually two hundred and fifty indices were reduced to forty-two independent variables which explained seventy-six percent of the variance among all counties (Cutter, Boruff, & Shirley, 2004).

3.6 Contrasting Methods for Data Collection (Top-Down vs. Bottoms-Up)

This thesis used a top-down data collection method, meaning that all of the demographic and climate data were strictly gathered from secondary sources. Top-down research methods are convenient and effective for researchers conducting broad-scale comparative assessments which have been acknowledged as useful approach for revealing the differential effects of climate on society (Vasquez-Leon, et al., 2003). Despite these strengths, there is growing recognition for expanding beyond secondary data, to also incorporate bottom-up approaches when conducting vulnerability assessments. Bottom-up data collection methods include targeted survey data and interviews. Research using bottom-up approaches accounts for context specificity by involving local community stakeholders directly. Researchers can improve their analysis by incorporating qualitative data collected from the insider's perspectives who are analyzing their own risks. To shed light on this type of approach Zharafshani et al., (2016) stated that "a participatory paradigm in determining the drought vulnerability of a given community is in line with [the] view that farmers determine their own drought vulnerability while development practitioners play the role of facilitator in participatory vulnerability assessment" (p. 8). The main difference between bottom-up and top-down deductive research is that the community defines its own vulnerabilities and capabilities; whereas outsiders are passive.

The blank vulnerability scoping diagram (VSD) presented in Figure 2 is a meta-analysis tool presented by Polsky, Neff and Yarnal (2007) for facilitating comparisons of vulnerability assessments that use dissimilar measures to assess differential vulnerability. I believe that this visualization tool could also be an excellent aid for a researcher attempting to facilitate vulnerability assessments that use bottom-up data collection methods and a community based approach. Hypothetically, a researcher could bring a large image of the VSD to a community meeting, broadly what each of the three categories represent, and then have the community define their own vulnerabilities. The filled out VSD seen in Figure 3 represents the categorization of vulnerability factors used in this thesis. The intention of filling out a blank VSD seen in Figure 2 was to demonstrate how the general categories are flexible can be tailored to incorporate a wide range of factors. There is no universal view on what indicators should be included in vulnerability assessments and there is a lot of room for creativity with the basic guiding dimensions of exposure, sensitivity and adaptive capacity. Each of the three general categories can incorporate qualitative indices including culturally and regionally relevant information to communicate a more accurate and detailed picture of the multi-faceted nature of drought in a variety of local contexts. The composite indices that were applied in this thesis are customizable and can easily be swapped to accurately represent emerging concerns in tribal lands.

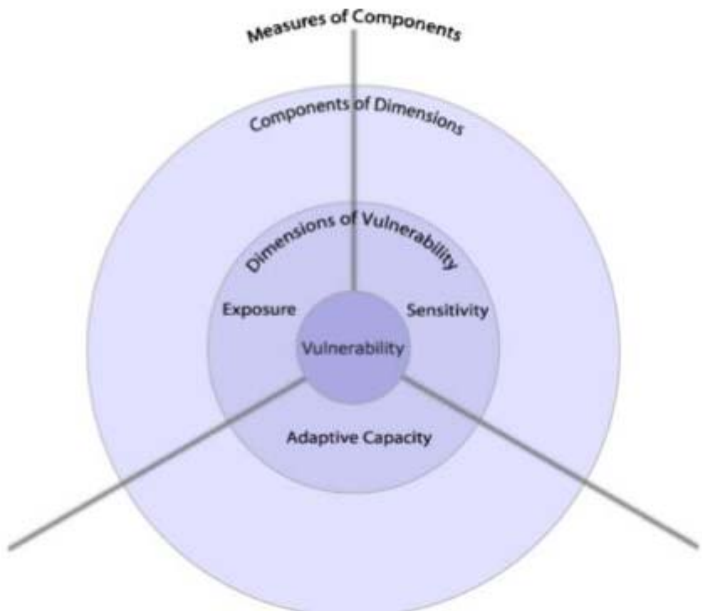


Figure 2. Blank vulnerability scoping diagram (VSD) (Polsky et al., p. 478).

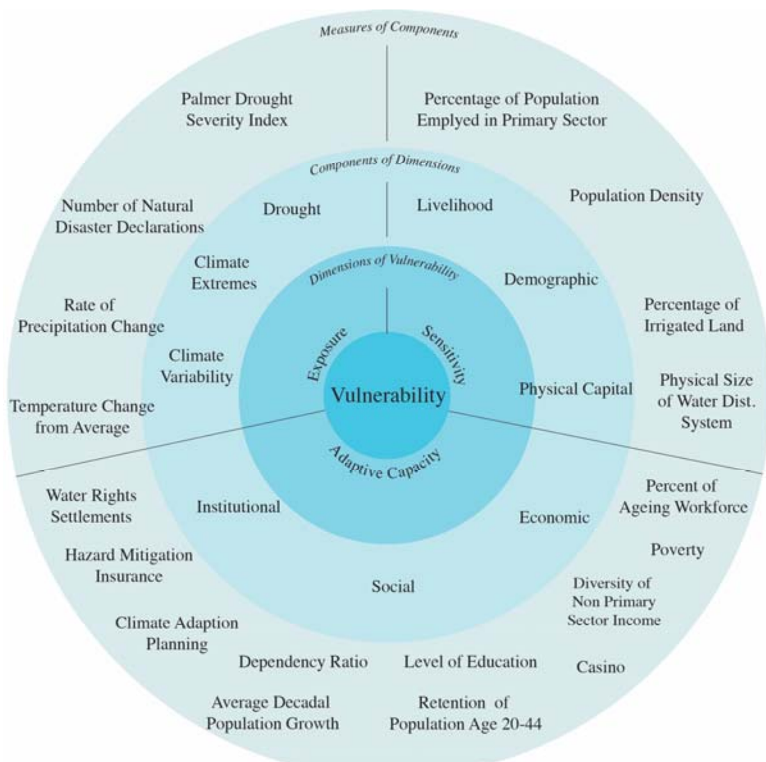


Figure 3. VSD based on research presented in this thesis. Hazard = drought, Exposure Unit = tribal entity. Adapted from (Polsky et al., p. 479).

3.7 Gaps, Challenges and Uncertainty in Vulnerability Analysis

The first of four key challenges is due to several theoretical confusions that arise when reviewing literature in preparation for conducting a vulnerability assessment. Often researchers neglect to specify the theoretical underpinnings of their work, which can lead to confusion distinguishing between disciplines. To address this uncertainty, O'Brien et al., (2007) created a diagnostic tool which helps researchers critically analyze the questions asked, methods applied and variables used. While conducting a literature review it is important to be aware of the defining characteristics of various streams of vulnerability research. By learning the defining elements of various approaches for conducting vulnerability research as presented above, this foundation will hopefully assist the researcher categorize assessments into their respective frames and find studies that best match his/her research objectives.

Secondly, several difficulties emerged when narrowing the scope of topics that could potentially be used within the contextual/IAA for the assessment presented in this thesis. In this world view, environmental issues do not present themselves in well-defined boxes and multiple disciplinary perspectives are included. Defining the vulnerable entity, the boundaries and the temporal reference for this study was subject to uncertainty. Often in data poor local environments national/statewide averages are applied as proxies to represent vulnerability at smaller scales. In this assessment, three large scale climate division averages were applied as proxies to represent climate variation at the tribal scale (see Section 5.5.1.5).

A third challenge is inherent uncertainty when developing and narrowing down indicators. For example, a study conducted by Pearson et al., (2008) found that there were more than fifty vulnerability assessment models that have been used only for agricultural research applications. Within the exposure index alone, there are numerous drought indicators to choose from and there is not a consensus regarding which variables are the most effective at reporting exposure to climate change.

The final challenge lies in the need for constant re-assessment when researchers operate under time and resource constraints. Vulnerability assessments often use indicators that report a current snapshot of vulnerability. This data becomes arbitrary if it is not regularly updated. Vulnerability is dynamic, and indicators and maps are static. Single observations found in composite vulnerability maps do not tell us who is becoming more vulnerable or less vulnerable as time goes on. Therefore, it is critical that as new adaptation strategies emerge and conditions change the information is regularly updated.

Chapter 4: Study Area Background & Drought

This chapter provides relevant background into the ecological setting of the Southwestern US, and the scale of analysis for assessing climate variability in this thesis. Additionally, a summary of the historical background of Indigenous people of North America is offered, followed by and an overview of current socio-economic status of American Indians.

4.1 The Ecological Setting

The southwest consists of six states (AZ, CO, CA, NV, NM, UT, CA). There are several different interpretations for what geographies constitute the American Southwest. Jones and Gutler (2016) define it as "the land surface area bounded by bounded by 25°-40° N, 99°-117°W which includes most of the southwestern US and northern Mexico" (p. 4640) (see Figure 4). The geographic area studied in this thesis lies between 41° 59' 42.94 to 32° 6' 42.16" Northern latitude 120° 48' 36.33" to 105° 31' 30" Western longitude, encompassing a total geographical area of 57,287 mi^2 (see Figure 5 and Table 2).

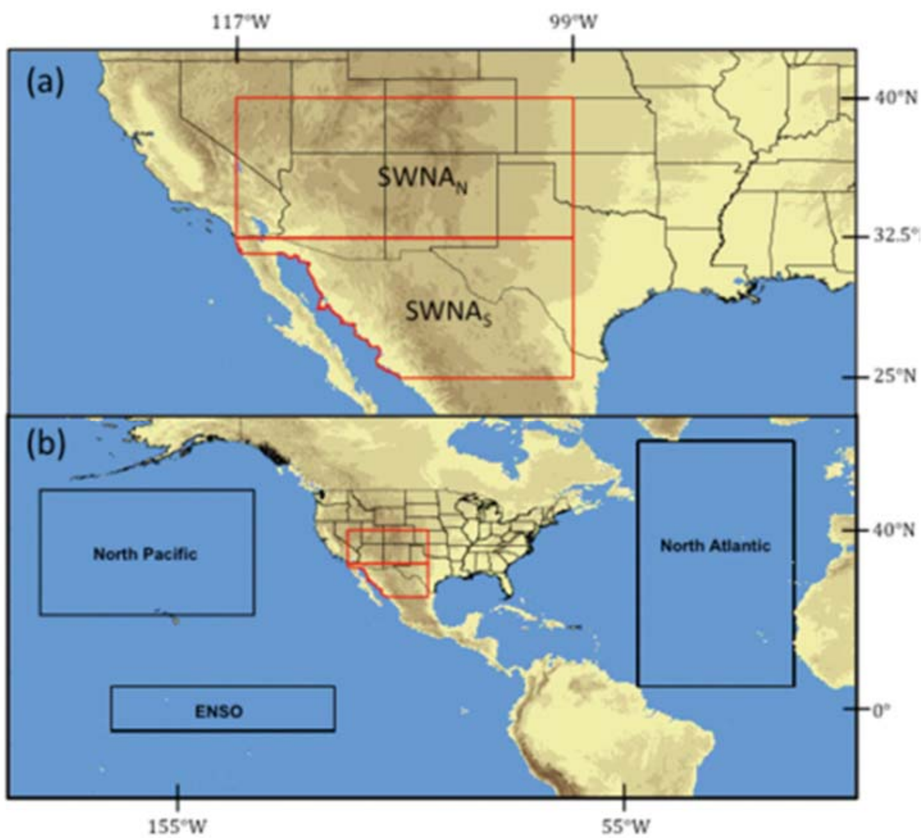


Figure 4. Rough geographic boundaries of the Southwest (Jones & Gutler, 2016).

Several tribal territories seen are located on marginal lands in semi-arid climates which are isolated geographically from regional economic centers. There is a large concentration of tribes within the Great Basin, Mojave, Sonoran, Chihuahuan deserts. Climate conditions experienced across the study region include low humidity with high temperatures during the day and low temperatures at night. The soils in these deserts are generally classified as aridisols, which contain little to no organic matter and have a coarse texture but are very fertile if water is introduced. Aridisols are typically alkaline and composed mostly of salts such as chlorides, sulfates, and carbonates (Lee, 2017). They are actively eroded by wind and will typically exhibit a pale light color near the surface. During long periods of soil moisture deficit salinization is common and the light color is due to the salts that have been formed in the soil during the evaporation process. In addition to the desert, there are also vast formations of sandstone where clays, shales and mudstones appear.

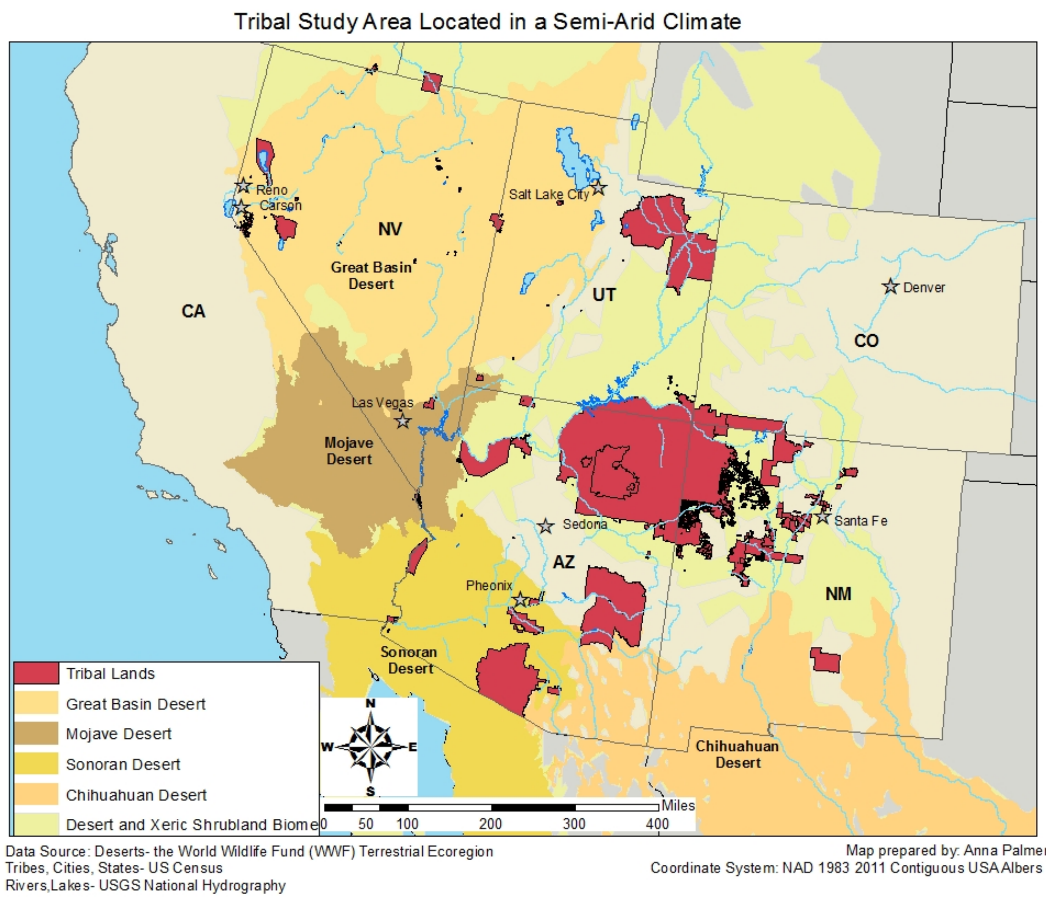


Figure 5. Study Area located in a semi-arid climate.

Generally, the climate across the study area is semi-arid and receives between 300 to 800 mm or 7-30 inches of rain annually (NCDC, 2012) (see Figure 6). The Potential Evapotranspiration (PET) is greater than precipitation meaning that the average annual water loss from transpiration by plants and from evaporation from the earth is higher than annual precipitation, making these areas particularly susceptible to droughts. Annual precipitation is sharply seasonal. During the summer months beginning in mid to late June a monsoon season arrives. Short and intense rain bursts occur that drench areas, causing overflow. Water then quickly evaporates in the summer heat. In the winter, precipitation falls between October and March. Snow is a key characteristic for maintaining the ecosystem health of the region.

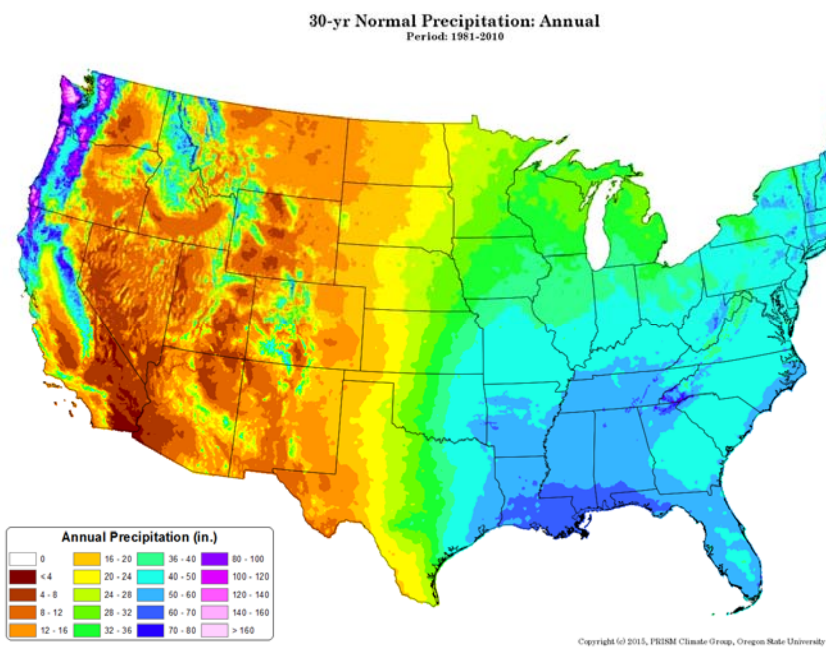


Figure 6. Average annual precipitation in the US (retrieved from PRISM, 2015).

Precipitation variability in the Western US is driven by the Pacific Decadal Oscillation (PDO), the dominant year-round pattern of the North Pacific and El Niño-Southern Oscillation (ENSO) sea surface temperatures (SSTs) (see Figure 4). When SSTs are warm, El Niño events emerge which impacts winter temperature and precipitation, hurricane seasons, and coral bleaching. Warming phases of ENSO are known as El Niño events which are associated with unusually wet winters leading to higher snow pack and water year stream flows during the

Spring. El Niño phases are also associated with decreases in the summer precipitation and warmer temperatures. Conversely, cooler than average SST's contribute to the La Niña phase of ENSO, which leads to dry winters, more year round precipitation and cooler temperatures. This year, SST's across the Pacific have been warm enough to cross the ocean threshold for an El Niño event (NOAA, 2017). The positive atmospheric feedback loop from El Niño resulted wetter than average conditions and strengthened snow and rain storms across the southern tier of the study area and all along the Western coast. A wetter than average 2016-2017 winter resulted in modest drought relief regionally. However, this relief is only short-term and has not made a dent in recovering from the decade of precipitation deficit that the study region has been facing. Furthermore, after a record rain event in February the tallest dam in the US, the Oorville dam nearly collapsed because it was not engineered to handle such a large amount of precipitation (Spencer, 2017).

The ecological setting of the study area is also influenced by four major river systems, including the Colorado, the Truckee, the Snakee and the Walker River. The largest of which is the Colorado River whose water quantity has been over allocated for decades. Due to the over consumption of surface water supplies combined with the lack of precipitation, the Lower Colorado River was recently identified as the number one most endangered river in the country (American Rivers, 2017). This mighty river still supplies water to 40 million people and has seen below average runoff all but three years since the year 2000. Furthermore, water levels of huge reservoirs such as Lake Mead, Lake Powell and Elephant Butte are dropping at rapid rates. To date, Lake Powell is half empty, At the beginning of 2000, Lake Powell was at 94 percent of capacity today, water levels have dropped to a low of forty-nine percent capacity (Bureau of Reclamation, 2017). And the Elephant Butte Reservoir in New Mexico is at roughly ten percent of its capacity with the lowest amount of water available for irrigation in since 1954 (Reed, 2016).

Figure 7. Lower Colorado River diversion canal (retrieved from: American Rivers, 2017).

Figure 8. Lake Mead water supply hits record lows (Credit: Wikimedia Commons User Cmpxchg8b via Public Domain, 2009).

4.1.2 Climate change impacts in Southwestern US. Recent reports identify that observed impacts of climate change in this region include extended drought, dune migration, higher than average annual and seasonal temperatures, extreme variability of precipitation regimes, longer dry seasons with increased fire risk, melting snowpack, decreasing ground and surface water supplies, and increased frequency of extreme heat and flooding events (Overpeck et al., 2013). Scientists have found that the Southwest has been experiencing sustained aridification and hydroclimatic shifts linked to short and long term climate variability over the past six decades (Cayan et al., 2001; MacDonald, 2010). The Southwest has generally been experiencing below-normal precipitation during all but a few years since 1999, creating a persistent water shortage (National Weather Service, 2007).

While droughts and variable precipitation patterns are not novelties in this region there is a heightened risk that semi-arid regions will become drier as both precipitation (P) and evaporation (E) rates change with increasing greenhouse gas (GHG) concentrations. Jones and Gutler (2016) assert that: "Southwest North American (SWNA) aridification is distinguished from the droughts of the past because it is caused by long-term trends in P and E related to anthropogenic global warming rather than the episodic ocean forced precipitation deficits that characterize historical SWNA droughts" (p. 4647). In addition to the detrimental impacts that are *already* being felt, GCMs predict that semiarid regions of the American West will continue to be disproportionately impacted by climate change over the next hundred years (Cook et al., 2015; Barnston & Lyon, 2016). The hazard potential of climate irregularities and extended drought and water scarcity is of grave concern as it is coupled with a massive growth in the agricultural sector, as well as urban and suburban population over the last century. As the region has not received enough precipitation to meet that demanded by humans, plants, and animals, the West has relied upon large scale centralized solutions and aquifer draw down. These solutions not sustainable in the face of unprecedented climate irregularities. The next section provides information into a few US policies which have promoted westward expansion and created an unsustainable demand for future water expansion.

4.2 Westward Expansion, Climate Change, Drought and Adaptation Planning

Colonial-driven transformation of human and natural systems by the US government in the 19th and 20th centuries systematically forced the expulsion of tens of thousands of American Indians from their traditional homelands and pushed Indigenous people into marginal territories, often located in isolated arid or semi-arid lands. John Wesley Powell prophetically remarked to Congress at an 1893 irrigation conference that "Gentlemen, you are piling up a heritage of conflict and litigation over water rights, for there is not sufficient water to supply the land." Despite this grave warning, and several others from scientists throughout the years, Congress continues to pour infrastructural investment to "fix" the water scarcity problem of the West. Federal and state policies continue to subsidize water, and set unrealistically high expectations for the carrying capacity that the cities in the region can sustainably maintain.

The reality of water scarcity is not being felt today in the price of water. Due to faulty logic and short term thinking ground water has been pumped in excess and demand is growing every day. Today, we are reaching an age of dawning limits. Technological fixes are not enough to adequately confront the reality of dwindling supply. For example, the Hoover Dam, which stores water reserves in Lake Mead, had been acclaimed as the be-all-end-all to meet all energy needs and water demand, to this day, it serves as the main water storage facility on the Colorado River. However, water reserves in Lake Mead have hit a record low since the construction of the dam in 1936 (Holthaus, 2015) and there is no doubt that water scarcity is a life-threatening problem that not even the Hoover Dam can fix. Westward expansion of US settlers was based on a dominant social paradigm (DSP) that believed in manifest destiny. Native American's were the first people to inhabit this region while US settlers only began migrating here during the late 18th and early 19th century. The first notable US policy that set the pre-text for Westward migration of American settlers was the Public Land Survey System (PLSS). PLSS was a land ordinance established in 1785 which used a precise strategy based on meridians to facilitate the process of surveying and selling land extending from the one hundredth meridian all the way to the Pacific Ocean. PLSS facilitated The Homestead Act of 1862 which gave "homesteaders" plots of land for free so they could pursue mainly extractive based economic endeavors related to lumber, lumber-related activities, mining, ranging and subsistence farming. In relation to the Homestead Act, is the Railroads Act which between 1850-1870 allocated public land to railroads. The government gave railroads a subsidy and ribbon of land 10 miles wide to encourage the building of high quality lines. They sold every other plot of land and attracted a customer base where each small community could access the line. The legacy of splitting the land into a checkerboard pattern can still be seen as several plots were sold to private timber industry logging that clear cut the forest.

