CONSIDERATIONS FOR CLIMATE CHANGE AND VARIABILITY ADAPTATION ON THE NAVAJO NATION

March 2014

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Western Water Assessment

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1 Alexander, C., Aseff, A., Finch, D., Krakoff, S., Teel-Simmonds, J., V., Vilsack, West, N., Williams, S., Zarzecki, L. (2011). Framework Tribal Climate Change Adaptation Report for Consideration by the Navajo Nation. University of Colorado Law School. CU Boulder Renewable and Sustainable Energy Initiative (RASEI) Seed Grant Project. Unpublished report (on file with authors).

Abbreviations

Af- Acre-feet per year
APS- Arizona Public Service Company
BIA- Bureau of Indian Affairs
BLM- Bureau of Land Management
BOR- Bureau of Reclamation
CAP- Central Arizona Project
CERT- Council of Energy Resource Tribes
CHR- Community health representative
CIER- Canadian Center for Indigenous Environmental Resources
CO_2- Carbon dioxide
CWA- Clean Water Act
DCP- Navajo Nation Drought Contingency Plan
DPA- Diné Power Authority
EQIP- Environmental Quality Incentive Program
ESA- Endangered Species Act
FMP- Forest Management Plan
GCMs- Global circulation models
GHG – Greenhouse gas
IEPPA - The Indian Energy Promotion and Parity Act of 2010
IHS- Indian Health Service
Intertribal COUP- The Intertribal Council on Utility Policy
IPCC- Intergovernmental Panel on Climate Change
IPP- Independent power producer
ITEP- Institute for Tribal Environmental Professionals
IWRM- Integrated water resources management planning
MOU- Memorandum of Understanding
MW- Megawatts
NAAA- Navajo Area Agency on Aging
NAM- North American Monsoon
NAPI- Navajo Agricultural Products Industry
NCA- National Climate Assessment
NDOH- Navajo Division of Health
NDWR- Navajo Department of Water Resources
NEPA- National Environmental Policy Act
NFD- Navajo Forest Department
NFPI- Navajo Forest Products Industry
NGS- Navajo Generating Station
NHPA- National Historic Preservation Act
NIIP- Navajo Indian Irrigation Project
NMTC- New market tax credits
NN- Navajo Nation
NNC- Navajo Nation code

NNDA- Navajo Nation Department of Agriculture
NNDFW- Navajo Department of Fish and Wildlife
NNDNR- Navajo Nation Department of Natural Resources
NDOH- Navajo Division of Health
NNDWR- Navajo Nation Department of Water Resources
NNEPA- Navajo Nation Environmental Protection Agency
NNSDP- Navajo Nation Special Diabetes Project
NNTAO- Navajo Nation Traditional Agricultural Outreach
NPS- National Park Service
NRCS- Natural Resources Conservation Services
NTEC- National Tribal Environmental Council
NTP- Navajo Transmission Project
NTAA- National Tribal Air Association
NTEC- National Tribal Environmental Council
NTUA- Navajo Tribal Utility Authority
NW- Northwest
NWF- National Wildlife Federation
NWC- Navajo water code
NWF- National Wildlife Foundation
PDSI- Palmer Drought Severity Index
PJ- Pinyon-juniper
PM2.5 – Particle pollution less than 2.5 micrometers in diameter
PRISM- Parameter-elevation regressions on independent slopes model
PTC- Production tax credit
PWS- Public water systems
PV- Photovoltaics
REA- Rapid ecological assessments
RETF- Renewable Energy Task Force
SDWA- Safe Drinking Water Act
SOI- Secretary of Interior
SPI- Standardized Precipitation Index
SRP- Salt River Project
SW- Southwest
SWCA- Assessment of Climate Change in the Southwest United States
SWTCCW- Southwest Tribal Climate Change Workshop
US- United States
USDA- United States Department of Agriculture
USEPA-United States Environmental Protection Agency
USFS- United States Forest Service
USGS- United States Geological Survey
VACR- Vulnerability, adaptive capacity, and risk assessment
VOCs- Volatile organic compounds
WCA- Water Code Administration

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Photo: Julie Nania.

EXECUTIVE SUMMARY

Our goal with this report is to provide the Navajo Nation and its communities with information that we hope will be useful for the Nation as it engages in adaptation planning in response to climate change and variability. In Chapter 1, we discuss actions being undertaken by Native peoples around the United States in response to climate change and also provide some context about federal Indian law and the Navajo Reservation. In Chapter 2, we present an example of one way to approach the adaptation planning process, all the way from scoping and engagement to strategy implementation and monitoring and evaluation. Chapter 3 presents a synopsis of available information on climate changes currently being observed in the Southwestern United States and on the Navajo Reservation and introduces potential future climate changes in the Southwest. Chapters 4 through 12 focus on nine key sectors or resources: water, farming, range, health, tourism, biodiversity, forest, community infrastructure, and energy. For each sector or resource, we provide information that is relevant for the adaptation planning process described in Chapter 2. This information includes: (1) an introduction to the resource; (2) potential climate change and variability impacts on that resource; (3) an assessment of legal, political, economic, and other vulnerability and adaptive capacity factors that may contribute to or lessen impacts; (4) some potential adaptation strategies; and (5) an initial survey of funding options to facilitate adaptation planning and implementation efforts.

We hope that *Considerations for Climate Change and Variability Adaptation on the Navajo Nation* provides a helpful platform for Navajo decision-makers to continue assessing how to best adapt to a changing climate while managing the Reservation's unique resources in whatever manner the Nation feels would be most beneficial for its people