Shortly after homesteaders began moving West the smaller streams of this arid region started running dry as they were being diverted onto soil by smaller groups and individuals (Sterling 1940). By 1888, Congress realized that "the arid region of our country could only be made habitable by irrigation" (Sterling 1940 p. 421). They needed to build larger canals and construct dams and reservoirs to support rapid economic development. To reach this goal, Congress hired Major John Wesley Powell, the director of the United States Geologic Survey (USGS) to make a general topographic map of the region, measure available water resources and identify sites that were feasible for reservoirs. Powell has become a symbol for environmentalists because he had always warned that there was never enough water in the West to meet the demand that Congress had encouraged.

The seemingly favorable conditions of the region have caused it to attract metropolitan populations that continue to grow at a rapid rate. The US Congress found that of the five metro areas with the largest numeric population increases between 2000 and 2006 most were in the West, including Phoenix, Arizona" (Fuller & Harhay 2010, p. 250). Over time, the extractive and agrarian based jobs that once dominated the region have diversified into a broader range of economic activities that include real estate, commercial activities and high tech industry that serve a strong influx of people. By the 1960's most of the homesteads established in the 19th century had been sold, subdivided, and developed as vacation home sites, tourist destinations and small mountain resorts serving the growing metropolitan areas in the Southwest (US Forest Service, 1972). Human influence has no doubt transformed The Valley of the Sun from an arid and inhospitable place to a major sunbelt destination. Sheridan 1995 commented that:

> Nearly every family owned its own home and had two cars. People planted Bermuda grass in the summer and rye grass in the winter and filled their yards with subtropical plants. There were no limits – to water, energy, or easy credit. It was suburbia triumphant, a strange, sun-dazed experiment taking shape on the northern edge of the Sonoran Desert as air-conditioning and flood irrigation kept the desert at bay (p. 281).

Supporting population growth in the Southwest has been an interesting experiment. But the reality persists that there is not sufficient water supply to maintain population growth in Western metropolitan areas. While droughts and variable precipitation patterns are not novelties in this region, climate irregularities and growing urban and suburban populations have created an unsustainable demand for water that will need to be addressed as we enter into a more variable future. The following section describes the multifaceted nature of drought.

4.3 Drought as a Natural Hazard

Drought is a complex phenomenon and one of the least understood natural hazards (Swain & Swain, 2011). Drought is currently understood as a manmade disaster linked to climate variability (United Nations, 2010). Drought is an insidious hazard of nature. It originates from a deficiency of precipitation that results in a water shortage for some activity or some group (National Drought Mitigation Center, 2017). Traditional understanding of drought assumed that it consists of interactions among three main components - rainfall, runoff and soil moisture. Drought is complex because it is difficult to identify when it is actually happening unlike other natural hazards, (e.g. earthquakes, hurricanes and floods). "We may say truthfully that we scarcely know a drought when we see one" (Tannehill 1947, p. 15). Droughts vary in intensity, duration and geographic coverage. The severity of drought is directly related to the demand and supply relationship of water (Dracup et al., 1980). Drought can never be measured with a common metric and definition (Wilhite & Vanyrkho, 2000). Due to the multi-faceted nature of drought, it cannot be defined by its cause and is usually defined by its effects. The study of drought has to be context and user specific (Wilhite, 2000).

In some regions, drought may mean any period without rain for more than one week; while in other regions, drought may be defined as one year without rain. Until the 20th century, the U.S. still identified drought as 21 or more days with rainfall 30% below normal (Kallis, 2008). Widely accepted classifications of drought fall into three categories- meteorological, hydrological or agricultural. To quantify drought either a single or multi-index approach can be used and numerous indices exist for measuring drought and are applied within each of these contexts.

4.3.1 Meteorological drought. A meteorological drought is a significant decrease in climatologically-expected precipitation, it refers to precipitation deficiency over a specified period of time. They can vary from location to location, depending on needs or applications (UN/ISDR, 2007, p.5). In identifying meteorological drought, Palmer (1965) proposed an index known as the Palmer Drought Severity Index (PDSI). PDSI is widely used index to measure drought. According to Peng et al., (2012) PDSI measured is:

> based on the principles of a balance between moisture supply and demand, in the calculation man-made changes are not considered. The index generally ranges from -6 to +6, with negative values denoting dry spells and positive values indicating wet spells.

PDSI scores are standardized to local climate and are able to demonstrate the regional condition of drought. It includes average temperature, total precipitation, parametrization of soil type and water holding capacity of the top layers of the soil. The effects of this type of drought are determined by characterizing how rainfall deficiencies vary depending on geographic location. Monthly PDSI values were averaged at a Climate Division level between 2000-2016 as a component indicator for Exposure in this study. Another index commonly used is the Standardized Precipitation Index (SPI), which was developed by McKee, et al. (1993) to quantify a precipitation deficit for different time scales.

4.3.2 Hydrological drought. The second type of drought, hydrological drought, is defined as a deficiency in water supply that is associated with decreased river flow, reduced reservoir and lake storage, and lowered groundwater levels (Yevjevich, 1967). The effects are based on the negative impact of water resource availability caused by below normal stream flow or decreased volume of lake or groundwater. Hydrological drought occurs when a community receives below normal precipitation for a number of years and they no longer have access to water supplies to sustain their livelihood as their reservoirs and nearby rivers are depleted. Indices used to monitor this type of drought are the Surface Water Supply Index (SWSI) or the Reclamation Drought Index (RDI) for determining water supply and runoff deficiencies. These indices, take the demand for water into consideration, restricting water use and water rationing are usually the solutions to deal with this type of drought.

4.3.3 Agricultural drought. A third type of traditionally defined drought is agricultural drought. t is identified by a lack of availability for crops in the growing season. Agricultural drought happens when soil moisture is insufficient to support the average crop growth (Smith, 2006). Plant water demand depends on climatic conditions, stage of growth and other plant specific characteristics thus agricultural drought impacts vary from crop to crop. Insufficient moisture may result in low yield. UN/ISDR (2007, p.5) remarked that, 'Infiltration rates vary depending on antecedent moisture conditions, slope, soil type, and the intensity of the precipitation event. Soil characteristics also differ. For example, some soils have a higher water-holding capacity, which makes them less vulnerable to drought. It is caused by the deficiency in soil moisture. The indices used to measure this focus on precipitation shortages in relation to agricultural impacts, through deficiency in soil moisture. It can be measured using the Palmer Drought Hydrologic Index (PDHI) or the Crop Moisture Index (CMI).

Agricultural drought is regarded as a severe form of drought because it affects not only the farmers themselves, but can cause ripple effects at multiple scales. For example, in the case of tribes in the Southwestern United States- at first the biophysical impacts of reductions in rainfall and the continued experiences of prolonged drought on tribal lands affect soil quality directly limit ranching and agricultural practices (Cozzetto et al. 2013, Redsteer et al., 2013). At first, those effects limit food supply of the American Indian families that that are highly dependent on the calories from subsistence resources from crops and cattle, additionally food security of that family is threatened if that family is dependent upon the income from the export of agricultural product, furthermore the tribal economy as a whole will suffer, even further impacts are occur in local and regional economies that depend on exports from tribal lands. This contributes to the food security of individuals and families in places off of the reservation places that are dependent on the import of tribal agricultural and rangeland products. It is critical that tribal farmers adapt to drought, particularly in Arizona which has the largest concentration of tribal lands and American

Indian farmers in the US. According to the Arizona Farm Bureau "21 million farm acres in Arizona are tended to by producers on the state's twenty American Indian tribes and nations. This accounts for nearly 80 percent of all land in farms in Arizona" (Murphree, 2017). Without adaptations Arizona agricultural and ranching production will eventually become a larger issue and affect food prices and supply.

4.3.4 Misunderstanding of drought leads to increased vulnerability. It is highly likely that severe and sustained drought will stress water sources in many already over-utilized areas, forcing farmers, energy producers, urban dwellers and plant and animal life to compete for the region's most precious resource. Historically, small-scale tribal farmers have been treated unequally in resource distribution conflicts. The 'root causes' of agricultural vulnerability on tribal lands include (i)being located marginal lands, (ii) lack of political influence. According to Blaikie 'root causes' tend to reproduce vulnerability over time. Due to dynamic political forces, it is likely that rural tribal communities will not receive adequate water resources to effectively be able to cope with drought in the future.

Currently, the limitations of the three objective definitions and indices mentioned in the first section that are used to determine risk to drought focus strictly on the biophysical impacts. The reductionist methods used to quantify drought and determine drought severity lead to misunderstandings. Thus, action taken to reduce risk may be misdirected. This misdirection may in turn increase community vulnerability, unnecessary resource depletion, misuse of informational, technological, and financial resources, and inappropriate mitigation measures (Smakhtin & Schipper, 2008). Misunderstanding the consequences of drought causes policy makers to not fully consider the ramifications of planned water diversions (Fuller, 2010). Relief is typically diverted to avoid the rural areas with low population density rater water supplies are diverted to serve areas with high population density. Furthermore, due to mis-information, over the past 10 years increasing rates of ground water pumping has artificially reduced the true impacts of drought. As drought events are far too often being portrayed as environmental deficiency, we fail to deal with them efficiently and effectively (Trottier, 2008). Now ground water tables are at an unprecedented low levels and the poor planning of the past has resulted in negative consequences for the future.

4.3.5 US drought monitor. Drought data are important information on which a wide range of users in various sectors such as agronomists, hydrologists, climatologists, water resource managers and planners, researchers, urban managers, and decision makers in government and private sectors depend. Weekly updates reporting the severity of conditions are produced by the US Drought Monitor. This data is reported on a scale of D0-D4. The severity scale is comprised of a unique blend of information from five key indices. These values are climate specific and derived from NOAA/NCDC climate stations and a network of over 270 on the ground reports. Expert judgement is then applied to interpret the qualitative information from on the ground reports and quantitative data from five indices to report traditional percent area, or categorical percent area of current drought conditions. Figure 9 shows the National US drought monitor for the first week of February. Categorical nominal values represent Short Term (S) or Long Term (L) and lines are drawn to delineate the dominant impact areas. Additionally, for each of the 50 States, six Climate Regions and eighteen Hydrological Unit Codes (2 digit) reports are generated as a percentage of total land area that is experiencing conditions. D0- in yellow represents Abnormally Dry indicating conditions that fall between 21 and 30 percentile range to D4 – in red represents Exceptional Drought indicating the percentile range is between 0 and 2. The purpose is to be able to compare current conditions of drought across the US and track the duration and severity of drought.

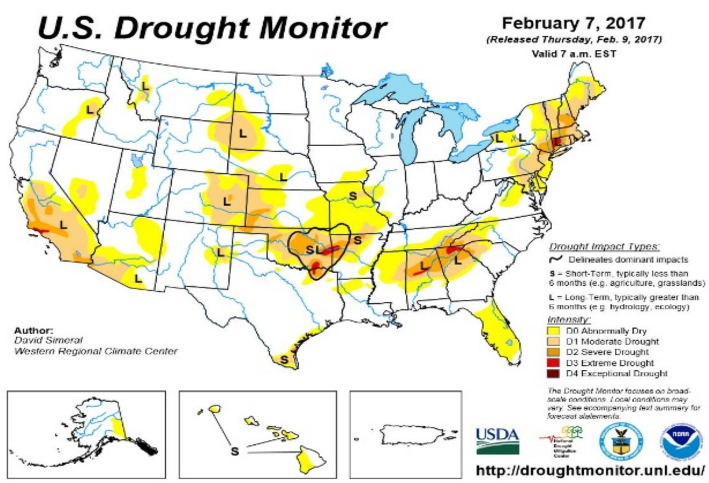


Figure 9. US Drought Monitor.

4.3.6 National drought mitigation center. The National Drought Mitigation Center (NDMC) "helps people and institutions implement measures to alleviate societal vulnerability to drought" (Nagarajan, 2009, p. 332). The Drought Impact Reporter released in 2011 reports direct social costs on National, Multistate, State, County, and municipal scales. The NDMC synthesizes user reports, media reports, National Weather Service Drought Information Statements, other agency reports and legacy reports to helps decision makers perceive the social impacts of drought. Several behavioral phycology studies have reported that when actors are able to perceive the threat they are more likely to respond (Alcamo et al., 2008). The metrics reported by the NDMC quantify impacts using objective measures including – dollar amounts of economic damages, infrastructure costs, sector specific impacts, social and public health costs. This is a useful tool because if the effects of drought can be quantified, government relief can be designated to alleviate the areas that are in extreme drought conditions. For example, the Dust Bowl of the 1920s and 1930s resulted in untold suffering due to lack of rain. In June 1934 over 1,100 counties had received emergency drought designation triggering President Roosevelt to request 525 million dollars in drought relief from Congress. Over half (275 million) dollars of this federal aid was intended to relieve the pioneer subsistence farms that failed due to insufficient rain, and the suffering livestock industry through providing emergency feed, buying starving animals from farmers and slaughtering excess herds for food relief (Cook, Seager, & Smerdon., 2014).

4.3.7 Strengths and weaknesses of current drought monitoring. Widely accepted classifications of drought are determined through operational assessments of weather station, satellite and soil moisture data to generate indices such as the PDSI or SPI. An integrated suite of indicators supports the US Drought Monitor which synthesize information to produce locally relevant drought reports, as well as written summaries of current conditions. The US Drought Monitor is good at analyzing recent events, placing the current situation into a historical context and forecasts future drought to boost planning efforts inform decision makers and encourage positive action. However, to date, the objective reporting of future risk clearly informs that the US can expect greater increases in temperature, radical changes of precipitation regimes, longer durations of dry spells and are consistently sounding the alarm that there are perpetual declines in natural water sources. While all of this effort is good educational, the effective transformation of this information into policy responses is lacking (Fuller, 2010). My critique is that the methods reporting current conditions and future risk represent a reductionist way of thinking. Using western interpretations of science abnormal moisture deficiency is detected and drought is reported in a particular region. However, for people who are not trained in science it is difficult to trust/interpret the information being produced and there is little incentive for decision makers to develop successful adaptation policies.

To address some of the limitations of the definitions and metrics which are used to objectively quantify drought, impact reporting efforts the NDMC attempt to transform impacts of climatic changes into direct costs on society so that relief can be directed. However, these efforts are not adequately moving the needle for increased policy response or long-term adaptive response. Furthermore, meteorological drought phenomenon translated into direct economic costs do not capture the social and cultural consequence of drought. Current efforts do not comprehensively account for the true impacts of climate change as they do not include the indirect costs of social malaise and deterioration. Because drought definitions and operational indexes are limited in scope and do not measure how social impacts of drought vary from household to household, within regions, or between tribes there is a need for "drought preparedness" which will be discussed in the next section.

4.3.8 Challenges of monitoring drought on tribal lands. This thesis argues that monitoring and "drought preparedness" measures must be taken from the county and tribal level all the way up to the national level in order to cope with drought in the 21st century. However, a relatively high level of technical ability is required to quantify drought. For example, the PDSI is a widely used drought index but the complexity and lack of transparency associated with the calculation of the PDSI makes it difficult for researchers to calculate independently (Jacobi et al., 2013). To solve the problem of limited human capital on tribal lands assistance from NGO's and regional planning offices could assist tribes with the technical challenges of quantifying drought.

It is difficult to determine the severity of drought on tribal lands as the current monitoring efforts generally do not report drought on a tribal scale. The NDMC does not report any impacts of drought on the tribal scale. In terms of the U.S. Drought monitor the data can be catered to fit tribal lands as there is free to access and can be downloaded in the form of excel spreadsheets or GIS shapefiles that can be extracted to apply to specific borders. Data are available by the US drought monitor and can be downloaded on a week by week basis going back to the year 2000. Personally, I faced challenges while attempting to reconstruct drought indices within tribal borders. At first, I attempted to count the number of droughts by extracting the weekly shapefiles from the US drought monitor. But it was difficult to quantify when each week ebbs and flows between D0-D4. I was constantly faced with the question - How can you tell when one drought ends and another one begins? One recent update I noticed on the US drought monitor were two separate reports of drought conditions on the Navajo and Hopi reservations (See Figure 10 and 11). It would be beneficial if the US drought monitor expanded their coverage to produce weekly drought severity reports for all reservations. This information would help natural resource managers, farmers and governments make more informed and timely judgments about when to begin conservation measures.

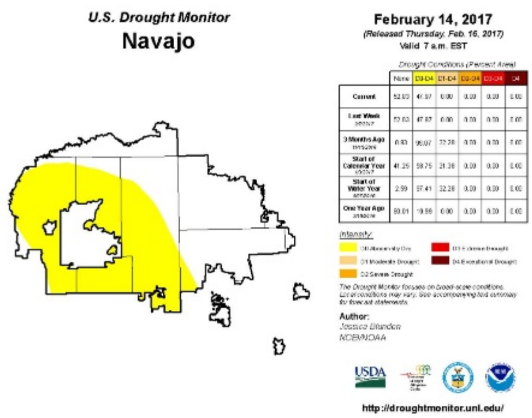


Figure 10. Navajo drought monitor.

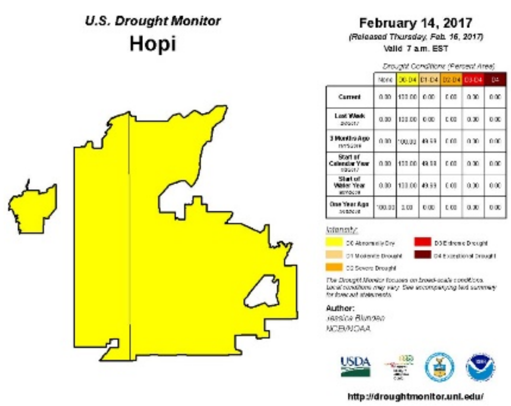


Figure 11. Hopi drought monitor.

4.3.9 Benefits of drought preparedness. “Drought Preparedness” includes drought planning, plan implementation, proactive mitigation measures, and public education. These measures “reduce the social, economic, and environmental impacts of drought and the need for federal emergency relief expenditures in drought-stricken areas” (National Drought Policy Commission, 2000). Advanced planning gives decision makers, resource managers and citizens the chance to relieve the most suffering at the least expense by taking steps ahead to reduce the potentially catastrophic effects of drought. Drought is commonly known as a "creeping phenomenon" because droughts develop slowly and can emerge over an extended timescale of months or even years before they are realized to be occurring. One benefit of this long time frame is that it provides room for adaptive governance to because it does not occur all at once giving agents the time to anticipate potential harm and intervene to reduce those impacts.

The instability of the climate system in the Southwest has potentially devastating impacts for agrarian tribal societies in the Southwest. Historically drought has led to the collapse of agrarian based societies. For example, Lima et al 2016 used tree ring data from the semi-arid Andean region of Tarapaca to identify an abrupt increase in climatic aridity and concluded that the agro-pastoral depopulation of Aymara population was in part caused by a multi-decadal decline in rainfall. As temperatures increase there will no longer be a steady stream of water in summer and fall that farmers rely upon. These changes are a serious cause for concern when considering the feasibility of sustaining agriculture on tribal lands.

4.3.9.1 Planning for drought. Drought planning is broadly known as actions taken by individual citizens, industry, government and others before drought occurs with the purpose of reducing or mitigating impacts and conflicts that arise from drought. Forty-nine states have some type of drought plan. In most cases, state drought impact and response plans have only been useful for reactive, short term mitigation. However, these efforts have not been focused on developing pro-active and/or committed, long-term mitigation programs. A challenge for future research is to create networks that will initiate a long-term drought mitigation planning and drought monitoring system that is institutionalized and publically available to influence how people cope with drought.

4.3.9.2 Drought mitigation. Nine States have drought mitigation plans. Taking pro-active mitigation measures reduces drought 'crisis' which refers to an unstable or crucial time or state of affairs in which a decisive and undesirable change is impending or occurring, and which requires extraordinary emergency measures to counteract. By taking steps ahead of time to prevent known impacts from a natural disaster, $4 are saved for every $1 expended" (FEMA, 2005). Monitoring, planning and mitigating for drought is more effective than reacting in crisis mode as it gives decision makers, natural resource managers and citizens the chance to relieve the most suffering at the least expense.

Chapter 5: Methodology

5.1 Overview

This thesis presents the first large scale comparative cross-territory study of tribal climate vulnerability. Composite index scores and maps display the relative agricultural vulnerability to climate change of 72 tribes, nations, pueblos, bands and colonies in the Southwestern United States. A top-down deductive approach was used to identify nineteen sub-indices that were further summarized into six composite indices that represent multiple dimensions of overall vulnerability (see Figure 13). Research tools included literature review, which aided in the development of a conceptual framework, followed by secondary data collection, data analysis and mapping with Geographic Information Systems (GIS). Attendance at the Native Waters on Arid Lands Conferences in 2015 and 2016 provided the impetus for including all tribes living in the semi-arid region of the US and guidance to focus on agriculture as the key vulnerable sector. The nineteen vulnerability indicators seen in Table 3 reflect discussions among research team members, feedback from Native Waters on Arid Lands project partners, and participants in several expert meetings. The relevance of selected indicators was validated further after a preliminary version of this assessment was presented to a technical team, stakeholders, and tribal representatives during the Native Water on Arid Lands Conference in 2016. The following chapter commences with a summary of the general procedure applied in this thesis. Next, the overview of the climate and ecological setting in the study area is provided. An overview of the social setting of tribal nations is described and the criteria for sample selection of the tribes discussed in this thesis is outlined. After the biophysical and social vulnerabilities are identified, a technical description of the step-by-step analytical procedure is outlined. The chapter concludes with a detailed description and theoretical justification for the indices used to assess the relative agricultural vulnerability on tribal lands.

5.2 The Study Area - Seventy-two Native American Communities

This thesis includes seventy-two federally recognized reservations and off-reservation trust lands. Table 2 shows the distribution of sixty-nine culturally distinct tribal nations pueblos, bands and communities across the Southwest. They are organized based on the state they are located within and the total population living within sovereign tribal borders of that state Three tribes have more than one census assigned GEOID associated with a single culturally distinct tribal entity, which is what accounts for the discrepancy between sixty-nine and seventy-two. These tribes were chosen in particular because agriculture and fishing operations have been of particular cultural significance to the indigenous civilizations that have been living in the region for centuries. According to Macdonald (2010):

> Archeological evidence and early historical accounts tell us that peoples such as the Hopi, Zuni, Rio Grande Pueblo, and Pecos Pueblo built large villages and practiced irrigated agriculture along rivers including the Little Colorado, the Rio Grande, and the Pecos. Indeed, native peoples engineered small check dams and irrigation canals beginning about 2,000 years ago (p.21261).

Agriculture, fishing and ranching continue to be incredibly important socially and economically for many tribes living in the region. Within these 72 sovereign borders live over 396,000 American Indians. A rough estimate provided by the US Census (2015) reports that approximately six percent of the workforce is employed in the primary sector (agriculture, forestry, fishing and hunting, and mining) while less than two percent of the US population as a whole is employed in such activities. That six percent represents nearly 7,200 American Indian primary producers. It is critical that American Indian farmers adapt to climate change because rainwater will not be adequate to facilitate sustained agricultural and ranching production in semi-arid climates as we enter into a more variable future.

Table 2

Tribal lands and populations in five Southwestern States

State	No. of Tribes	No. of Tribes in Thesis	Total State Population	Tribal Population (on reservation)	% Tribal Population	Total State (acres)	Approx. Tribal Land (acres)	% Tribal Land
AZ	21	20[3]	6,641,928	261,360	3.9%	72,954,045	25,673,425	35.2%
NM	23	21[4]	2,084,117	80,565	3.9%	77,817,599	3,637,195	4.7%
UT	8	3[5]	2,903,379	25,900	0.9%	54,334,336	4,538,939	8.4%
CO	2	2	5,278,906	1,410	0.03%	66,619,553	1,256,944	1.9%
NV	19	18[6]	2,798,636	27,197	1.0%	70,764,321	1,346,932	1.9%
Total	**73**	**69[7]**	**19,706,966**	**396,432**	**2%**	**342,489,853**	**36,453,435**	**10.6%**

3 **AZ** has 21 federally recognized tribes; 20 are included in AZ for this study. The San Juan Southern Paiute Tribe of Arizona does not have a GEOID provided by the US Census. If San Juan were included there would be 21 tribes.

4 **NM** has 23 federally recognized tribes; 21 are included in NM for this study. Some sources count the Navajo Nation as a NM tribe. However, 66% of Navajo land and water are in AZ, while 26% are in NM and 8% are in UT (so they are counted in AZ). Additionally, some sources count the Fort Sill Apache Tribe as a NM tribe, but 0 people live there according to the 2015 census and therefore are not included. If Navajo Nation and the Fort Sill Apache tribes were included there would be 23 tribes.

5 **UT** has 8 federally recognized tribes; 3 are included in UT for this study. Some sources include the Navajo Nation, The Confederated Tribes of Goshute Reservation and the Ute Mountain Tribe as UT tribes, however, 58% of Goshute reservation land is in NM while only 42% is in UT (so they're counted in NM), the Ute Mountain tribe has 79% of its land in CO and only 3% of their land in UT (so they're counted in CO). Additionally, The Northwestern Band of the Shoshone Nation are listed as a UT tribe, but there are 0 people living there according to the 2015 census and therefore are not included in this study. If Navajo, Goshute, Ute Mountain and the Northwestern Band of the Shoshoni Nation were included there would be 8 tribes.

6 **NV** has 19 federally recognized tribes; 18 tribes are included in NV for this study. Some sources include the Summit Lake Paiute Tribe of Nevada as a NV tribe, but there are 0 people living there according to the 2015 census. If Summit lake were included there would be 19 tribes.

7 While there are 69 unique Tribes with distinct histories there are 72 GEOID's included in this thesis as some tribes have territories that are separated geographically

5.2.1. Criteria for sample selection. The following four parameters were the criteria for the selection of tribes in this study:

1) Tribes are federally recognized **-** Many tribes are located on remote and ecologically sensitive lands which have suffered from prolonged drought, increasing temperatures, seasonal variability and decreasing water supplies. Their federal status indicates the trust responsibility which obligates all branches and agencies “to protect tribal self-governance, tribal land, assets resources and treaty rights”. The term ‘federally recognized tribe’ is a US government designation for a sovereign Indian tribe that has official relations with the United States and implies certain incontrovertible treaty rights for Native Americans.

2) Tribes are in five out of six Southwestern states (Arizona, Colorado, Nevada, New Mexico and Utah) **–** The Southwestern US is home to 182 federally recognized tribes (Federal Register, 2017). Overpeck, et al., (2012) noted that “the Southwest has the highest proportion of federal and tribal lands in the nation” (p. 18). Despite the fact that climate change is having a significant impact in California, it was not included. Due to the size and diversity of the state, it deserves its own separate analysis and was considered beyond the scope of this study. By removing California from the study area 109 federally recognized tribes were excluded. The sample size was reduced to a much more manageable size (72 tribes total).

3) Tribes have GEOID’s - There are 630 American Indian legal and statistical areas for which the US Census Bureau provides data (US Census Bureau Geography Division). This thesis discusses seventy-two distinct American Indian legal statistical areas. This eliminated one federally recognized reservation from being included in the study, as the 5,400 acres that make up the San Juan Southern Paiute Tribe of Arizona are currently subsumed by Navajo Nation and do not have an associated GEOID (Arizona State University, 2010).

4) A human population greater than zero are reported as living on the reservation lands according to the most recent five-year American Community Survey (ACS) **–** This criterion eliminated 3 reservations- The Fort Sill Apache Tribe of New Mexico, The Summit Lake Paiute Tribe of Nevada, and the Northwestern Band of the Shoshoni Nation of Utah, as they have a population of zero reported in the most recent population estimates (US Census, 2015).

5.3 General Procedure

The general procedure and research framework applied in this thesis can be grouped into three general phases (see Figure 12). Phase one included the identification of tribal units that would be the primary scale of assessment. The IAA was selected as the most appropriate research framework. It involves creating a profile of social and biophysical vulnerabilities. During phase one the decision was made to use a deductive approach for indicator selection and top-down data collection methods. Developing the theoretical foundation and gathering data in phases one and two took approximately one and a half years to complete. During the second phase, time constrains prompted the application of climate division scale data as an appropriate scale for three proxy indicators within the exposure index. The ultimate selection of nineteen sub-indicators were finalized based on data availability, expert judgement, literature review discussions with a technical team, stakeholders and tribal leaders during the Native Waters on Arid Lands conference in 2016. Phase two officially ended after the raw data was gathered. Phase three involved data normalization of sub-indices where arbitrary equal weights were chosen. The final stages of assessment included mapping of final indicator scores using GIS, statistical analysis using R-Studio, and explanation of relative vulnerability.

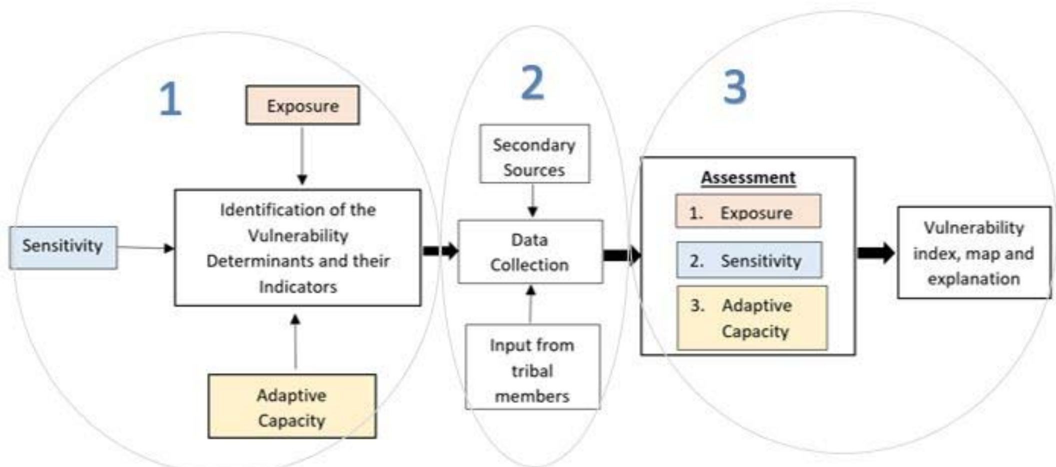


Figure 12. Approach for vulnerability assessment - can be broken down into three major phases (adapted from Mendoza et al., 2014).

5.4 Analytical Procedure

Vulnerability to climate change is measured as a function of exposure, sensitivity, and adaptive capacity (Adger, 2006). Table 3 identifies the hypothesized functional relationship between indicators and vulnerability. The theoretical justification is elaborated upon in the specific descriptions of each index provided in sections 3.5, 3.6 and 3.7. Ultimately, nineteen indicators were chosen to represent vulnerability in consideration of discussions among research team members and feedback received from the Native Waters on Arid Lands project partners. Figure 13 illustrates the thematic categories of composite indices which together comprise composite vulnerability. The conceptual framework for this assessment is rooted primarily in five studies: Carter et al., 2010; Gbetibouou, Ringler & Hassan., 2010; O'Brien et al., 2004; Wiréhn, Danielsson & Neset, 2015; Ravindranath et al., 2011. These formative papers were chosen as they provide a strong theoretical foundation and characterize comparative climate change vulnerability assessments with a particular focus on agriculture. They also use the IAA and follow similar research methods involving top-down data collection to quantify and map relative vulnerability over large geographic areas. Most of the sub-indicators are directly consistent with literature focusing on agriculture as the vulnerable system, and climate change as the stressor (Wiréhn et al., 2015).

5.4.1 Normalizing indices. Based on the hypothesized functional relationship of an indicator to agricultural vulnerability, all nineteen sub-indices were normalized using one of the two formulae given below. The minimum-maximum transformation method was used applied to raw data values from several secondary sources mentioned above. The min-max method creates a unit-less measure so that accurate cross-tribal comparisons can occur by setting the values of indices to fall onto a common linear scale ranging from zero to one (one having the maximum influence on vulnerability and zero having least or no influence on vulnerability). Equation 1 was applied if the index was hypothesized to have an upward (↑) functional relationship indicating that vulnerability increases with a corresponding increase in the value of the indicator. This was used for variables that measure frequencies such as poverty rate, which are positively correlated with climate change vulnerability. Alternatively, Equation 2 was applied if the index has a downward (↓) functional relationship, indicating decreases in climate vulnerability with a corresponding increase in the value of the indicator. The second equation was used for variables that measure frequencies such as the acre foot entitlement to water rights, where the greater the value of water rights a tribe is allocated, the lower the vulnerability.

Equation 1. $Y_{ij} = \frac{\left(X_{ij} - (MINd)\right)}{(\mathrm{MAX}d) - (\mathrm{MIN}d)}$

Equation 2. $Y_{ij} = \frac{(\mathrm{MAX}d) - X_{ij})}{(\mathrm{MAX}d) - (\mathrm{MIN}d)}$

In the two equations above X_{ij} represents the raw value of the index (i) corresponding to tribe (j). MIN_d equals the minimum value of indicator (i) among the sample of 72 tribes. MAX_d equals the maximum value of indicator (i), among the same of 72 tribes. The resulting normalized score Y_{ij} corresponds to the value of index (i) linked to tribe (j). The min-max transformation of sub-indicators is a common method applied by several researchers currently conducting vulnerability assessments (Esteves et al., 2016; Ganapuram et al., 2015). Microsoft Office Excel 2016 was the software package used for the normalization calculations and subsequent summarizing of scores that represent relative agricultural vulnerability.

5.4.2 Equal weights. Arbitrary equal weighting techniques were used for the indices within each of the three vulnerability elements. This is the least complex method widely utilized in the literature (Brooks et al., 2005; Lucas & Hildernick, 2004; O'Brien et al., 2004; Ravindranth et al., 2011) Equal weighting simply means that all variables are given the same weight. This essentially implies that all variables included in this study are "worth" the same amount in the composite. Other weighting techniques include the Analytic Hierarchy Process (AHP), which is one of the most widely used methods for evaluating and ranking alternatives, or the Principal Components Analysis (PCA), which can also generate weights based on statistics for component indicators (Gbetibouou et al., 2010).

5.4.3 Summarizing. After normalizing the nineteen raw index values into a comparable range falling between zero and one they were grouped into three main dimensions of vulnerability, namely exposure, sensitivity, and adaptive capacity. The eleven sub-indices for adaptive capacity were further broken into three smaller sub-categories. The separation of social, economic and institutional dimensions is useful for explaining and visualizing relative adaptive capacity. The composite indicators for each dimension were constructed by using the simple average of the normalized sub-indicators included in each dimension. The composite index scores and maps for EI, SI, ACI reflect the cumulative effect of vulnerability as determined by the sub-indicators grouped within each of those three dimensions. The final composite Agricultural Vulnerability Index (AVI) was generated using the simple average of the three dimensions with an equation that was operationalized by Nagarajan and Sreedhar (2015). AVI represents overall vulnerability that occurs when considering EI, SI and ACI in aggregate.

$$Composite\ Agricultural\ Vulnerability\ Index\ (AVI) = \frac{(\mathrm{EI} + \mathrm{SI} + \mathrm{ACI})}{3}$$

5.5.4 Data display and classification. Microsoft Excel 2016 was used to normalize nineteen sub-indicators to a range between zero and one, and to calculate four simple averages for EI, SI, ACI, and AVI. Four composite index scores were uploaded into GIS and joined to the corresponding geographic tribal entities. In GIS, quantiles were created to separate tribes into classes having either very high, high, moderate, low, or very low vulnerability (Ravindranath et al., 2011). Quantile classification creates five equal categories that have the same number of features (tribes) in each class. This method treats each dataset similarly resulting in comparable maps where the top 20% are grouped into the highest vulnerability class and the bottom 20% represent the lowest vulnerability class. Once the final indicator scores were classified indicators maps were created to display the three vulnerability dimensions and overall vulnerability. The final results can be both socially and spatially referenced which is useful for understanding outcomes as vulnerability is associated with social and environmental phenomena, which often have locational components (O'Brien et al., 2004).

5.5 Vulnerability Indicators

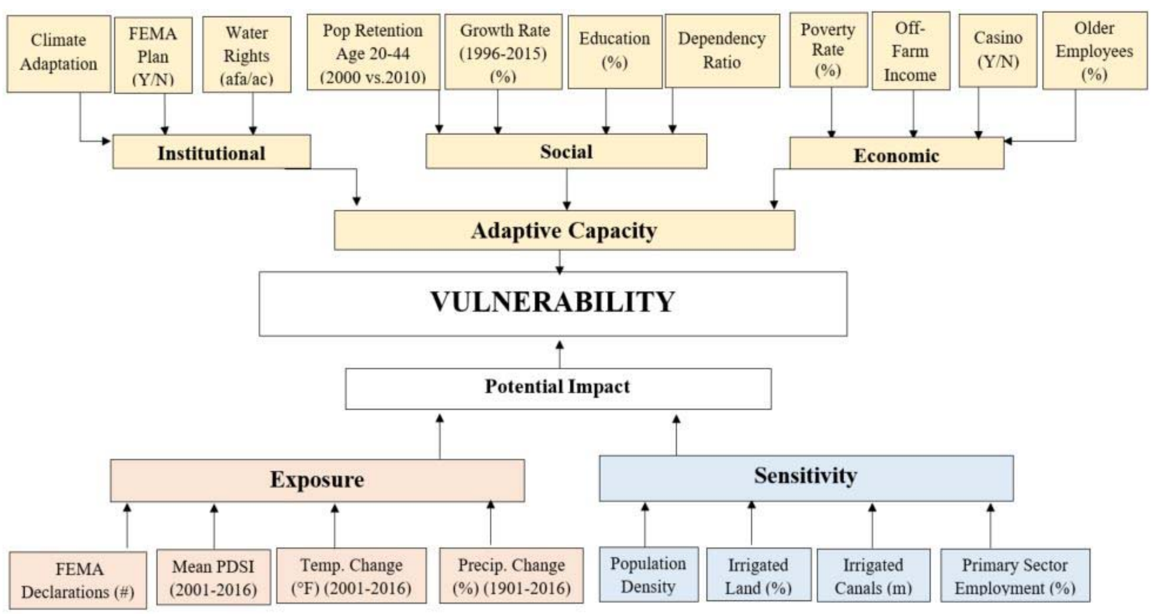


Figure 13. Contribution indicators to composite vulnerability index (adapted from Gbetibouou et al., 2010 p.17).

Table 3

Indicators selected and hypothesized functional relationship chosen for the construction of tribal vulnerability assessment

	Dimension	Component indicators	Abbreviation	Functional Relationship	Correlation between indicator and vulnerability
EXPOSURE	Drought	Palmer Drought Severity Index (2001-2016) [3, 4, 6 (a)]	PDSI	↓	The smaller value of PSDI (indicating higher levels of long term drought), the higher the vulnerability.
	Extremes	FEMA disaster declarations (1990-2017) (#) [3, 6 (a)]	FEMA	↑	The greater the # of FEMA declarations (indicating greater risk for climate extremes events), the higher the vulnerability.
	Variability	Rate of Precipitation Change (1901-2016) (%) [2,3,4 (a)]	PRCP_CHG	↓	The smaller the value of PRECIP_CHG (indicating precipitation decreases are occurring at a faster rate), the higher the vulnerability.
		Temperature Change (200-2015 vs long term average) (°F) [2, 3 (a)]	TMP_CHG	↑	The greater the value of TEMP_CHG (indicating increases in temperature from long-term average), the higher the vulnerability.
SENSITIVITY	Human	Population Density (population/mi^2) [2, 3, 4 (b)]	POPDENS*	↑	The greater the population density, the higher the vulnerability.
	Livelihood	Primary Sector Employees (%) [1, 2, 5, 7, 8]	PRM_SCT	↑	The greater the ratio of agricultural employment, the greater the vulnerability.
	Physical Capital	Extent of Irrigation (%) [1, 2, 3, 4, (a)]	IRR_LND	↓	The higher the proportion of irrigated area, the lower the vulnerability.
		Perennial Water Distribution Network (m) [6 (b)]	IRR_LGNTH*	↓	The longer the length of man-made perennial water distribution network (canals ditches or aqueducts) the lower the vulnerability

Table 3 *Continued*

ADAPTIVE CAPACITY	Social	Level of Education (%) [7]	NO_HSD	↑	The higher the proportion of people with less than a high school education, the higher the vulnerability
		Dependency Ratio [2,5]	DEPND	↑	The greater the dependency ratio, the higher the vulnerability.
		Average Decadal Population Growth Rate (1996-2015) (%) [2,5 (a)]	GRWTH_R	↓	The greater the rate of population growth, the lower the vulnerability.
		Population Retention Ratio Ages 20-44 (2000 vs. 2010)	RETN_R	↓	The larger the retention ratio of population aged 20-44 between 2010-2000 the lower the vulnerability.
	Economic	Poverty (%) [3]	PVRTY	↑	The higher poverty rate, the higher the vulnerability.
		Older Employees (%) [2,5]	OLDR_EMP	↑	The greater the ratio of older employees, the greater the vulnerability.
		Off-farm Income Sources (#) [8]	OFF_FARM	↓	The greater the number of non-climatic dependent sectors present, the lower the vulnerability.
		Casino (Y/N/IP)	CASINO	↓	Casino operations, reduce vulnerability
	Institutional	Water Rights Settlement (afa/acres)	WATR	↓	The greater the water entitlement, the lower the vulnerability.
		Climate Adaptation (score) [9] [(a)]	ADAPT	↓	Climate adaptation planning efforts, reduce vulnerability.
		FEMA Hazard Mitigation Plan (status) [6 (a)]	INSRNC	↓	FEMA approved hazard mitigation plans, reduce vulnerability.

Notes: [(a)] Not identical to the original source. [*] The logarithm of the sub indicator was used. [1] O'Brien et al., (2004), [2] Wiréhn et al., (2015), [3] Gbetibouou et al., (2010)., [4] Ravindranath et al., (2011), [5] Carter et al., (2010), [6] Polsky, Neff & Yarnal, (2007), [7] Cutter & Finch, (2008), [8] Esteves et al., (2016) [9] Mendoza et al., (2014).

5.5.1 Exposure index (EI). Exposure consists of the hazard itself and the objects in danger (e.g., exposure to hazards, the geographical location). Exposure can be interpreted as the direct danger (stressor) and the nature and extent of external changes to a region's climate. Climate stress can be defined as long-term climate conditions and climate variability, as well as the magnitude and frequency of extreme events McCarthy et al., (2001). Climate stressors identified in this assessment include climate variability in temperature and precipitation patterns, the frequency of extreme weather events, and the natural hazard of long term drought. American Indian farmers in this region are forced to cope with a more unstable future because climate conditions largely affecting crop growth include both average climate conditions such as temperature and rainfall variability but also extreme or irregular events, such as floods and drought (Li et al., 2015). The exposure index (EI) seen in Figure 14 is intended to identify which tribes are more vulnerable than others based on external biophysical forces. The assumption is that tribes and climate divisions that have already been exposed to higher frequencies of extreme events, greater severity of drought, and greater variability in temperature and precipitation are more vulnerable. The four indicators included in exposure are summarized below.

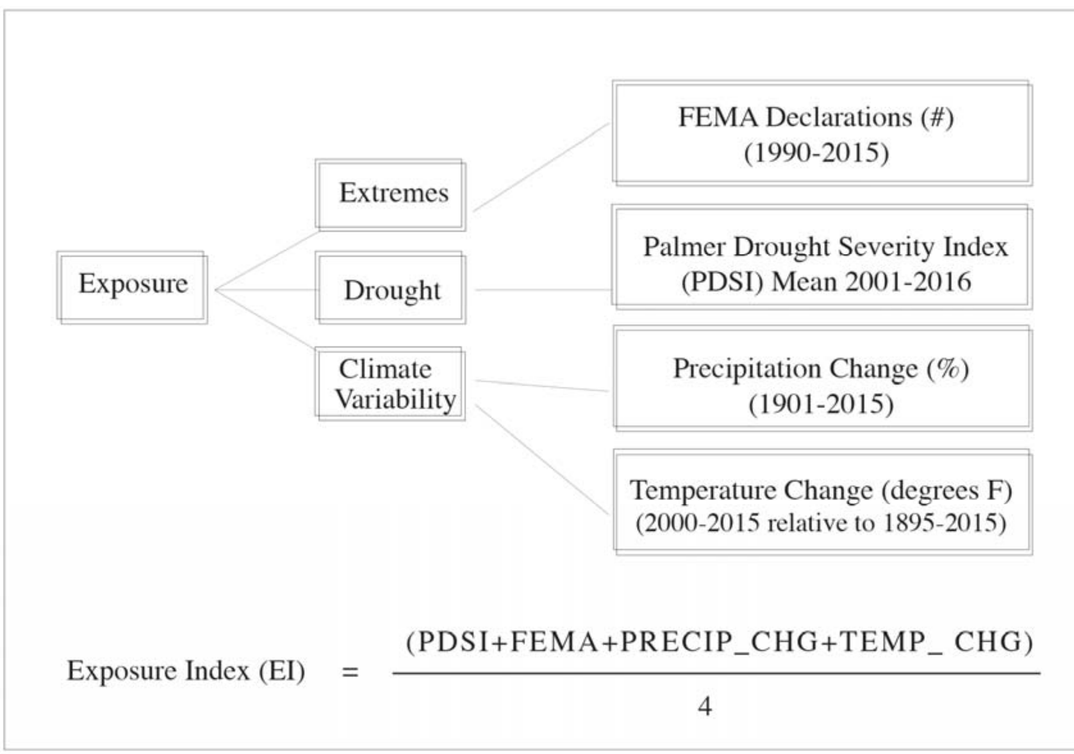


Figure 14. Components of Exposure Index (EI).

5.5.1.1 Mean Palmer Drought Severity Index (PDSI). Generically, “a drought is a deficit of precipitation that can lead to significant water stress that negatively affects natural and human systems” (Ficklin et al, 2015 p. 136). Drought begins with an accumulated precipitation deficit (meteorological drought), which in turn leads to a reduction in soil moisture content (agricultural drought) and eventually causes a reduction of surface water supplies (hydrological drought). Precipitation and moisture deficits usually accumulate for several months before either hydrological drought or agricultural drought manifest themselves. Choosing the most appropriate definition and method of measurement for drought depends upon the audience and the causation, which range from rainfall deficiencies, through run off deficiencies, to the availability of water for crops in the growing season. The PDSI was ultimately chosen as a proxy for a more localized drought index. Despite the implicit limitations of using a metric at such a large scale, PDSI has proved to be a reliable measure to study drought over small regions (Horváth, 2002), countries (Makra et al., 2002), continents (Briffa et al., 1994), as well as a global scale (Dai, 2011). Fincklin (2015) found that PDSI also “significantly correlated to moisture content and streamflow in many regions around the world” (p. 136). Generally, it is a soil moisture algorithm ranging from -6 to 6 with negative values indicating dry spells and positive values indicating wet spells. The PDSI classification scheme in the US applies a ±4.0 extremity threshold. Values ranging 0 to -0.5= incipient drought; -1.0 to -2.0 = mild drought; -2.0 to -3.0 = moderate drought; -3.0 to -4.0 = severe drought; and greater than - 4.0 = extreme drought. The values seen in Figure 15 were applied to all 72 tribes in this study. Those areas having low average. PDSI values for the period 2001-2016 were identified as being more vulnerable as they have sustained greater exposure to persistent drought conditions.

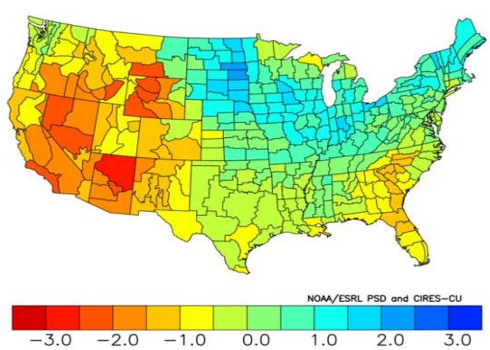


Figure 15. Palmer Drought Severity Index (mean 2001-2016). (Data retrieved from- NOAA/NCEI, 2017).

5.5.1.2 Variance in temperature (TEMP_CHG). Crops, livestock and people are vulnerable to temperature increases. The Southwest is getting hotter consistent with ongoing global changes in climate. The EPA reported that every part of the Southwest experienced higher than average air temperatures between 2000-2015 compared with the long term climate average (1895-2015). Some climate divisions are nearly 2°F warmer than average. The indicator seen in Figure 16 was applied to seventy-two tribes falling within twenty-three corresponding climate divisions. Six tribes were counted in two climate divisions. The EPA (2016) did not report values for the two most northern climate divisions. TEMP_CHG demonstrates which climate divisions have experienced the highest temperature departure from their respective long-term average. Enhanced temperatures between 2000-2015 above the long-term average contributes to vulnerability.

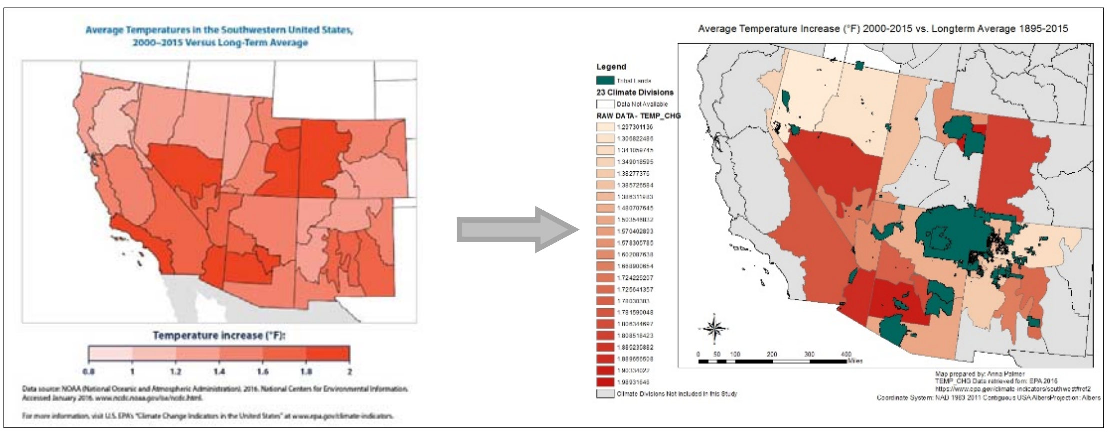


Figure 16. Temperature Change 2001-2016 relative to 1895-2000. (Data retrieved from- EPA 2016).

5.5.1.3 Precipitation change (PRECIP_CHG). Climate change is altering precipitation regimes making farming and ranching more difficult. Decreases in rainfall limits available water supply for crop growth and livestock watering. The percent change in precipitation between 1901-2015 was calculated by the EPA (2016) using NOAA's nClimDiv gridded dataset. **"**This indicator shows annual anomalies, or differences, compared with the average precipitation from 1901 to 2000" (EPA, 2016). Much of the Southwest has experienced a significant decrease of precipitation over the last century and some climate divisions have experienced as much as thirty percent decrease over that time. Indicator values seem in Figure 17 were applied was applied to seventy-two tribes falling within twenty-five corresponding climate divisions. Eight tribes received scores based on averages of two climate divisions. Negative percent changes in precipitation contributes to vulnerability.

A limitation of this metric is that it does not distinguish types of precipitation and therefore does not capture the serious consequences of decreased snowpack, which is one of the most significant impacts of climate change in the Southwest (Reedster et al. 2013). For example, decreasing snowpack has major impacts for the Pyramid Lake Paiute Tribe. Historically, snowmelt has contributed to spring time river flows. The critically endangered and spiritually significant Cui-ui fish relies on snow pack because it hatches its egg in spring when its growth is optimized by the cold mountain run off. The negative consequences of reduced snowpack are not captured by this assessment.

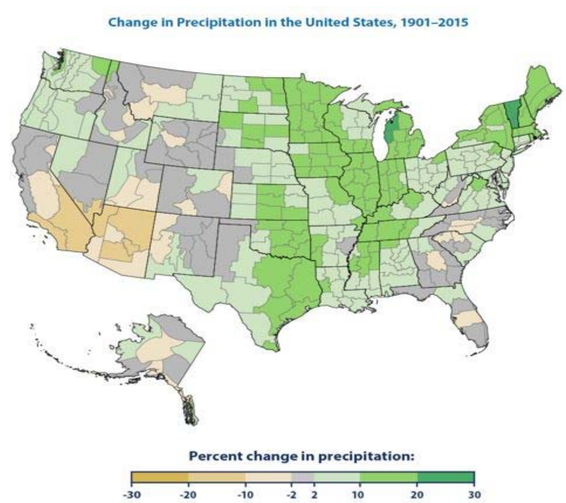


Figure 17. Precipitation change 1901-2015 (Retrieved from EPA, 2016).

5.5.1.4 Disaster declarations (FEMA). The only indicator for the EI that was collected at the tribal scale is the number of natural disasters declared by FEMA between 1970-2015. Climate stresses such as drought, flood and fire act on a number of previous, long term vulnerabilities defined by access to resources. Social groups with limited financial capital experience greater difficulty preparing for and recovering from natural disasters such as this (Blaikie et al., 1994). Tribes with low levels of coping capacity are disproportionately impacted by climate extremes. Figure 18 shows the devastating impacts of a flood which occurred on Navajo nation in August

2016. It displaced twenty-seven families and washed away entire homes, farms and livestock (Landry, 2016). A greater frequency of declarations indicates greater exposure to climate extremes and higher vulnerability. Following the assumption that changes in global climate will increase the severity and frequency of natural disasters (Gbetibouou., 2010, O'Brien et al., 2004).

Figure 18. Flood on Navajo Nation (Retrieved from Landry, 2016).

5.5.1.5 Scale for Exposure Index - twenty-five climate divisions in the American Southwest. To capture impacts of climate variation, the divisional averages of twenty-five climate divisions were applied to seventy-two Indian tribes/bands/communities (see Figures 19, 20 & 21). Data at the climate division scale were extracted from NOAA/NCEI (2017) and the EPA (2016) datasets for three sub-indices in the exposure index. Eight tribes that had more than forty percent of their land split in-between two climate divisions received the average of both climate division values which increased the number of unique climate division scores from twenty-five to twenty-eight. Figure 21 shows a histogram of tribes in each climate division.

Figure 19. Climate divisions- map of the 344 climate divisions in the conterminous US. Divisions highlighted in gray are discussed in this thesis.

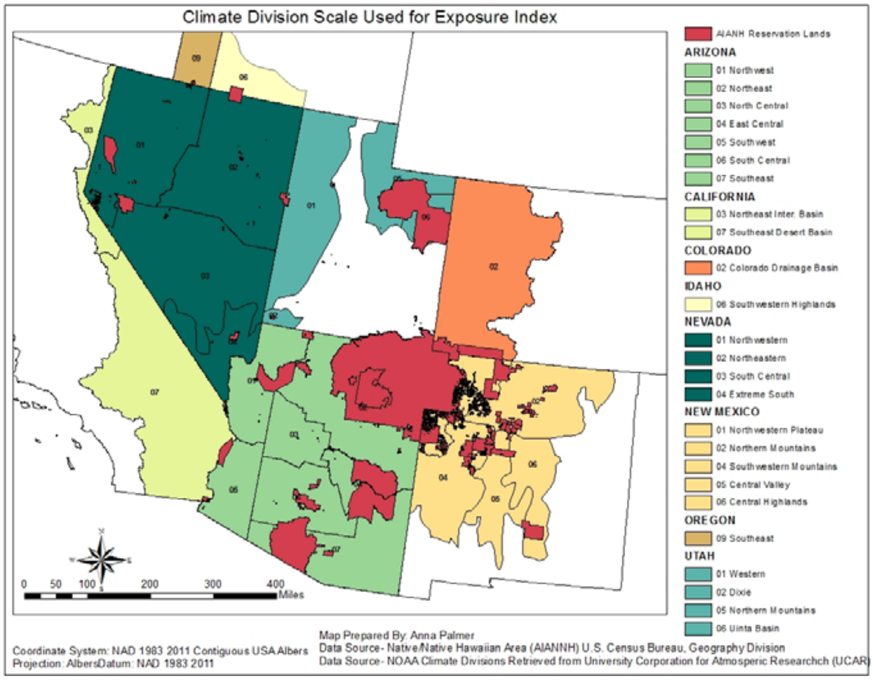


Figure 20. Exposure index study area - 72 Federally recognized tribes with the majority of land area located within 25 climate divisions.

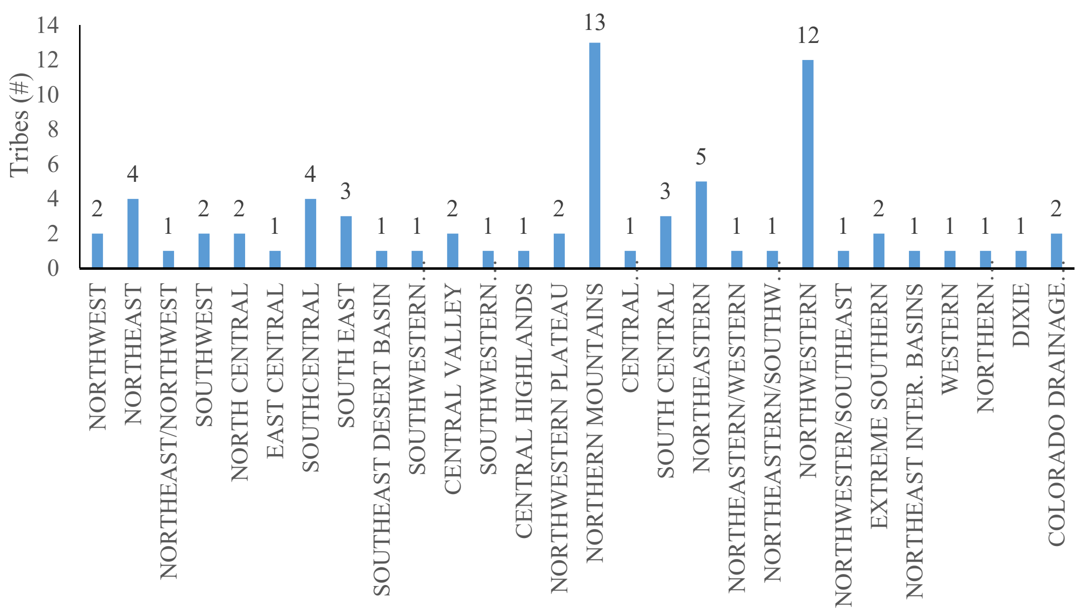
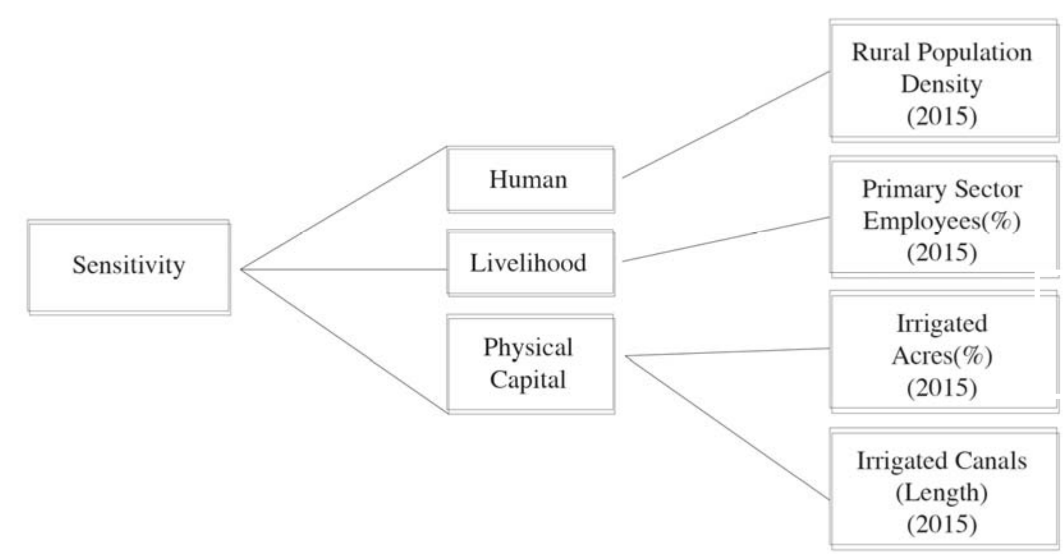


Figure 21. Histogram – number of tribes within each corresponding climate division.

5.5.2 Sensitivity index (SI). Sensitivity describes the human–environmental conditions that can worsen the hazard, ameliorate the hazard, or trigger an impact. The sensitivity dimension is intended to measure the internal sensitivity of an exposed system. Three sensitive components were identified and quantified by four measurements (see Figure 22). The first component represents human or demographic sensitivity, measured by population density. The second component is livelihood sensitivity, measured by the percentage of primary sector employees. The third component is the level of physical capital which encompasses the physical assets and produced assets that enable people to pursue their livelihoods (Carney, 1998). Here, physical capital includes the percentage of irrigated land that a community theoretically utilizes for crop and livestock production as well as land leases, tourism and other economic ventures. The four indicators included in SI are summarized below.



$$\text{Sensitivity Index (SI)} = \frac{(POP\_DENS+AG\_EMPLOY+IRR\_LND+IRR\_LGNTH)}{4}$$

Figure 22. Components of the Sensitivity Index (SI).

5.5.2.1 Rural population density (POP_DENS) Greater population densities indicate greater vulnerability of exposed populations. Gbetibouou et al., 2010 stated that "the assumption here is that regions that are relatively less inhabited are less sensitive in terms of adverse climate change impacts as compared to regions with high population densities given the same degree of exposure to climate hazards" (p. 177). The functional relationship of this indicator with vulnerability follows the common assumption that population density increases vulnerability due to the absolute number of people that could be effected by disasters and human losses. However, this assumption can be challenged due to the fact that semi-arid rural areas might be more vulnerable than more densely populated regions because of geographic isolation and limited opportunities for earning income. According to the US Census Bureau's classification system, rural areas consist of open countryside with population densities less than 500 people per square mile and places with fewer than 2,500 people. Using this definition only eight tribes have population densities greater than 500 people per square mile and all the rest are considered rural. While vulnerability generally increases with population density, it is important to acknowledge that tribal nations with low population densities are also vulnerable because rural residents typically have lower incomes and are more dependent on locally based resource extraction economies (e.g., farming, rangelands, and fishing) that will be impacted by climate change. Because of the log-normal distribution of the data a logarithmic transform of the data (10log) was used to calculate the sub-indicator score for POP_DENS.

5.5.2.2 Percent employed in agriculture (AG_EMPLOY). Primary sector jobs on tribal lands in the arid Southwest are vulnerable in an era of changing climate and severe drought. Drought is a recurrent phenomenon disproportionately causing socio-economic imbalance in rural tribal areas. Many American Indians are dependent on primary sector activities for subsistence farming and economic development. The purpose of this indicator is to identify which tribes have greater dependence on primary sector activities reported by the US Census, such as crop production, animal production and aquaculture, forestry, logging, fishing hunting and trapping, and support activities for agriculture and forestry. Gbetibouou et al., (2010) highlighted that "the presence of this indicator refers to the ability of farmers in a region to shift to other economic activities in response to reduced agricultural income which could result from adverse climatic conditions such as drought" (p. 178). Higher proportions of those employed in agriculture correlate to higher vulnerability.

5.5.2.3 Percent of irrigated land (IRR_LND). Potential drought impacts on rain-fed ecosystems in the Southwest are broad. Farmers who cultivate marginal, rain-fed lands are more vulnerable than those with access to the most productive lands. Several studies have noted that "having access to water for irrigation purposes increases the resilience of farmers to climate variability" (Gbetitbouou et al., 2010 p. 177). Aforementioned research provides the impetus for numerous technological improvements in irrigation efficiency on tribal lands (Guatam et al., 2013). Settlements to deliver water rights are decided through a bureaucratic process and ultimately approved through the US Congress. Reedster et al., (2013) elaborated that "congressional action is needed to approve settlements and allocate the funding necessary to build water-delivery infrastructure" (p. 398). The irrigated land indicator goes back to the legal precedent in the Winters Doctrine stating that if a federally recognized reservation cannot farm then they cannot develop a livable homeland and the land is not serving their "intended" purpose. A significant threshold determining the resilience of tribal communities is the amount of irrigated acres they have. The data for this indicator was gathered from six sources, including Tiller (2015); BIA Fact Sheets (2015); the United States Department of Agriculture (2012); the Arizona Department of Water Resources (2014); the New Mexico State Engineer Office (2004) and Colorado River Research Group (2016). There is uncertainty regarding the accuracy of reported values.

$$Percent\ Irrigated\ Land = \frac{Irrigated\ Land\ (ac)}{Total\ Land\ (ac)}$$

5.5.2.4 Length of perennial irrigated canals (IRR_LNGTH). One of the major contributors to vulnerability across tribal borders is a lack of water infrastructure which is in severe disrepair or totally lacking on some reservations. To capture the extent of water system technology present, the physical size of the water distribution network was measured with an index similar to the one used by Polsky et al., (2007). However, there is very limited data publically available to quantify this variable. The best secondary data source available was the 1997 Topologically Integrated Geographic Encoding and Referencing (TIGER) database of hydrologic features (U.S. Census Bureau, 1997). These same TIGER/Line files were also used by Wilhelmi and White (2002) in an agricultural vulnerability assessment of Nebraska. Methods involved downloading the 1999 TIGER/line dataset and projecting it into the NAD 1983 US Albers coordinate system in GIS. Irrigated canal features representing "man-made channels to transport water" were clipped to reservations boundaries. Subsequently a definition query was run on the CFCC column to distinguish between features labeled H21 - representing perennial canals, ditches, or aqueducts and H22 - representing intermittent canals, ditches, or aqueducts. This index only measures perennial ditches, as rain fed intermittent ditches are more vulnerable to climate change. Then the length of H21- line features was summarized within each reservation boundary using the 'summarize' tool in GIS. Results represent a length measurement in meters of man-made perennial canals, ditches, or aqueducts within reservation boundaries. They were imported into Microsoft Excel and joined to tribes based on the AFFGEOID identifier provided by the US Census. Finally, due to the variance in the sample the logarithm of the length was used for the final IRR_LGNTH sub-indicator.

According to the IPCC (2014) "crop farming in arid zones requires irrigation" (p.1759). The analysis conducted for this thesis, found that thirty-eight reservations do not have perennial irrigation networks, thus, infrastructure investments are needed to reduce sensitivity to long-term drought conditions. This index is inversely related to vulnerability, meaning that as length goes up, vulnerability goes down. It is intended to identify tribes that do not have adequate infrastructure and need further government investment. It is important to note that there is a large amount of uncertainty regarding the accuracy of the metrics reported in the 1997 Census. Because of the log-normal distribution of the data a logarithmic transform of the data (10log) was used to calculate the sub-indicator score IRR_LENGTH.

$$Irrigated\ Length = log_{10}\ (Perrenial\ Canals\ (m))$$

5.3.3 Adaptive capacity index (ACI). Adaptive capacity must be enhanced to minimize sensitivity and ensure the long-term sustainability of agricultural and rangeland activities on tribal lands. The chapter focusing on indigenous communities within the third National Climatic Assessment (NCA) noted that "in the past, Native peoples in the Southwest adapted to natural hazards through unique strategies guided by their cultural beliefs and practices" (Reedster et al., 2013, p. 394). Tribal communities have proven to be remarkably resilient to historic conditions, surviving in some of the most extreme environments while being located on marginal lands. Unfortunately, those adaptation strategies that have worked thus far might not be sufficient as we enter into a more variable future. Due to modern circumstances tribes are especially vulnerable to climatic and non-climatic stressors. Emerging threats have galvanized a concerted effort by several tribes to forge ahead with climate-change adaptation options. Human choices have profound implications on the adaptive capacity of socio-ecological systems. As McCarthy et al. (2001) asserted, "harmful impacts of climate change generally can be alleviated by adaptation or exacerbated by mismanagement" (p. 947). Adaptation seems to be the only option to reduce and/or delay the losses resulting from climate change. For this thesis, the variables that are grouped into the adaptive capacity indicator (ACI) reflect the internal ability of tribes to adjust practices and behaviors so that the impacts of climate change are reduced. Kelly and Adger (2000) argue that “any analysis of vulnerability must consider the “architecture of entitlements,” the social, economic and institutional factors that influence levels of vulnerability within a community or nation and promote or constrain options for adaptation” (p. 326).

An adaptive capacity index was constructed based on these three broad sets of factors: institutional, economic and social that represent the relative internal capacity for tribes to adequately cope with climate change. Figure 23 illustrates the relationship between eleven sub-indicators that were grouped into three composite indexes to reflect the averaged value of a set of normalized variables in each factor. These three composite indexes were then averaged a second time to create the adaptive capacity index. The following eleven indicators are that were included in the ACI are summarized below.

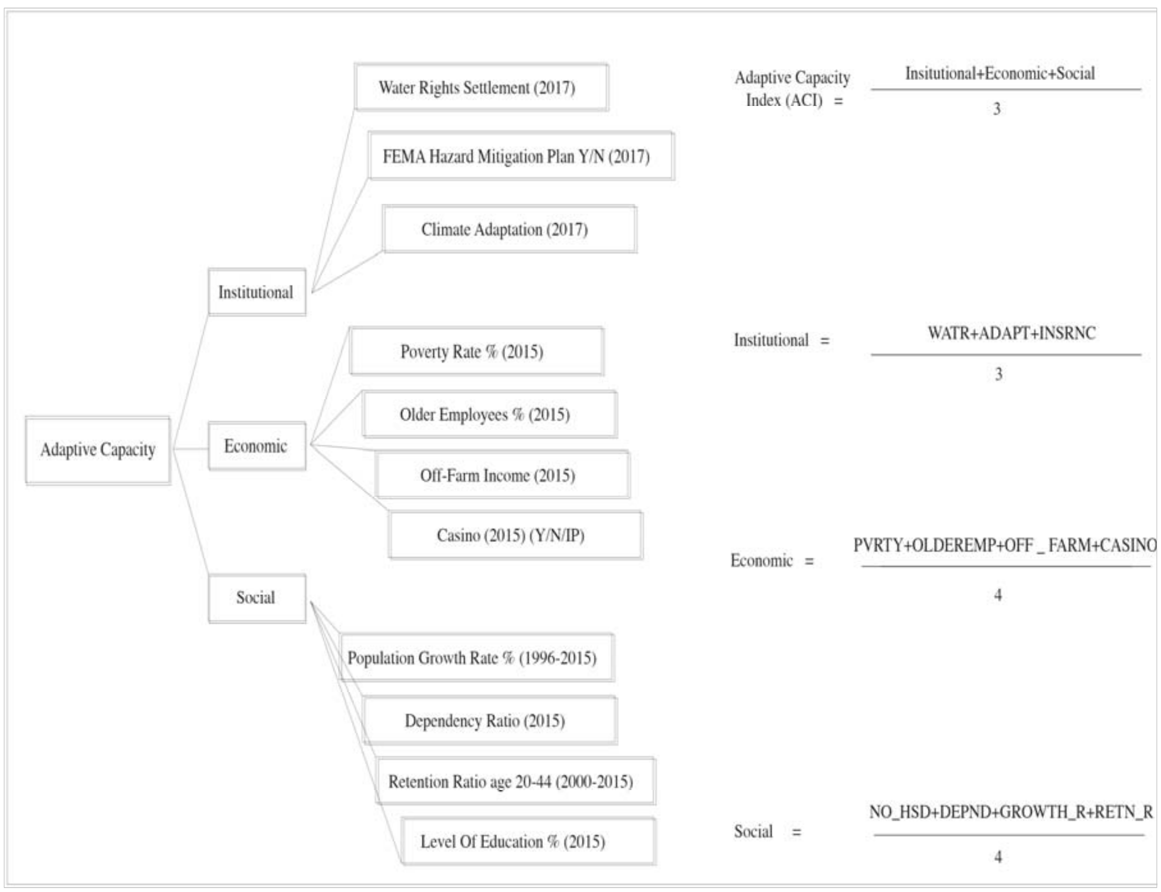


Figure 23. Components of the Adaptive Capacity Index (ACI).

5.3.3.1 The institutional dimension of adaptive capacity was analyzed through a political-economy lens. Water rights are examples of entitlements that are included in the adaptive capacity index in this study and are rooted in PEA literature. This type of information, indicates the ability of communities to cope with any external stress that is placed on their livelihoods and well-being. Three sub-indicators were chosen for this index to reflect the structures of institutions which are contributing to or hindering adaptive capacity. Institutions include formal political structures but also loose "rules of the game" that encompass shared understandings and resulting behaviors of participants (Crawford & Ostrom 1995). Crawford and Ostrom elaborate on their definition:

> Institutions are enduring regularities of human action in situations structured by rules, norms, and shared strategies, as well as by the physical world. The rules, norms, and shared strategies are constituted and reconstituted by human interaction in frequently occurring or repetitive situations. Where one draws the boundary of an institution depends on the theoretical question of interest, the time scale posited, and the pragmatics of a research project (p. 582).

Given that institutions include characteristics of social norms, it has been argued that, a primary role of institutions is, in fact, to enable society to adapt (O'Riordan & Jordan, 1999). Three measurements were identified to represent institutional adaptive responses that reduce tribal vulnerability.

5.3.3.1.1 Water rights (WTR). Water rights are closely linked to the vulnerability and adaptive capacity of tribes (Reedster et al., 2013). Tribal water settlements ensure that American Indian people have safe, reliable water supplies and the means to develop their livable homelands. The water rights indicator used in this study was calculated as the adjudicated water entitlement (afa)/total reservation land (acres). One-acre foot is a quantity of water needed to cover: one acre (a) one-foot-deep (f) annually (a). Federally recognized tribes which have not gone through the adjudication process technically still have priority to water due to treaty water rights declared by the 1908 *Winters* decision. However, during water shortages these treaty rights are often not protected and the Federal government often fails to uphold their federal trust responsibility. Adjudicated water rights are particularly important as the Southwest enters into a more variable future because these federally protected settlement agreements ensure that treaty rights are met and validate tribal priority during shortages. Adjudicated water rights greatly enhance adaptive capacity as they demonstrate strong institutional capacity to adapt. Across the US, Stern (2015) reported that since 1978, 33 innovative settlements have been approved benefitting 36 distinct tribes. There are seventeen tribes included in this study which have gone through the adjudication process (seen in Figure 24). The functional relationship between adjudicated water rights settlements and vulnerability is inverse, meaning tribes with settlements are less vulnerable than those without them. This index is particularly relevant for American Indian lands and also reflects theories that social entitlements reduce vulnerability (Kelly and Adger, 2000).

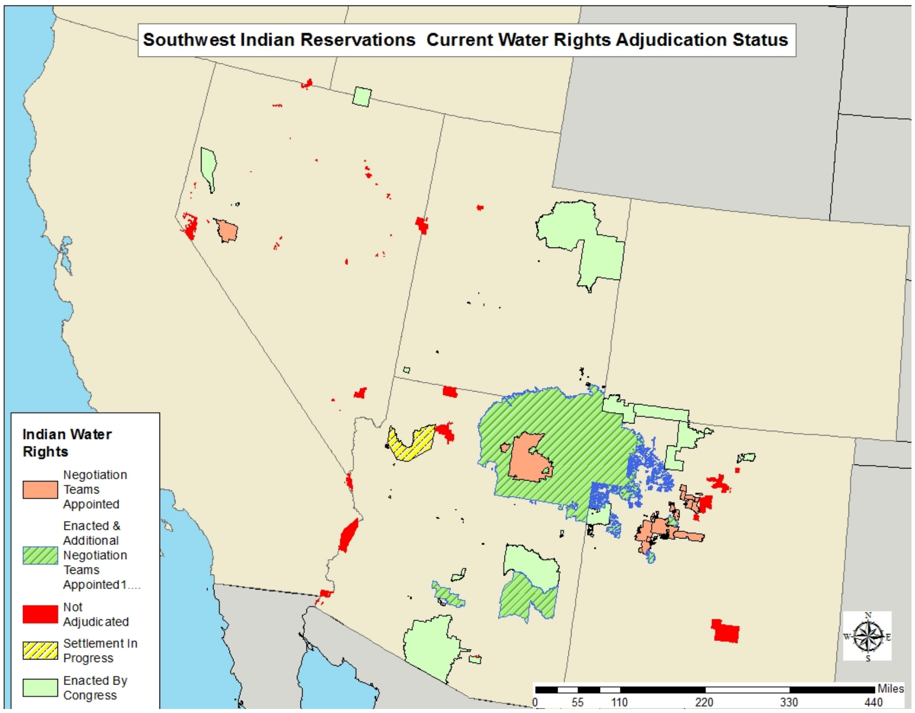


Figure 24. Current status of federally adjudicated water rights on tribal lands (Data retrieved from Stern, 2015).

5.3.3.1.2 Climate adaptation plan (ADAPT). Despite a lack of adequate funding, there is a concerted effort by many tribes to forge ahead with climate-change adaptation plans. Chief et al., (2014) asserted that “when indigenous peoples shape climate policies indigenous communities and livelihoods become more resilient” (p. 167). Tribes must cope with short-term climate variability and simultaneously adapt to long-term change. Tribes were ranked on an ordinal scale from 0.5 (representing extremely low institutional adaptive capacity) to 3.5 (representing extremely high adaptive capacity). Tribes in each category represent similar institutional characteristics and were coded based on the scheme below:

3.5 (extremely high) institutional adaptive capacity indicates that climate adaptation is a top priority demonstrated through -

- Recent up to date plan (hazard mitigation, wetlands, comprehensive, zoning updates);
- strong planning or natural resources department high levels of human/technical capital;
- recent demonstrated effort to reduce climate change vulnerability (awarded climate adaptation funding from BIA 2014-2016, Clean Water Act (CWA) funding from EPA, large scale energy project being funded by the DOE;
- participation in a regional, multi-jurisdictional, intertribal organization that is actively working on enhancing climate adaptation on tribal lands.

3 (high) institutional adaptive capacity indicates that climate adaptation is a top priority demonstrated through -

- Restoration or conservation efforts that are underway;
- a drought plan over ten years old that needs to be updated;
- strong planning or natural resources department high level of human/technical capital
- eligible for the CWA (319) list;
- participation in a regional, multi-jurisdictional, intertribal organization part that shares technical capacity;
- adaptive water conservation efforts in place (high tech agriculture, recently upgraded irrigation system).

2 (moderate) institutional adaptive capacity indicates that climate adaptation is important and institutions are actively capacity building/currently adapting as demonstrated through –

- Participation in a regional, multi-jurisdictional, intertribal organization;
- presence of a natural resources department but no formal plan in place;
- demonstrated effort for energy efficiency with award of an energy efficiency community block development grant (EECBG);
- eligiblity for other sections of the CWA other than (319);
- the government having conducted an environmental needs assessment and seeking external help due to limited internal capacity water resources department;
- actively working on a formal land use/preservation plan;
- recently receiving funding from BIA for climate adaptation but has not demonstrated any tangible adaptation/mitigation measures yet;

- having completed a clean-up/restoration project that is no longer underway.

1 (low) institutional adaptive capacity indicates that there is limited adaptation due to limited human capital being demonstrated through -

- participation in a regional, multi-jurisdictional, intertribal organization and does not have a natural resources department;
- lack of a climate adaptation initiative;
- a comprehensive plan >20 years old;
- absence of eligibility for any federal CWA or EECBG funding.

0.5 (extremely low) adaptive capacity indicates that there is limited adaptation due to insufficient human capital being demonstrated through -

- absence of all of the criteria listed above, and almost no information available about the tribe itself or its climate adaptation efforts.

Tribes were coded to achieve the goal of identifying innovative climate adaptation efforts that have already resulted in demonstrated success for mitigating the impacts of climate change on a tribal level. The research for this index investigated tribal mitigation efforts to understand the different stages of the climate adaptation process, as well as various barriers that are hindering tribal efforts to adapt. Long-term climate action or natural resource plans can be incredibly difficult to form and require high levels of human capital and technical knowhow to develop. Overcoming these barriers can be aided through strategic partnerships with extension offices, colleges or consulting firms outside of the tribal system.

It is important to note that this index is a latent variable and biased due to the subjective judgement of assigning a rank for climate adaptation based on limited information available online regarding the level of administrative capacity for climate planning. Resources informing this index included the information available on tribal websites and tribal profiles reported in the Tillers Guide (2015). Other resources were the BIA fiscal year funding from 2014, 2015, 2016, the EPA's website identifying which tribes are eligible for CWA grants; several reports regarding tribal involvement with federal, state, intertribal partners; information available on Institute for Tribal Environmental Professionals (ITEP) website and various sources on the web.

5.3.3.1.3 FEMA approved hazard mitigation plan (INSRNC). As of April 20, 2017 a total of 149 tribal governments out of 566 have FEMA approved hazard mitigation plans. Such communities benefit from hazard mitigation planning through understanding of natural hazards, development of mitigation strategies, and eligibility for certain non-emergency FEMA grants (Department of Homeland Security, 2017). The number of approved tribal hazard mitigation plans is up by thirty-two since 2015 (Carter & Peek, 2016). To date, twenty-three of the 72 tribes included in this thesis currently have FEMA approved hazard mitigation plans and an additional 14 are in the process of developing one. Tribes were ranked on an ordinal scale with values 0 representing the absence of a FEMA hazard plan, 0.5 representing that the tribe is in the process of being approved for a FEMA hazard plan, 1 representing that the tribe has a currently active hazard mitigation plan, and to 1.5 representing tribes that have a hazard plan that is currently active, but they are also in the process of updating it. Methods for collecting this data involved using the FEMA Mitigation planning portal interface on ArcGIS Online, and copying the relevant tabular data regarding current status into a separate data sheet in Excel.

5.3.3.2 Social and economic dimensions. Vulnerability to climate change is influenced by the underlying social structure that prevents social capital from eroding. According to Moser (1998), social capital is constructed by the reciprocity within communities and “stocks” of social capital include “well-known tangible assets such as labor and human capital” (p.4). The following eight indicators represent social and economic dimensions of vulnerability. At its core the concept encapsulates “features of social organization such as trust, norms and networks that can improve the efficiency of society by facilitating coordinated actions” (Putnam, Leonardi & Nanetti 1993, p. 167).

5.3.3.2.1 Retention rate (RETN_R). The retention ratio (RETN_R) of the working age population aged 20-44 over the last ten years was measured. RETN_R is a dynamic indicator representing technological and social factors which influence trends in vulnerability over time. Decadal growth of the working age population is a strong indicator of economic health and job opportunities, as well as decreased vulnerability. If the retention ratio decreased between 2000 and 2010 this indicates poor economic vitality with a greater risk of decline and increased vulnerability.

$$Retention\ Ratio = \frac{TOTAL\ Population\ (2010)\ between\ 20-44}{TOTAL\ Population\ (2000)\ between\ 20-44}$$

5.3.3.2.2 Dependency ratio (children/elderly) per 100 people (DEPEND). When the dependency ratio (ratio of elderly and children - nonworking persons - to people of working age) is high, vulnerability increases (Carter et al., 2010, Wirehn et al., 2015). The greater number of aging employees describes a less vital sector with a greater risk of decline. Additionally, if the dependency ratio, this high this indicates a high proportion of elderly and young members that are dependent upon income from working members. Therefore, large dependency ratio values represent a positive contribution to vulnerability.

$$Dependency\ Ratio = \frac{TOTAL\ Population\ between\ 0-14 + TOTAL\ Population\ over\ 64}{TOTAL\ Population\ between\ 15-64} * 100$$

Another perspective that Blaikie et al. (1994) noted was that communities with younger population can more easily take on projects that require physical labor, such as the construction of physical barriers to prevent erosion or substantial efforts to repair broken irrigation canals.

5.3.3.2.3 Average population change (%) between 1996-2015 (GRWTH_R). Average decadal growth rate is a proxy for in-migration (Carter et al., 2010). The observed population values from the 1996 Tillers Guide were recorded and merged with the observed population values from the 2000, 2010 and 2015 US Census. These four data points were used to calculate average decadal population growth rate over the past two decades. Net positive values indicate tribal vitality and net negative values will indicate outward migration, reduction in local services and limited access to resources.

5.3.3.2.4 High school diploma (NO_HSD). As Cutter & Finch (2008) noted, having a well-educated population reduces social vulnerability. The percentage of people above the age of twenty-five without a high school diploma is directly proportional to vulnerability.

5.3.3.2.5 Poverty (PVRTY). American Indian families on and off reservations are two-and-a-half times more likely than the average American family to live in poverty and the situation is worse for families on reservations (Kalt & Singer, 2004). Tribes with lower poverty rates are wealthier and have access to more credit, markets, technology and other resources that can be used to adapt to climate change. Greater poverty rates contribute to vulnerability. Poverty determines vulnerability principally by limiting access to resources which enable coping with extreme weather events.

$$Poverty\ (\%) = \frac{\#\ in\ Poverty}{Total\ Population}$$

5.3.3.2.6 Older employees (OLDR_EMP). Older employees (aged 55-66) as a proportion of the working population (aged 20 – 66) was calculated. The greater the number of aging employees, the less vital the sector and the greater risk of decline. Therefore, the functional relationship has a negative contribution to the adaptive capacity and a positive contribution to vulnerability.

$$Older\ Employees\ (\%) = \frac{Workforce\ Population(aged\ 55-64)}{Civilian\ Labor\ Force>16}$$

5.3.3.2.7 Off farm income (OFF_FARM). A ratio between the number of off farm sources of income that contribute to tribal economies was calculated by recording the total number of off farm sources of income present divided by a possible twelve off farm sectors. These off farm sectors recorded by the US Census include - 1. Construction. 2. Manufacturing 3. Management, business, science, and arts occupations 4. Retail trade 5. Transportation, warehousing and utilities 6. Information 7. Finance and insurance, and real estate and rental and leasing 8. Professional, scientific, and management, and administrative and waste management services 9. Educational services and health care and social assistance 10. Arts, entertainment, and recreation; and accommodation and food services 11. Other services, except public administration 12. Public administration.

5.3.3.2.8 Presence or absence of a casino (CASINO). Casinos represent important revenue streams for many tribal economies. They also represent physical capital aid in economic development. The presence of a casino reduces vulnerability.

5.5.4 Summary of data sources. All data sources that will be used in this assessment were retrieved from secondary sources including: The National Oceanic and Atmospheric Administration/National Climatic Data Center (NOAA/NCDC, 2017) for the average Palmer Drought Severity Index. The US Environmental Protection Agency (EPA, 2016) for the variance of precipitation and the percent change of precipitation. The Federal Emergency Management Agency (FEMA, 2017) for the number of disaster declarations between 1990-2017. The United States Census American Community Survey (US Census, 2005, 2010 and 2015) for several demographic statistics. The United States Census TIGER/Line GIS files (1999) for perennial-irrigation canal length**.** The United States Department of Agricultural Census (USDA, 2012) for the irrigated acreage on a fraction of reservations. The Bureau of Indian American Affairs (BIA, 2016), which provided four factsheets for the Walker River Paiute, Pyramid Lake Paiute, Ute Uintah and Ouray, and Duck Valley tribes for data on irrigation length, and irrigate acres. The Tillers Guide to Indian Country (1996, 2005, 2015) for information about irrigated acres, climate adaptation measures, and 1996 reports of population that were used to calculate in-migration. Finally, a report by the U.S Congressional Research Service (Stern, 2015) was the main source for Water Rights. Alternative water rights that are protected by state entitlements or recent water-infrastructure investment were also applied for the Cocopah, Colorado River Indian Tribe, Fort

Yuma, Fort Mojave and the Walker River tribes. The data sources used for these five tribes are the (United states Department of the Interior, 2012; Arizona Department of Water Resources, 2014; New Mexico State Engineer Office, 2000; Colorado River Research Group, 2016). Appendix B “Data Source and Technical Documentation” summarizes the data tables used for each indicator.

Chapter 6: Results and Discussion

This next chapter presents the results for the vulnerability index scores. In section 5.2 the final sub-indicator values are provided to give a profile of the Southwestern tribal nations. Values of the fourteen most and least vulnerable indigenous communities are shown in Table 5 and discussed in this section. In section 5.3 maps of the vulnerability scores are displayed and discussed.

The ultimate purpose of this thesis is to demonstrate the value of conducting integrated vulnerability assessments as an effective method for enhancing sustainability planning on tribal lands. Highly actionable assessments will provide key insights for local decision and policy makers and ultimately serve as the basis for targeting policy interventions. The results from this study provide a broad portrayal of relative vulnerability on tribal lands but these findings should be applied with caution when describing individual tribal vulnerability. More research is needed to reach firm conclusions as there is far more intricacy surrounding local adaptive capacity and community level responses than is captured by this assessment. Nevertheless, even with its broad perspective, the application of an integrated assessment approach (IAA) for vulnerability research facilitated a structured exploration into relevant topics and current challenges that tribal communities are confronting. Operationalizing this research framework was beneficial for understanding and communicating several issues and common themes affecting vulnerability on tribal lands. Ultimately, this thesis highlights key challenges that tribes are facing when confronting climate change. The maps display relative vulnerability based on composite-index scores that are supplemented with a profile of demographic, economic, institutional, and biophysical drivers of vulnerability.

6.1 Final Sub Indicator Values

The mean, median, minimum, and maximum of raw sub indicator values and their units are displayed in Table 4 below to give an overall profile of all of the tribes in the study area. The length of the irrigated canals, as well as the population density give a view of how sub-index values could skew the distribution. Therefore, a logarithmic transformation was used for these two sub-indices prior to normalization and summarization of the composite sensitivity index. Results from Table 4 demonstrate the range of capital and adaptive capacities and vulnerability when exposed to drought across the tribes in this study. Table 5 average values for the mean, minimum and maximum are presented for the fourteen most and least vulnerable communities.

Table 4

Sub-indicator values

Sub-Indicator	Unit	Mean	Median	Minimum	Maximum
Exposure					
Drought	PDSI 2001-2016 (average)	-1.73	-1.77	-1.07	-2.63
Disasters	FEMA Declarations 1990-2017 (#)	0.99	0	0	10
Precipitation Change	Rate of change 1901-2016 (%)	-2.4	0.3	5	-13
Temperature Increase	2001-2016 Relative to 1901-2017 (°F)	1.5	1.4	1.2	2.0
Sensitivity					
Population Density	Total Pop/land(mi^2)	295	27	.64	7142
Primary Sector Employment	Percent	7	3	0	55
Irrigated Acres	Percent	7	.5	0	110
Length of Water Distribution System	Meters	34,301	0	0	1,042,855
Adaptive capacity					
No High School Diploma	Percent Persons (25+)	21	20	6	47
Dependency Ratio	Number of Children and Elderly per 100 of the working population	57	55	27	116
Population Growth	Average growth rate 1996, 2000, 2010, 2014/4	13	10	-13	59
Retention Ratio	Average net in-migration 2000-2010 as a proportion of pop. 2000	.62	.80	-1.3	141
Poverty	Percent	36	31	9	63
Older Employees	Percent (workforce 55+/ working pop)	19	18	2	57
Off-farm Income	# of sectors present/12 potential off-farm sectors	10	11	12	2
Casinos	Presence or absence	0.5	1	0	1
Water Rights Settlement	afa/total acres	0.3	0	0	3.99
Adaptation	Rank (1 Low, 2 moderate, 3 high, 3.5 extremely high)	2.6	3	1	3.5
Hazard Mitigation Plan	Presence or absence (0, 0.5 (IP), 1(Y), 1.5 (Y & IP)	0.43	0.5	0	1.5

Table 5

Comparison of sub-indicator values for tribes with the highest and lowest agricultural vulnerability

		14 Most Vulnerable				**14 Least Vulnerable**			
Sub-Indicator	**Unit**	**Mean**	**Median**	**Min**	**Max**	**Mean**	**Median**	**Min**	**Max**
Exposure									
Drought	Mean PDSI	-2.16	-2.12	-2.63	-1.38	-1.42	-1.31	-2.12	-1.09
Disaster Declarations	Absolute	1.5	0	0	10	-1.14	1	0	7
Precipitation Change	Percent	-6	-10	-13	4	1	1	-9	4
Temperature Increase	(°F)	1.5	1.5	1.3	1.9	1.5	1.3	1.3	1.9
Sensitivity									
Population Density	Pop/land (mi^2)	829	50	41	7142	58	41	1.4	264
Primary Sector Employment	Percent	15	7	0	56	3	2	0	7
Irrigated Acres	Percent	1	0	0	56	12	2	0	110
Water Distribution System	Meters	6,598	0	0	88,562	19,486	10,340	0	66,163
Adaptive Capacity									
No High School Diploma	Percent persons (25+)	28	30	15	47	17	17	6	27
Dependency Ratio	Ratio	63	57	39	116	57	53	47	113
Population Growth	Average	8	7	-12	27	13	9	-12	60
Retention Ratio	Net in-migration	0.63	0.92	-11	1.4	0.53	0.67	-11	1.2
Poverty	Percent	36	35	14	58	29	27	14	40
Older Employees	Percent	16	17	3	40	20	18	10	28
Off-farm Income	Ratio	7	7	2	12	10	12	10	12
Casinos	Y/N	0.4	0	0	1	0.78	1	0	1
Water Rights Settlement	afa/land acres	0.08	0	0	1.1	0.3	0.04	0	1.7
Climate Adaptation	Ordinal Rank	2	2	0.5	3.5	3	3	1	3.5
Hazard Mitigation Plan	Ordinal Rank	0.17	0	0	1	0.85	1	0	1.5

6.1.1 EI map and quantile classification. The final EI values mapped in Figure 25 range from between .06 and .79. Quantile classifications broke values for 72 tribal areas into five classes with roughly fourteen tribes in each class (see Figure 26). Results show that six of the fourteen most exposed (Very High) tribes are found in the Northwest climate division in Nevada. Figure 27 highlights the Northern Mountain division in NM and the Northwestern division in NV which have the largest number of corresponding tribes (these had thirteen and twelve tribes respectively). Other major geographic areas of concern are the very highly exposed tribes found in the four corners region of Arizona. The Shapiro-Wilks normality test was run to check if the exposure index was normally distributed. The p-value for the Shapiro test was below alpha 0.05, thus, we reject the null hypothesis. Shapiro indicates the data in the exposure index is not normally distributed. The distribution seen in Figure 28 and 29 shows that the distribution is slightly positively skewed and that there are outliers on either end of the distribution. The large concentration of tribes in a few climate regions skewed the distribution.

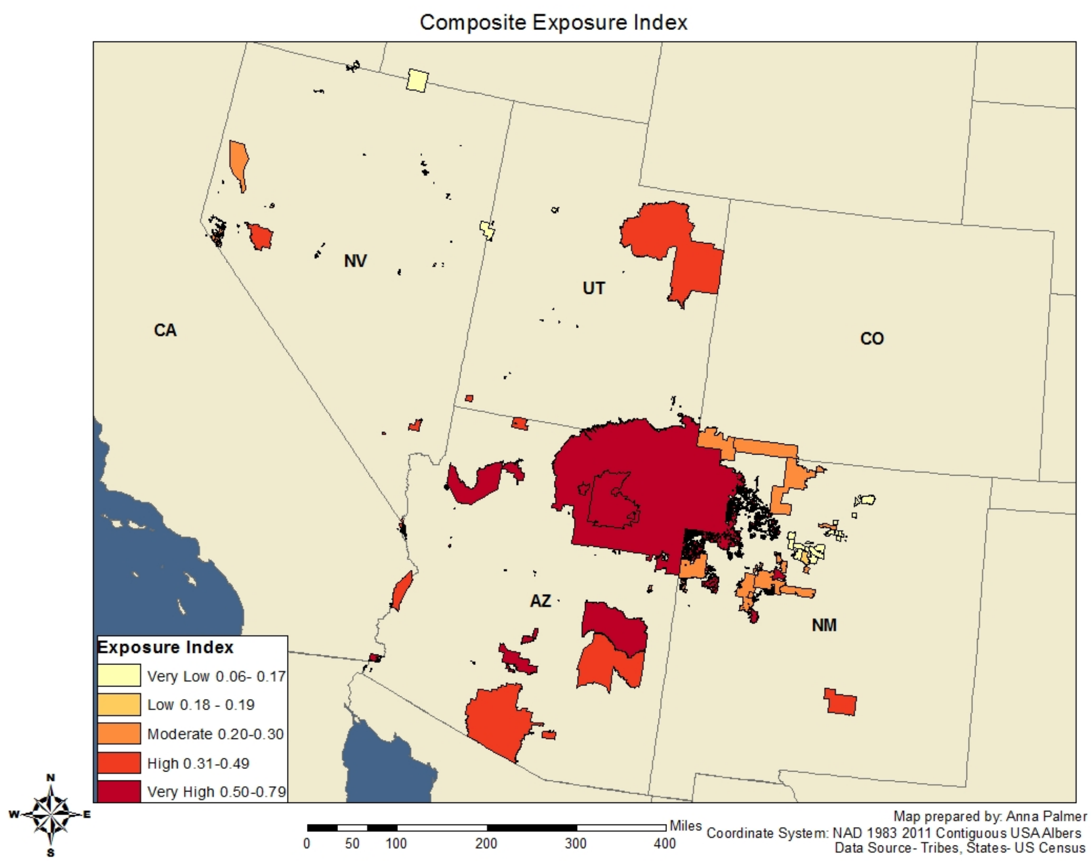


Figure 25. Composite EI map.

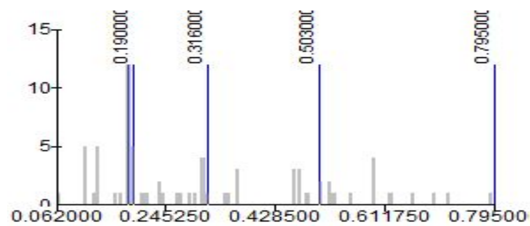


Figure 26. Composite EI quantiles - ranging from 06 and .79.

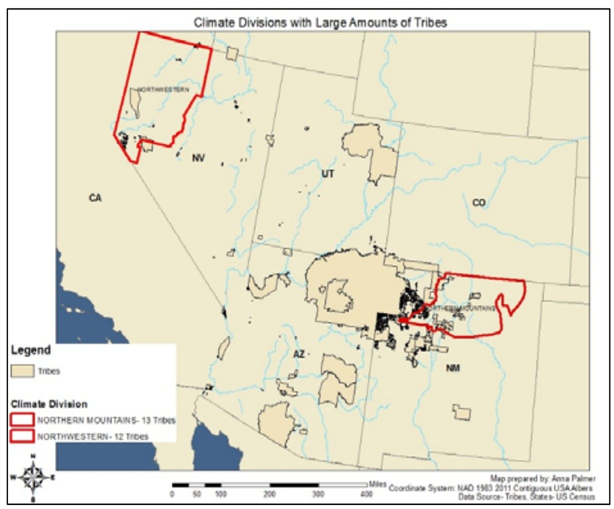


Figure 27. Climate divisions with the largest number of corresponding tribes.

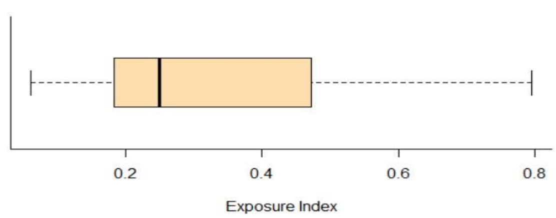


Figure 28. Boxplot of composite EI - checking for normality.

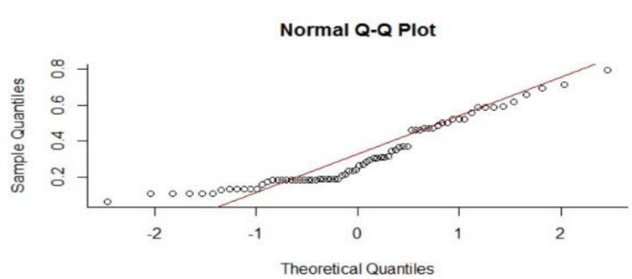


Figure 29. Q-Q plot of composite EI - shows outliers on both ends and a positive skew.

6.1.2 SI map and quantile classification. The SI scores mapped in Figure 30 range between .23 and .87. Values for each quantile class are seen in Figure 31. The p-value for the Shapiro test was above alpha 0.05, $p = 0.051$ thus, we fail to reject the null hypothesis. Shapiro indicates that data in the sensitivity index is normally distributed (see Figure 32 and 33). Results show that twelve out of the top fourteen most sensitive tribes are in the Northwestern and Northeastern climate divisions in NV. Generally, these are smaller tribes in rural areas which is why they are difficult to identify in the map. Only one tribe has water running through their territory, the other thirteen, according to the US census have zero acres of surface water. Despite limited water availability all but two of the most sensitive tribes are currently practicing agriculture.

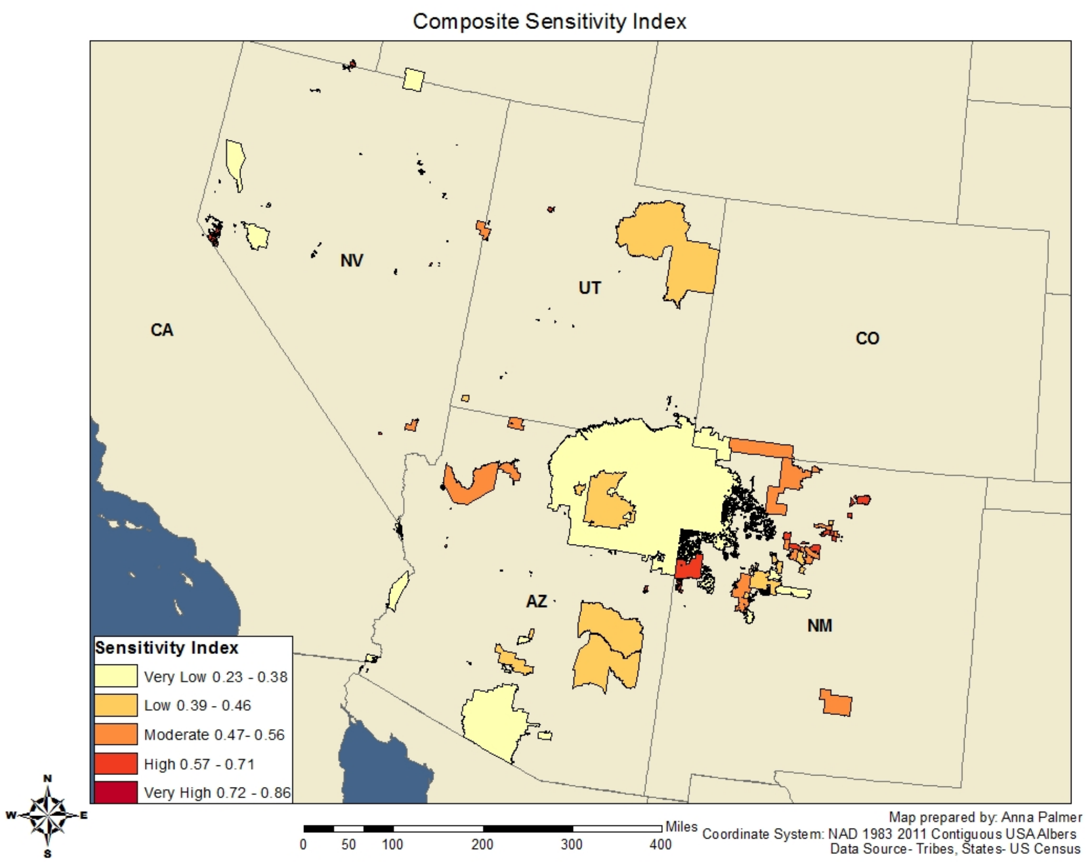


Figure 30. Composite SI map.

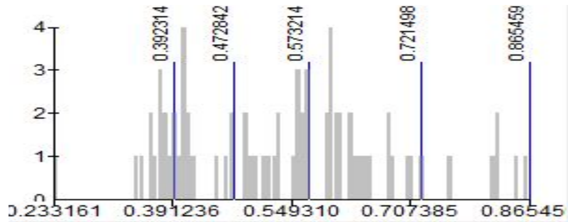


Figure 31. Composite SI quantiles - values ranging between .23 and .87.

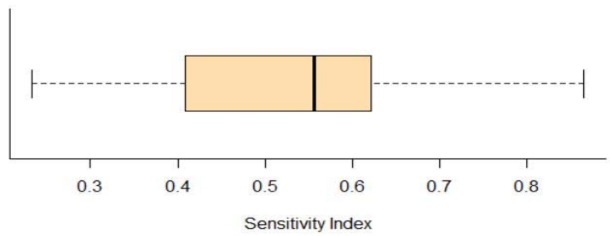


Figure 32. Boxplot of composite SI - normally distributed.

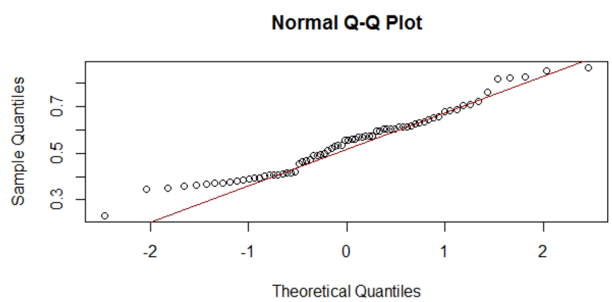


Figure 33. Q-Q plot of the normally distributed composite SI.

6.1.3 ACI map and quantile classification. The ACI classes mapped in Figure 34 ranges .32 to .95. The breaks for the quantile classification are seen in Figure 35. The p-value for the Shapiro test was not above alpha 0.05, p=.002. Shapiro indicates the data is not normally distributed in the adaptive capacity index. There are with outliers at the positive end (see Figures 36 and 37). There was not a strong geographical component to adaptive capacity but results suggest that the climate divisions with the most limited adaptive capacity (Very Low) are in Northeastern NV and the Northwestern AZ climate divisions, with four corresponding tribes each divisoin. Overall, the fourteen tribes in this class have an above average dependency ratio, a below average number of off farm income sources, and below average institutional climate adaptation all of which contribute to vulnerability.

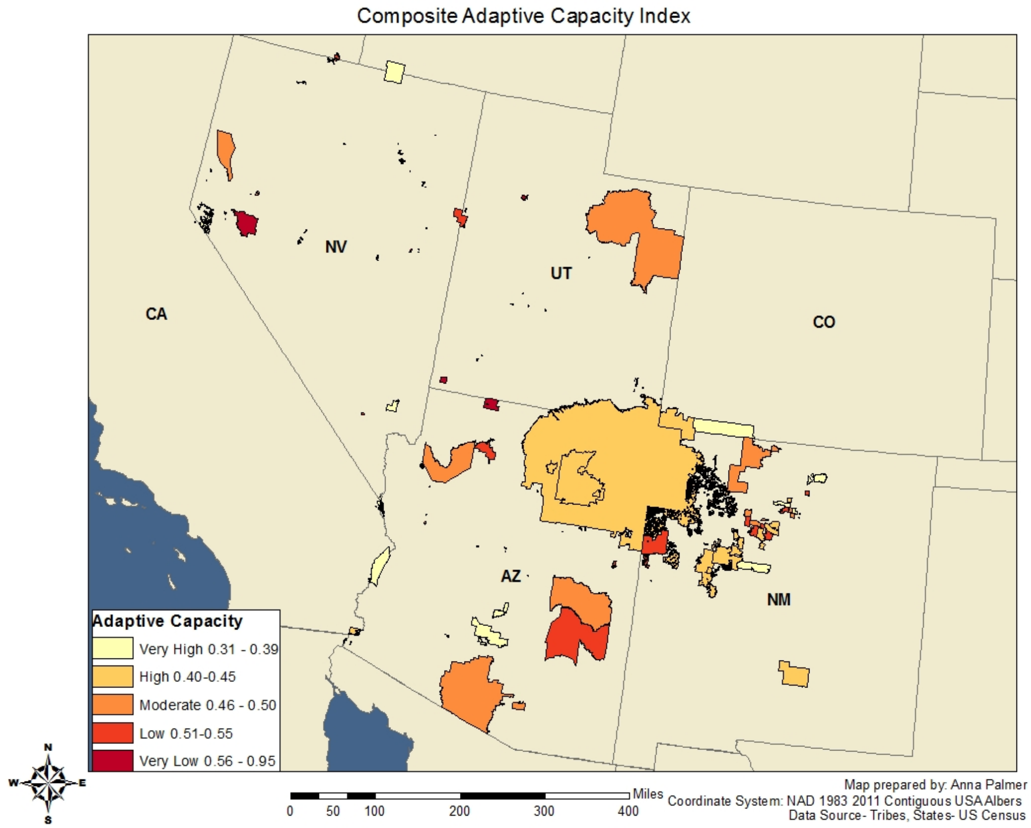


Figure 34. Composite ACI map.

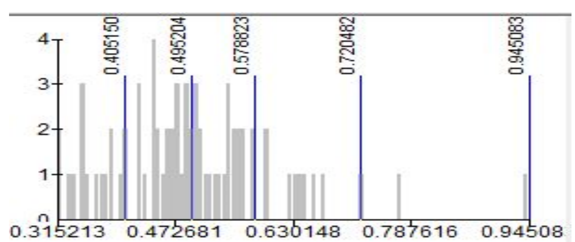


Figure 35. Composite ACI quantiles - values ranging from .32 to .95.

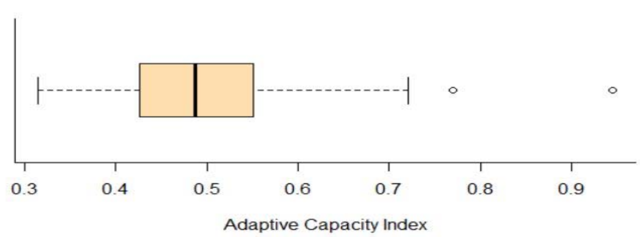


Figure 36. Boxplot checking for normality in the composite ACI distribution- note outliers on positive end.

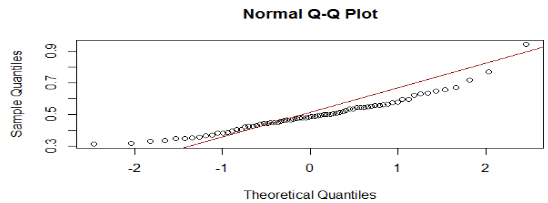


Figure 37. Q-Q plot of composite ACI - showing a non-normal distribution.

6.1.4 Composite AVI map and quantile classification. The composite ACI scores mapped in Figure 38 range from .45 to .57. The corresponding quantile breaks for each of the classes are shown in Figure 39. The p-value for the Shapiro test was not above alpha 0.05, p=.01. Shapiro indicates the data is not normally distributed in the composite vulnerability index and q-q plots show outliers on the positive end of the distribution (see Figures 40 and 41). The scores for the fourteen tribes with the greatest overall AVI is seen in Table 5. Here, results show that these tribes generally have well above average values in several indices as compared with the fourteen tribes with the lowest overall vulnerability. For example, they have higher exposure to drought, greater population density, lower water rights and institutional adaptive capacity.

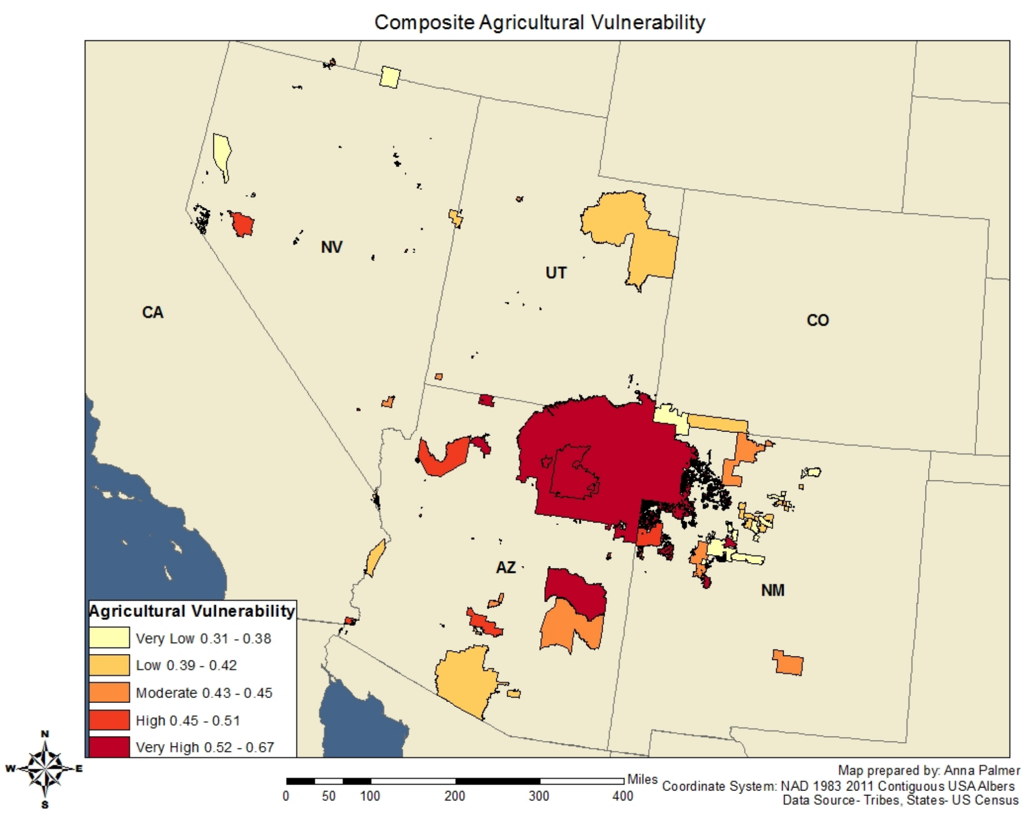


Figure 38. Composite AVI map.

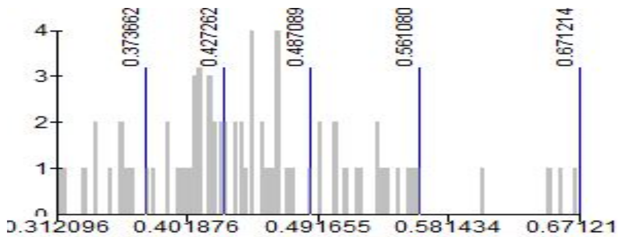


Figure 39. Composite AVI quantiles - values ranging from .32 to .67.

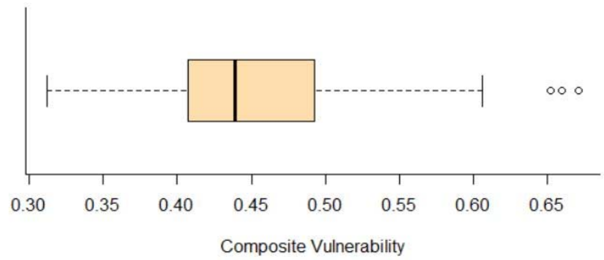


Figure 40. Boxplot checking for normality in the composite AVI distribution- note outliers on positive end.

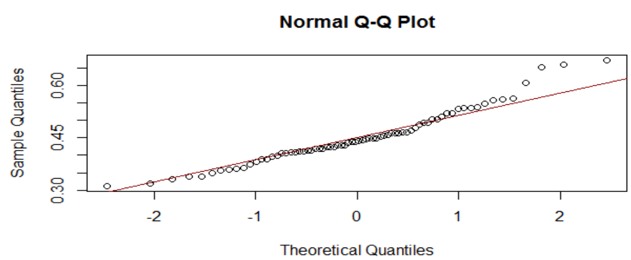


Figure 41. Q-Q plot of composite AVI – does not show normality and has positive skew.

6.2 Drawing Conclusions from Correlation Analysis Between Variables

Literature on index construction argues that a good measure of the validity for composite indices is the internal correlation between the component indicators used (O'Brien et al., 2004). The composite agricultural vulnerability index constructed in this thesis is an example of a formative index where exposure, sensitivity, and adaptive capacity indices represent multiple independent dimensions. In a formative measurement model, the index is measuring a phenomenon which is influenced by the indicators (Hellvick, 2002 cited by Leinchenko et al., 2004). But the indicators each represent unique components of vulnerability that are not all necessarily correlated with each other. For example, different properties and factors will contribute to the vulnerability of a system such as, the number of FEMA declarations, population density, irrigation rates and the presence of a casino. These indexes need not correlate with each other to serve the purpose of this formative assessment, which is intended to describe relative vulnerability. If all vulnerability-increasing properties are present, this thesis argues that vulnerability is increased and compounded.

An analysis of Pearson's Product-Moment Correlation Analysis (2-tailed) and Spearman's Rank Correlation Analysis (2-tailed) were conducted to understand the associations between the exposure, sensitivity and adaptive capacity indexes. Two-Tailed correlations were run because there was no *a priori* hypothesis as to the sign of the correlation among these three indices. Two interesting relationships emerged from these tests, though correlations were generally weak (see Table 6). There was a negative correlation between exposure and sensitivity and a positive correlation between sensitivity and adaptive capacity, though they were modest correlations.

Steps for calculation first involved the Mardia skewness test for multivariate normality between EI and SI. This test showed no violations so the Pearson's correlation was appropriate (see Table 6). With an alpha of .01, the following hypothesis was tested:

H0: The Exposure Index(EI) is not correlated with the Sensitivity Index(SI) (ρ=0)

HA: The Exposure Index(EI) is correlated with the Sensitivity Index($\rho \neq 0$)

The p-value was .0006 so the null H0 was rejected. There appears to be a significant negative correlation between EI and the SI. This indicates that there is not a strong geographic component of biophysical exposure contributing the relative sensitivity of tribes. Next, the Mardia skewness test was run between EI and ACI. This test showed that data were not multi-variate normal so the Spearman's Rank Correlation Analysis (2-tailed) was appropriate (see Table 6). The following hypothesis was tested with an alpha of .01:

H0: EI is not correlated with the ACI (ρ=0)

HA: EI is correlated with ACI ($\rho \neq 0$)

The p-value was .038 so we fail to reject the null H0 showing that there is no significant relationship between EI and ACI. A third and final multivariate normality test was run between SI and ACI. Mardia indicated that data were not multivariate normal so the Spearman's Rank Correlation Analysis (2-tailed) correlation was appropriate. The following hypothesis was tested with an alpha of .01:

H0: SI is not correlated with the ACI (ρ=0)

HA: SI is correlated with ACI (ρ≠0)

The p-value was 0.00 indicating that there is a significant relationship between SI and ACI. This positive correlation is in line with theory that areas with high levels of sensitivity have limited adaptive capacity. The relationships between variables can be seen in Figure 42.

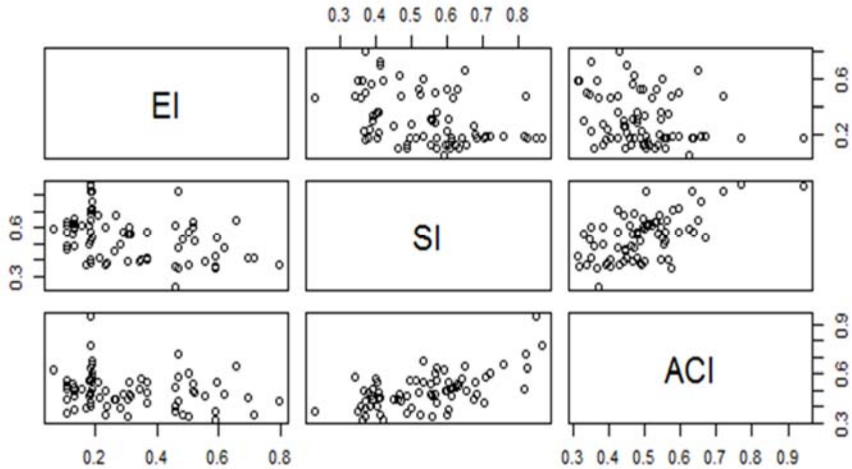


Figure 42. Scatter plot of three component indicators.

Table 6

Correlation results

		Sensitivity Index	**Exposure Index**	**Adaptive Capacity Index**
Exposure Index	Pearson Correlation	1	-0.40(**)	-
	Sig. (2-tailed)	-	0.0006	-
	Spearman Correlation	-	-	-0.24
Sensitivity Index	Sig. (2-tailed)	-	-	0.04
	Spearman Correlation	-	1	0.52(**)
	Sig. (2-tailed)	-	-	.00
Adaptive Capacity Index	Pearson Correlation	-	.-	1
	Sig. (2-tailed)	-	-	-

** Correlation is significant at the 0.01 level (2-tailed).
df = (70)

The indicator values seen in Table 7 on the following page demonstrates the overlap and diversities vulnerability scores between individual tribes with various social groupings. Generally, the data show that tribal communities with Very Low vulnerability are extremely adaptive, have hazard mitigation plans, more perennial irrigation, less poverty and greater water rights entitlements. The case is converse tribes with Very High vulnerability which tend to be less adaptive, do not have hazard plans, less agriculture, greater poverty and do not have federally approved water rights settlements. Since vulnerability is not directly measurable, uncertainties associated with the indicators, data and methods can be considered to be part of the uncertainty associated with the vulnerability assessment. Despite the uncertainty according to the values, there is an important role that drought plays in vulnerability and can be seen by comparing the difference in values in the most and least vulnerable communities.

Table 7

Selected tribal nation sub-indicators values

Tribe/Nation/ Reservation	Climate Division	Poverty	Water Rights (afa)	Primary Sector Employed	Irrigated Land	FEMA Insurance	Institutional Adaptation	Vulnerability Category
Duck Valley	Northeastern, NV/Southwestern ID	24%	114,082	6%	11,390 acres 4% total land	In Progress	Extremely Adaptive	Very Low
Pyramid Lake Paiute	Northwestern, NV	34%	34,456[i8]	7%	1,990 acres 4% total land	Yes	Extremely Adaptive	Very Low
Ute Uintah and Ouray	Uintah Basin/Northern Mountains, NM	12%	481,035	26%	83,217 acres 2% total land	Yes	Moderately Adaptive	Low
CRIT	Southwest, AZ	23%	719,248[ii]	13%	74,045 acres 25% total land	No	Highly Adaptive	Low
Zuni	Northwestern Plateau, NM	42%	10,600	4%	40 acres 0.01% total land	In Progress	Highly Adaptive	Moderate
Walker River	Southcentral, NV	33%	2,500[iii]	4%	1,095 acres 6% total land	No	Extremely Adaptive	High
Gila River	Southcentral, AZ	52%	653,500	5%	27,152 acres 7% of total land	Yes	Extremely Adaptive	High
Navajo	Northeast, NV	42%	605,330	4%	74,308 acres 5% total land	In Progress	Extremely Adaptive	Very High
Hopi	Northeast, NV	31%	0	3%	279 acres 0.02% total land	Yes	Extremely Adaptive	Very High
Battle Mountain	Northeastern NV	34%	0	23%	0 acres	No	Low Adaptability	Very High
Yomba	Southcentral, NV	50%	0	56%	450 acres 10% total land	No	Moderately Adaptive	Very High

(i)The Pyramid Lake Paiute Tribe has unique federal water rights status due to the endangered Cui-ui fish and Lahontan Cutthroat trout in Pyramid Lake. Wright (2015) reported water rights totaling 34,456 (afa) based on acquired water and unused claims (p.6).
(ii) CRIT was one of the first tribes to quantify water rights for the *Arizona v. California* decision in 1922 which is used to settle water disputes (Colorado River Research Group, 2016 p.2) However, CRIT does not have a modern adjudicated water right agreement that is protected by federal law
iii) Walker River does not have a modern agreement of federally adjudicated water rights. An unpublished BIA (2016) report states that the Walker River Indian Irrigation Project is estimated to use 2,500 acre feet of groundwater per year. This groundwater was the only comparable quantity reported.

6.3 Alternative Data Visualization Spider Diagrams

Another effective way to draw comparative conclusions from index values derived from vulnerability assessment is by representing the values in the form of spider diagrams or radar charts. This data visualization technique reduces the complex phenomenon of differential vulnerability into an easily interpreted form. Spider diagrams are used to represent three or more vector valued-variables on an axis starting from one central point (OECD, 2008). Each of the spokes represents composite index scores and provide insights into the drivers of, and differences in vulnerability across tribal lands. Areas where the shape enlarges represent areas of vulnerability. For example, the spider diagram in Figures 43 represents the index scores of two tribes that were determined to have the highest and lowest vulnerability. Duck Valley, had the lowest composite overall agricultural vulnerability index (AVI) score is represented by the inner yellow shape. While, the Yomba Tribe had the greatest vulnerability is represented by the outer red shape.

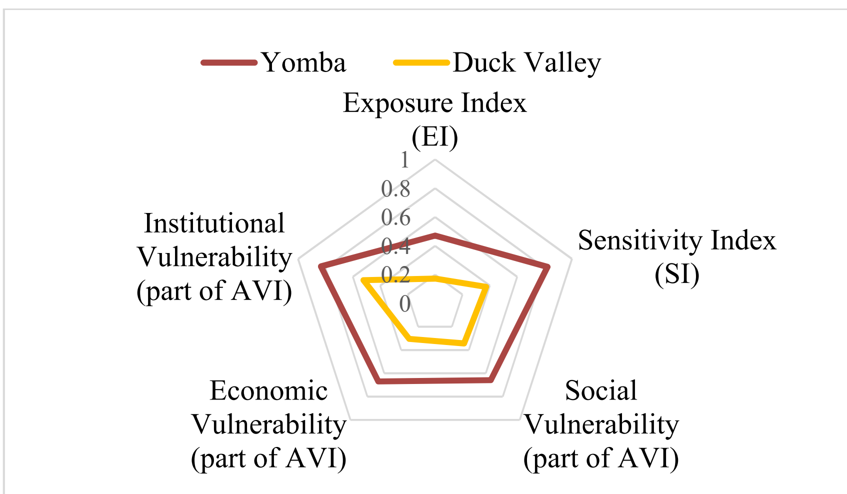


Figure 43. Spider diagram of two tribes with the highest and lowest AVI scores.

These results theoretically make sense when drawing comparisons between sub-indices of each tribe. For example, in 2015, the Duck Valley Fallon Paiute Shoshone tribe achieved a water rights settlement after forty years of litigation. The settlement included a sixty-million-dollar investment from the federal government to upgrade the Duck Valley's water systems (see Figure 44). The federal government will support the functioning of these water systems in perpetuity (Shilling, 2015).

Figure 44. Duck Valley's new and improved water system.

Data of sub-indices show that the primary sector makes up twenty percent of Duck Valley's work force compared while fifty-six percent Yomba's workforce is employed by primary sector activities. Duck Valley has a more diverse economy with ten out of twelve economic sectors present while Yomba has three out of twelve economic sectors present. Duck Valley also has a lower poverty rate at twenty-four percent compared tribe with the Yomba tribe which has a fifty percent poverty rate. Also, Duck Valley is less isolated geographically and is located close to Elko city. Their government is also a part of an intertribal organization known as the Upper River Snake Tribes (URST) council that works together to adapt to climate change. Figure 45 shows where the tribes are geographically located. Figure 46 shows Yomba Reservation.

Figure 45. Map of tribes determined to have the highest and lowest overall AVI.

Figure 46. Yomba Reservation.

The next comparison is between two tribes that were both grouped into the Low Vulnerability category for the overall Agricultural Vulnerability Index. Theoretically, the model should not only identify tribes that are outliers and merit particular concern, but it should also categorize tribes representing similar characteristics into appropriate groups or quantiles. For example, the following two tribes, the Tohono O'odham Naiton and the Colorado River Indian Tribes (CRIT) fell into the same Low Vulnerability category. Figure 47 shows that they reflect similar vulnerabilities subindicators scores as is visualized by clearly similar vector-shapes. The following similarities in data were seen, both tribes are located in the Sonoron Desert and have relatively large populations (see Figure 48). The Tohono O'odham has an adjudicated water rights settlement and CRIT has alternative water rights agreements. Furthermore, both tribes were considered as having highly adaptive governments. Finally, both tribes have a large amount of economic diversity supported by revenue from casinos and a large amount of non-agricultural dependent economic sectors. These strengths indicate that both tribes are climate resilient.

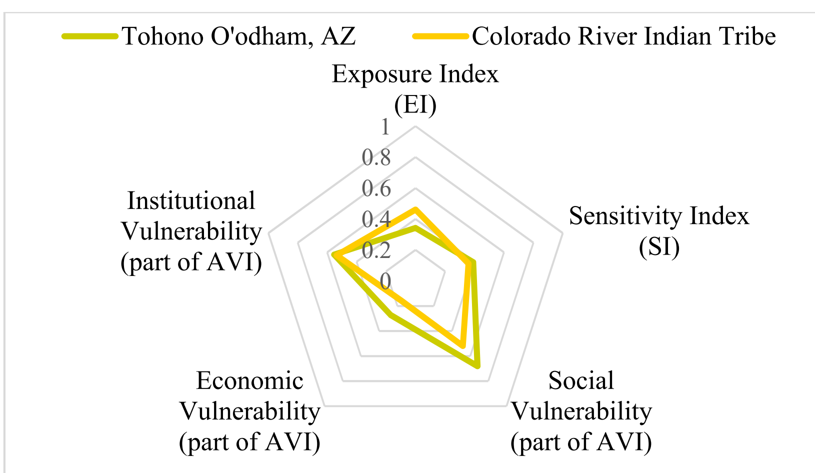


Figure 47. Spider diagram of two tribes with low AVI scores.

Figure 48. Map of tribes both categorized into the same quantile indicating low AVI scores.

6.5 Limitations of this Model

The first limitation and source of uncertainty for assessment results are the differences in scale and variability across individual tribes. Results of comparative analyses are more accurate if communities demonstrate similar biophysical and social characteristics. That was not true for this thesis, as tribes included are drastically different. For example, the smallest reservation included is roughly 20 acres in size, the Yerington tribe in NV, and the largest tribal territory, the Navajo nation is roughly 15,460,055 acres, slightly larger than the state of West Virginia. Similarly, tribes are located across a range of climates. A recommendation for future research would be to apply a typology for grouping tribes that have similar characteristics. A good model to follow for this is Alessa, Kliskey & Altaweel (2009) study presenting a typology for assessing mountain settlements. Furthermore, since vulnerability is not directly measurable, uncertainties are associated with the indicators, data and methods.

There are also drawbacks associated with the application of divisional level data averages as proxies for specific climatic variations on tribal lands. However, it was beyond the scope of this study to create a finer resolution report on climate variability tailored for each reservation. High resolution local data informs operational vulnerability assessments which detect small scale biophysical variabilities. This information is then synthesized to inform short and long term adaptation strategies. For example, the weekly updates at the county level for the U.S. drought monitor signal when to begin using conservation measures in a drought. If this thesis was not limited by time, the author would have generated more accurate reflections of local drought exposure at the tribal level using daily or weekly weather station data from NOAA/NCDC for only those stations that fall within (or near), reservation boundaries. With this info a drought index such as the Standardized Precipitation Index (SPI) could be calculated.

The following paragraph reports that the climate division sub-indices for precipitation change and drought are correlated with one another. As previously mentioned, three sub-indicators at the climate division scale were applied to the 72 tribes in the Exposure Index. To validate the reliability of these observed metrics, it was necessary to explore the statistical relationship between these three indices. Using the raw sub-indicator values of the climate division scores both a Pearson's correlation two-sided test and linear regression analysis were performed. Pearson's test confirmed a significant correlation and interaction between PDSI and PRECIP_CHG (see Table 8 and Figure 45). Results show that PDSI and PRECIP_CHG were positively correlated at the 99% confidence level with a correlation co-efficient of (.44). The interaction between these two variables is likely caused by an overlap of precipitation data used to calculate both indices. There was not a significant correlation between PDSI and TEMP_CHG although the correlation co-efficient showed a linear relationship between these two values (0.34) as well. Next, a multiple linear regression was calculated to predict the PDSI as the independent variable based on two dependent variables PRECIP_CHG and TEMP_CHG. The regression was non-significant (F (2, 20 =2.44), $p < .05$) with an R^2 of .20. The null hypothesis for the F-test was rejected with a p-value of .11, greater than alpha .05. The data suggest that PRECIP_CHG and TEMP_CHG overall did not explain a significant proportion of variance in PDSI. Not surprisingly, the regression also confirms that PRECIP_CHG significantly accounted for variance in PDSI with a p-value of .04 less than alpha .05. Both PDSI and PRECIP_CHG sub-indices were still included in the composite Exposure Index. The statistically significant positive correlation between the two indices limits the accuracy of the exposure index, as each sub-index is supposed to represent a unique aspect of vulnerability. However, this assessment does not claim to be a precise reflection of vulnerability. The indexes that were included are conceptual, and more localized data, with a higher number of observations would improve the validity of the exposure index.

Table 8

Correlations between exposure sub-indices

		PDSI	PRECIP_CHG	TEMP_CHG
PRECIP_CHG	Pearson Correlation	1	.44**	-
	Sig. (2-tailed)		0.014	-
TEMP_CHG	Pearson Correlation	-	-	.14
	Sig. (2-tailed)	-	-	.43

** Correlation is significant at the 0.01 level (2-tailed). df=28

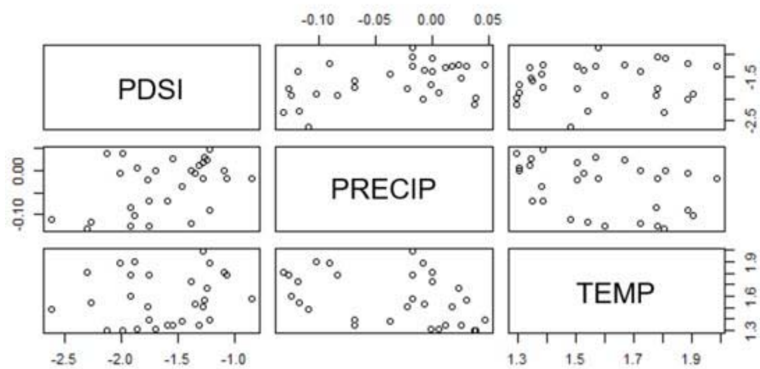


Figure 49. Scatter plot showing relationship between PDSI PRECIP and TEMP.

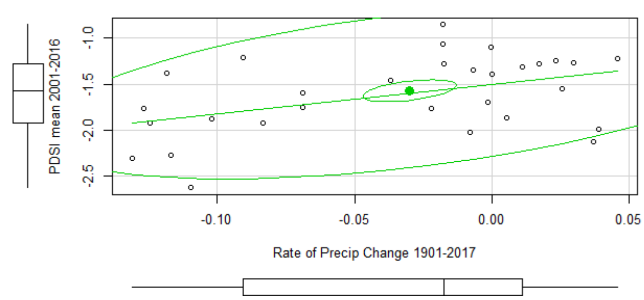


Figure 50. Significant linear relationship between PDSI and PRECIP.

Chapter 7: Conclusions

7.1 Adaptation in Action – Confronting Climate Change Vulnerability on Tribal Lands

The introduction of this tool is intended to help tribes advance the discussion, and more importantly, to partner and learn from tribes that might have similar challenges related to their semiarid climates and low precipitation rates. As previously stated, farming operations in the area in the Southwestern US rely heavily upon favorable climate conditions for economic production. The Southwest's decades-long drought has shriveled crops, dried up springs and forced ranchers to reduce their cattle herds. For example, the image in Figure 51 is shows the impacts of drought on the Hualapai reservation after a drought in 2003. The Hualapai reservation is an example of a tribe dependent upon water from the Colorado River whose flow varies depending on whether or not there are sufficient water levels in Lake Mead. Beyond concerns over inadequate freshwater supply to grow crops and livestock for subsistence and primary economic production. Another concern that several tribes face is losing the revenue from lease agreements made with non-Indians. Several tribes benefit from leasing their land to non-Indian farmers and ranchers, such as the Fort Mohave and Colorado River Indian Tribe in western Arizona, as well as the Gila River, Ak-Chin, Fort McDowell and Salt River Pima Maricopa tribes in central Arizona. Therefore, if water shortage and drought continue to ravage the west, and non-Indian producers decide not to renew their lease agreements because agriculture is no longer feasible, American Indian economies will be hurt from multiple angles.

Figure 51. Dead Cow killed by drought on Hualapai reservation (Retrieved from: Hualapai Tribe Department of Natural Resources, 2003).

Ultimately, safeguarding the livelihoods of thousands of American Indian producers through innovative climate adaptation is the most promising way to facilitate sustained agricultural and ranching production on the arid tribal lands of the American west. Enhancing local capacity to withstand shocks and stresses as only way to reduce harm caused by climate change. Thus, the next section provides a few examples of adaptations that were uncovered during the research process and stood out.

7.1.1 Tribal drought contingency, and grazing management plans. Since that photo of the dead cow was taken in 2003 the Hualapai Tribe department of natural resources wrote and passed a Drought Contingency Plan through the tribal government with the intention to mitigate the impacts of drought, and also create emergency management thresholds and responses. The Hualapai planning department also finalized a Master Plan for Grand Canyon West, a major tourist destination on the reservation. Other tribes such as the Zuni Tribe (2001) have also created drought contingency plans to be better prepared for the impacts of drought. Creating Grazing Management Plans is another powerful planning tool that has been put in place by several tribes such as the Hopi, Jicarilla Apache, Duck Valley, and Yomba tribes. These efforts involve putting up fencing, giving out permits and actively managing resources to achieve: healthier rangelands with improved water, nutrient, and fire cycles; improved plant community biodiversity and production; healthier native vegetation and vegetative cover; adequate forage reserves to ensure rangeland health during drought periods; improved wildlife habitat and watershed conditions; protection of critical cultural and natural resources; sustainable management and operation by tribe and Association that meet tribal land management objectives while providing a profitable operation for the individual Tribal rancher. Commonly a tribal Ranchers Management Associations are also formed in association with the Grazing Management Plan so tribal producers can manage all of the land, permitting and leasing agreements, and to achieve common goals of the Association members. Tribes with Grazing management associations are less vulnerable to devastating climate impacts because planning ahead always lessens harm down the road. One example of an incredibly innovative solution that arose from a partnership between Duck Valley and with USDA agricultural extension office is a cattle watering system such as the one seen in Figure 52. With a cattle watering system livestock herds are drought resistant because they can pump their own freshwater from groundwater tables.

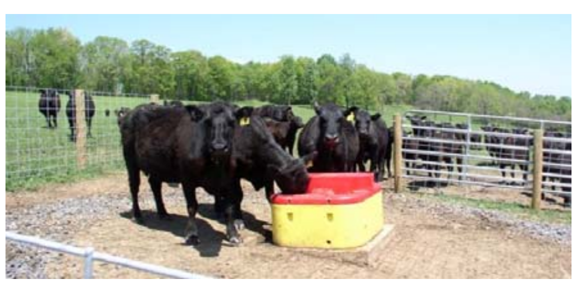


Figure 52. Cattle watering system (Retrieved from Whinscarver, 2014).

7.1.2 Sustainable agriculture. In the early 19th century many tribes were forcibly relocated to reservations west of the Mississippi river. American European government agent's promoted that farmers grow wheat over traditional crops and insisted on row cultivation rather than the inter-cultivation methods that had traditionally been used (Douglas, 1987). As the impacts of climate change on food production will become more pronounced in the coming decades, it will become increasingly necessary to shift agricultural strategies away from current industrialized practices towards a more resilient system of agriculture. Generally, there is a lack of and need for water infrastructure and innovation being applied elsewhere that could be used by tribes. But some tribes have already shifted to more modern and sustainable agricultural practices (see Table 9).

The first is the Tesuque Pueblo in NM. They have hired an indigenous farmer who is spearheading a sustainable foods initiative. He is growing enough food in hoop houses and traditionally to feed the entire community, and is saving seeds for Pueblo generations to come. The second example is the Duck Valley Tribe on the border of NV and ID. Their tribe has recently just succeeded in achieving water rights after forty years. The federal government has upgraded all of their water system leading to more sustainable agriculture, fishing and ranching opportunities. Additionally, Duck Valley will be the location of the first ever wind farm in NV. A few more examples of agricultural adaptation are seen in Table 9.

Table 9

Examples of adaptation in action

Tribe	**Agricultural Practices**
Gila River	**Diverse Crops:** Include: cotton, wheat, alfalfa, sorghum, barley, melons, pistachios, olives and citrus.
Ak-Chin	**Water conservation practices:** Sprinklers that save 30-40% of water. • Drip irrigation. • Switched to more efficient tractors: save the soil.
CRIT	• Row Crops • Drip Irrigation • Managing Soil • Exploring alternatives for multiple profitable crops.

7.1.2.2 High tech agriculture and water conservation practices. Few tribes are able to earn a substantial profit from agriculture. But Tribes such as the Gila River, Ak-Chin and Colorado River Indian Tribes have been able to make considerable profits by adapting farming operations over the past ten years. All three tribes listed in Table 9 above have plans to expand agricultural production and will continue to focus on optimizing efficient water use and enhancing local resilience.

7.1.2.3 Seed saving. Another form of specific resilience and adaptation that the Navajo and Hopi tribes as well as other Native Americans living in modern day Arizona and New Mexico have benefited from is seed saving. Drought resistant crop seeds have been saved for generations and are one of the products of traditional ecological knowledge. Selective methods of seeds overtime have naturally engineered seeds that when supported traditional farming methods, have allowed Hopi farmers to grow food on often dry and low rainfall plains. Figure 53 shows sixteen types of drought resistant corn. Having biodiversity is also a major component of ecological resilience.

Figure 53. Sixteen types of drought resistant corn used by the Hopi tribe (Credit Davenport K, 2016, Photo by Kelley Fowler).

7.1.2.4 Green houses. Many sustainable agriculture adaptation planning interventions occurring on tribal lands include the installation of green houses and hoop houses. Growing food indoors makes agriculture more resilient to variable climate conditions and green/hoop houses are becoming increasingly popular among farmers in this new era of climate variability. Figure 54 shows a geo-dome on Navajo Nation which provides spring like conditions all year round and can serve as a local food source for fresh vegetables. Subsistence farming is extremely important on Navajo Nation as many of its members.

Figure 54. Geo-dome on Navajo Nation (Credit Pacific Domes, 2011).

Another notable example is the significant efforts being made by the Tesuque Pueblo to make their farms more resilient. Farms on Tesuque used to grow alfalfa as a cash crop. Then in the early 2000's the production system totally revolutionized itself. The tribal government decided to hire an indigenous Quechan from Bolivia named Emigdio Ballon (seen in Figure 54). He has totally switched the agricultural production into a biodynamic subsistence based farming method, rather than a monoculture for profit. Today, agriculture is strictly practiced for subsistence purposes where 75 acres are cultivated with edible crops and two 1,500-square-foot hoop houses have dozens of plant varieties. Another social benefit of this switch is that all of the fresh produce is given to tribal members for free, helping to improve the health and wellness of the Tesuque Pueblo. While the biodynamic agricultural operation led by Mr. Ballon has not achieved 100 percent self-sufficiency yet to feed the 500 members of the Tesuque Pueblo, this initiative has major steps forward showing the benefits of working to achieve food sovereignty.

Figure 55. Innovative Farmer Emigdio Ballon on the Tesuque reservation (Credit Hester, 2015).

7.1.2.5 Partnering with universities and agricultural extension offices. Long term climate action plans on tribal lands can be collaboratively developed through strategic partnerships with colleges and universities that can bring new capacities to their system. For example, the university of Arizona is partnering with several tribes and providing information on drought conditions to help tribal leaders and resource managers better decide when to stake such steps as closing rangelands, and hauling water. These types of partnerships provide tribal governments with the science from downscaled climate data that help inform evidence based decisions. Using science to inform long-term policy and short term decisions is critical for adaptive governance.

7.1.2.6 Regional, inter-tribal, or multi-jurisdictional planning. Another example adaptation strategy that is benefitting from several tribes are joining inter-tribal/multi-jurisdictional. By engaging with a diverse group of stakeholders the exchange of science and knowledge can occur. Regional groups like the Great Basin Landscape Conservation Cooperative (LCC) have pushed the envelope for restoration on the landscape scale. They facilitate climate adaptation trainings for tribes. One theme that has emerged from working with groups of Native American's representing different tribes that are adapting to climate change is the significance of traditional knowledge that was not on anyone other non-Indian organization's portfolio. Tribes are encouraged to continue to use and traditional knowledge gleaned from elders, stories, and songs Challenges that no individual tribe can conquer alone. The Upper Verde River Watershed Protection Coalition (UVRWPC, the Coalition), Upper Snake River Tribes (USRT)

7.1.2.7 Department of energy (DOE) renewable energy grants. There are several solar and renewable energy projects as well as restoration projects occurring on tribal lands. In 2015 the DOE released $6 Million dollars of grants to help tribes cope. The Duck Valley is an impressive example of a tribe that is a recipient of one of these grants and currently making large scale energy and water distribution infrastructure updates. The Duck Valley Shoshone tribe will soon become the proud owner of the first renewable wind farm in the state of Nevada. Tribes are always looking for grant opportunities and greater availability of Federal funding could aid in the development of improving economic conditions on tribal lands. In the meantime, building skills for strategic grant writing could benefit tribes in gaining access to capital for specific climate interventions.

7.1.2.8 Formal planning efforts, zoning updates and the comprehensive plan. Several tribes have integrated climate change into decision-making in major sectors, such as economic development, education, fisheries, social services, and human health. However, overall, there is limited financial and human capital on native American reservations. The poverty rate in the US is 15.5 percent while the poverty rate on the tribal lands in the study area is 32 percent. Limited financial capital makes it tough to afford the planning staff, or private consulting firm to regularly update drought, hazard and comprehensive plans. A few tribes that have recently updated versions of comprehensive plans include the Hopi Tribe’s Comprehensive Economic Development Strategy (CED) (2015) the Tohono O’odham Nation’s Administrative Plan (2015) and the Navajo Nation CED (2010). The Salt River Pima Maricopa Tribes zoning map and ordinance updates (2015) are a good example of a tribe using modern planning tools. The Salt River Tribe is located in the Phoenix metropolitan area. The zoning updates for Salt River (seen in Figure 56) are supplemental to the Comprehensive Plan that was passed in 2006. Salt River has a clear vision for the type of culturally relevant and sustainable development that it wants to attract, a clear roadmap for how to get there provided by the General Plan, and some local ordinances to give some teeth to the general plan. Zoning helps insure that as the Community is developed sustainably over time it will become more like what the Community envisioned in the general plan.

All tribes could benefit from the comprehensive planning process. It is encouraging to see more and more tribes begin to participate in this type of activity. For example, one tribe that is very vulnerable to the impacts of climate change the Te-Moak Shoshone Tribe made up of four bands (the Elko, Wells, Battle Mountain, and South Fork) have recently begun the comprehensive planning process in 2015.

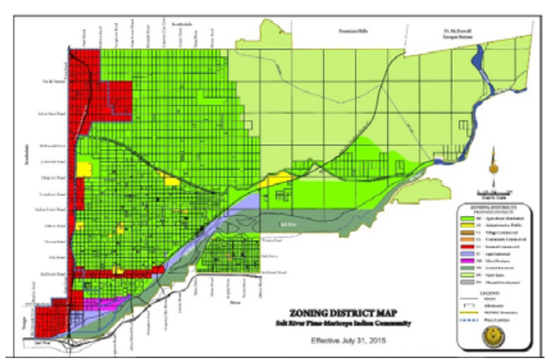


Figure 56. Zoning Updates on the Salt River Pima Maricopa Indian community reservation (Credit: Salt River Department of Planning, 2015).

7.2 Practical Application of this Model

The first application of the model presented in this thesis is providing empirical evidence for identifying tribes that are particularly vulnerable. The conclusions drawn from this thesis are firm enough to support the dire need for greater adaptive response among tribal members and other stakeholders in the Southwest. This research will hopefully convince tribes and others that preparing a vulnerability assessment, is a good first step when planning for the impacts of climate change. The aforementioned language, framework and evidence presented in this thesis could be used as support for grant applications that will persuade decision makers to disseminate funds needed for climate adaptation strategies. For instance, the BIA distributes annual grants for climate adaptation. The Ute Mountain Reservation received a grant in 2015 to hire a consultant to develop a hazard mitigation and climate adaptation plan.

The second potential application is for measuring the impact of hazards on particular tribes. The study reveals that drought significantly impacts livelihood of the tribal communities, by imposing impacts on four key issues: primary sector economic activities (agriculture, fishing, and livestock), domestic water use, Native American treaty rights and the spiritual and cultural identities of tribes. The factors included in a vulnerability assessment that uses bottoms-up can become a tool aiding legal arguments around resources that are allocated politically. For example, in some parts of Latin American and South America community based assessments are used to take inventories and create seasonal calendars and chronologies (Zharafshani et al., 2016). Tracking changes using a formal model is an important practical application. The same framework can be re-evaluated to measure their implementation and impact in reducing vulnerability.

The third use of this model is for guiding mixed methods approaches for future assessments. The bulk of this thesis is intended to synthesize information that creates an effective vehicle for facilitating vulnerability assessment comparisons. It offers a literature review and essential details for executing methods but it is not intended to provide an in-depth analysis of causes of vulnerability on individual tribal lands. Rather, it explores the broader processes affecting actors (exposures/sensitivities) and the practices (adaptations) that people develop to address these phenomena. In order to get an in-depth analysis, bottoms-up mixed methods approaches are growing in recognition for their effectiveness. Assessments using these methods diagnose problems and also promote solutions that help communities overcome emerging challenges. To promote the value of researchers taking the outsider role, the VSD seen in Figure 2 could be applied in a community based approach for starting the vulnerability assessment process. Ideally assessments would update in real time based on the constantly evolving status of vulnerability to create assessment systems that respond to emerging information regarding current and future climate conditions, as well as changes in the socioeconomic system.

It is important to note that while each sub-indicator included in this assessment has a theoretical justification for selection, that does not mean that it applies to every tribe. For example, a Hopi farmer mentioned to me at a Native Waters on Arid lands conference that they would not use any irrigation metrics to represent increased vulnerability because they have been desert farmers for as long as their people can remember. Thus, they shouldn't include it. Furthermore, the high school diploma index is a proxy for education and could be replaced with a measure of skills, including traditional ecological knowledge rather than formal degrees. The work presented above is intended to assist in brainstorming relevant variables. In this light, a few hypothetical examples of internal biophysical attributes of concern and potential indices that could be included in a future vulnerability assessment of tribal lands are included in Appendix A- "Internal Biophysical Areas of Concern - Descriptions, Symptoms and Indices that could potentially be included in a future Vulnerability Assessment".

7.3 Conclusion

Southwestern tribal communities are confronting several climate-related risks and their consequent impacts. Those employed in climate dependent sectors are forced to confront questions both practical and existential. These questions include- Can crops grow with less water? Will agriculture still be a feasible livelihood in 20 years? What options exist to minimize climate impacts and sustain agriculture, ranching and fishing operations for the short and long-term? In addition to those practical questions further complexities arise when considering the cultural and religious impacts climate change has on American Indian homelands. To adequately acknowledge the current existential threats of social malaise and deterioration, one must also ask- What will become of the culturally and spiritually significant ecosystem services, that are essential to maintaining many tribes' identities? To help galvanize effective policy responses and work to address challenges about the differential effects of drought and climate change on diverse human societies vulnerability assessments are a great tool.

The benefits of adopting an integrated vulnerability assessment framework and methodology illustrated by this thesis are as follows: First, to inform social adaptation to address maladaptive policies and promote proactive and informed responses on several levels. Second, to provide a useful tool to facilitate mainstreaming of climate change adaptation into local government plans. The holistic perspective afforded by addressing the architecture of entitlements, underlying drivers of vulnerability, and nature of adaptation supports a policy-relevant discussion highlighting feasible means for reducing vulnerability and facilitating adaptation. Third, appropriate policy responses are best realized from a common understanding of the breadth and depth of vulnerability which differs across local contexts and sectors. The quantitative and qualitative sub-indices reflecting areas of concern are easily customizable to ensure that assessments can be tailored to meet local needs. Finally, by locating the analysis in the present-day rather than in a hypothetical future, any philosophical doubt about the existence of climate change is avoided and the moral and scientific imperative to act becomes clear and straight forward. Thus, an overview of current conditions can reconcile near-term demands and immediate aspirations with long-term actions geared towards ensuring the future sustainability of tribal communities. The results presented in this thesis suggest that humans are capable of developing informed and practical assessment methods to monitor the threats imposed by climate change. These tools can be essential elements in guiding and measuring the future progress of tribal leaders and other concerned stakeholders in addressing this most urgent challenge.

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Appendix A: Internal Biophysical Areas of Concern; Descriptions, Symptoms and Indices that Could Potentially Be Included in a Future Vulnerability Assessment

Vulnerability Indicator:	Proxy for:	Mechanism for translation into vulnerability:	Measured by:
Institutional Adaptation	Hazardous business activities/unsustainable patterns of land use development	Consistent government support and approval for development projects that do not adequately consider long-term environmental impacts effectively contributes to a 'death by a thousand cuts' pattern of land use development and invitation for industry that harms the critical life-support systems in the community	- Number of environmental regulations and standards enforced. - Presence/absence of up-to-date zoning regulations and comprehensive plan that lays out the road map and vision for a more sustainable community.
Primary Sector Adaptation	Unsustainable land management practices	Farming practices failing to adapt to changing environmental conditions and continuing unsustainable methods such as flood irrigation in water scarce arid deserts; or annual tilling of mono-crops. In time this activity will destroy the ecological integrity of farmland and potentially lead to collapse of several systems.	- Number of acres that are farmed with Best Management Practices (BMPs). - Length of drip irrigation infrastructure installed.
		Uncoordinated/unregulated ranching activities that will eventually result in 'a tragedy of the commons' where each rancher continues to add additional heads of cattle without considering the collective carrying capacity of rangeland, which will be further limited by climate change and diminishing fresh water supplies.	- Presence/absence of a ranching committee that is supported by the government and has regulatory power - Number of projects undertaken to improve the long-term sustainability of ranching on tribal lands.

Appendix B: Data Source and Technical Documentation

	Variable Name	Variable Description	Units	Correl-ation	Scale	Year (s)	Data Table (s)	Table Field Calculation	Calculation Description	NOTES	Data Source
	AFFGEOID	Geographic Identifier that can be matched with TIGER Products and AFF products (14 digit)	N/A	N/A	AIR	N/A	S0601	id	In Excel, DATA , Advanced Filter to extract Census Data for 72 Tribes of interest out of the possible 695 AIANH areas		US Census, 2015
	GEOID	American Indian Area code (4 digit)	N/A	N/A	AIR	N/A	S0601	id2		In Excel, AFFGEOID (13 digit) is used for joins	
	Geography	Text decription of the American Indian Area name and legal/statistical area	N/A	N/A	AIR	N/A	S0601	Geo.display-label			
	Nation/Tribe	Name of Federally Recognized Nation/Tribe	N/A	N/A	AIR	2017	82 FR 4915	Supplemented Geography with current Tribe name	Wrote out the Federally Recognized tribe name	Some Geography descriptions are different than the federally recognized Tribe's name	BIA, 2017
	State	State(s) abbreviation	N/A	N/A	N/A	N/A	S0601	Assigned a state for each tribe	Typed the State Abbreviation(s) that AIR lands fall within	See Table 1 notes in document	US Census, 2016
	Acres Land	Land area (ac)	ac	N/A	AIR	2016	Census Cartographic Boundary File- U.S. AIANH 2016 500k	ALAND*0.000247105381	Conversion from square meters to acres	All geographic data projected into NAD 1983-2011 Contiguous USA Albers	
	Acres Water	Current on and off reservation trust water area	ac	N/A	AIR	2016		AWATER* 0.000247105381		Used summarize tool in GIS to SUM AWATER per tribe as TIGER quantifies based on geography	

Appendix B. *Continued*

	Tribal Area	Total Acres AIR Land and Water	ac	N/A	AIR	2016		Land Acres + Water Acres	Added land and water to get total tribal area		
	Climate Division	Name of geographic areas with similar climate conditions	N/A	N/A	N/A	N/A	NCDC Climate Division Geographic Boundary	NAME	Joined NCDC climate dvision boundaries shapefile, intersected them with tribes	Intersected with 28 narrowed down to 25 climate divisions falling in 8 states	NCDC, 2017
	CLIM_DIV	Climate division identifier (3 or 4 digits)	N/A	N/A	N/A	N/A	NCDC Climate Division Geographic Boundary	CLIMDIV	Assigned CLIMDIV identifier to each tribal entity	See Table 3 notes in document	NCDC, 2018
EXPOS-URE	PDSI	Palmer Drought Severity Index	Dimensionless	Negative	CLIM_DIV	2001-2016	Palmer Drought Severity Index (Mean 2001-2016)	choose Variable-PDSI choose type- mean, choose season January-December, choose 2001-2016	Raw index values were joined to 65 tribes that had the large majority of their area in 1 single climate division. 7 tribes with more than 40% of land in two climate divisions got an average of both applied		NOAA/NCEI, 2017
	PRECIP	Rate of Precipitation Change	% Change	Negative	CLIM_DIV	1901-2016	"Figure 3. Change in Precipitation in the United States, 1901-2015",	Used Excel to match climate divisions with respective tribes			NOAA, 2016
	TEMP	Temp. Increase relative to climate division average (1895–2015).	°F	Positive	CLIM_DV	2000-2016	"Figure 1. Average Temperatures in the Southwestern United States, 2000-2015 Versus Long-Term Average"		Raw index values were joined to 67 tribes as TEMP_CHG was not included for ID, or OR climate divisions, 5 tribes with more than 40% got an average		

Appendix B. *Continued*

EXPOS-URE	DSTR	FEMA Disaster Declarations .	Count	Positive	AIR	1990-2017	FEMA Declarations 4.3.17	SUM of Disasters per tribe	In Excel used Filter to remove (county) and city from "declared county area" column, then used filter to select AZ, NV, NM, CO, UT,	The Washoe Indian Reservation provided by FEMA was not broken down into the 4 colonies. Thus carson, dresslerville, stewart, wahsoe ranches all got the value 2	FEMA (NEMIS), 2017
	Land Area	Current on and off reservation trust land area in square miles	mi2	N/A	AIR	2016	Same as Acres Land	ALAND*0.000000386102159	Conversion from square meters to square miles	Land is calculated for on and off trust land together	US Census, 2016
SENSIT-IVITY	POPDENS	People per square mile of land area in square miles	logarithm of pop/ mi2	Positive	AIR	2015	S0601	HC01_EST_VC01 /Land Area	Divided total population by square miles of land area		US Census, 2015
	PRM_SCT	Percent employed in primary extractive industries (farming, fishing, mining, and forestry	%	Positive	AIR	2015	S2405	HC01_EST_VC02 /HC01_EST_VC01	Divided primary sector employed by total civilian employed over the age of 16		US Census, 2015
	IRR_LAND	Percentage of land under irrigation	%	Negative	AIR	2015	6 Data sources	Acres of Irrigated Land/Total Acres Land	Got best estimate of how many irrigated acres from Tillers Guide 2015, BIA FactSheets Reports and Personal Contact with Irrigation Engineer, USDA Ag Census 2012, Kelly Bleisner 2003, Arizona Department of Water Resourcs 2014, New Mexico State Engineer Office 2004, Colorado River Research Group, 2016	Yavapai Apache, Fort McDermitt, Yomba, San Carlos Apache, White Mountain Apache Duckwater, Moapa, Fallon Reservation, South Fork Band (Te Moak), Washoe Ranches	

Appendix B. *Continued*

SENSIT-IVITY	IRR_LNGTH	Length of perennial man made irrigated canals ditches or aqueducts	logarithm of meters	Negative	AIR	1997	Census 1997 TIGER/Line Files	log(H22- Perennial canal, ditch, or aqueduct)	Irrigated Canals Were Clipped to reservations then definition queries were run on CFCC column to distinguish between H21 - representing Perennial canal, ditch, or aqueduct and H22 representing Intermittent canal, ditch, or aqueducts.	Up to data fact sheets on length of irrigation networks were provided by the BIA for Walker River and Pyramid Lake Paiute tribes, the Duck Valley tribe and the Uintah and Ouray tribe.	
ADAPT-IVE CAPACI-TY	NO_HSD	Persons (age 25+) with no high school diploma,	%	Positive	AIR	2015	S0601	HC01_EST_VC46			US Census, 2015
	DEPEND	Dependency Ratio- Number of Children and elderly per 100 of the working population	Ratio	Positive	AIR	2015	DP05	HC01_VC08+HC01_VC09+ HC01_VC10+ HC01_VC18+ HC01_VC19+ HC01_VC20/HC01_VC11 +HC01_VC12+HC01_VC13 +HC01_VC14+HC01_VC15 _HC01_VC16+HC01_VC17	Divided Persons (age 0-14) + Persons (age 64+) by Persons (age15-64)		US Census, 2015
	POP_GRWTH	Average decadal growth rate of population	%	Negative	AIR	1996-2015	Tiller (1996), DP1(2000), DPDP1(2010), S0101(2015)	(VD01(2000)-Tillers(1996)/Tillers(1996))+(HD01_S001(2010)-HC01_VC01(2000)+HC01_VC03(2015)-HD01_S001(2010)/2	Calculated growth rates between 1996- 2000, between 2000-2010, between 2010-2015 then divided by 2 (representing decades)	1996 values were not reported by Tiller for Elko, Ely, Fort Yuma, Stewart, Woodfords,	Tiller 1996, US Census 2000,2010, 2015
	POP_RTN	Retention Ratio of population aged 20-44	Ratio	Negative	AIR	2010 vs 2000	DP1(2000), DPDP1(2010)	DPDP1(HD01_S006, HD01_S007, HD01_S008, HD01_S009, HD02_S0104)/DP1(HC01_VC09, HC01_VC10, HC01_VC11/ HC01_VC01)	Divided Persons(age 20-44) living in year 2010 by Persons age (20-44) living in year 2000		US Census, 2010, 2015

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ADAPT-IVE CAPACI-TY	POV	Persons living in poverty	%	Positive	AIR	2015	B17001	HD01_VD02/HD01_VD01	Divided persons whose Income in the past 12 months below poverty level/total population	Poverty rate was not reported by US Census for Skull Valley	US Census, 2015
	OLDER	Older employees aged (55-75+) as a proportion of the working population (16-75+)	%	Positive	AIR	2015	S2301	((HC01_EST_VC09*HC02_EST_VC09)+(HC01_EST_VC12*HC01_EST_VC12))/(HC01_EST_VC01*HC02_EST_VC01))	Multiplied the total estimate persons(55-75+) by labor force participation rate divided by the total labor force(16-75+)		US Census, 2015
	OFF_FARM	Number of non-climatic dependent sectors present	Ratio	Negative	AIR	2015	S2405	HC01_EST_VC03, HC01_EST_VC04, HC01_EST_VC05, HC01_EST_VC06, HC01_EST_VC07, HC01_EST_VC08, HC01_EST_VC09, HC01_EST_VC10, HC01_EST_VC11, HC01_EST_VC12, HC02_EST_VC13, HC05_EST_VC14	Counted presence or absence of each of these 12 non-primary activity economic sectors/12 possible off farm sectors	Sectors include - 1. Construction. 2. Manufacturing 3.Management, business, science, and arts occupations 4. Retail trade 5.Transportation and warehousing, and utilities 6.Information 7.Finance and insurance, and real estate and rental and leasing 8. Professional, scientific, and management, and administrative and waste management services 9.Educational services, and health care and social assistance 10. Arts, entertainment, and recreation, and accommodation and food services11.Other services, except public administration 12. Public administration	US Census, 2015
	CASINO	Presence or absence of Casino	Presence or Absence	Negative	AIR	2017	500 Nations	Identified which tribes have a casino	Coded data yes, no, in progress		

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	WTR	Congresionally authorized water rights settle ments	water settlement(afa)/acres	Negative	AIR	2017	Stern 2016, Tillers 2015, AZ Dept Natural Resources,	Got best estimate for federally or state protected			
ADAPT-IVE CAPACI-TY	CAP	Tribal climate adaptation planning status	Rank Very low- very High	Negative	AIR	2017	Tribal Website, Tiller 2015, ITEP, BIA, EPA, Climate.gov				
	INSURED	FEMA hazard mitigation plan status	Score 0.5,1, 1.5	Negative	AIR	2017	FEMA 2015				FEMA, 2016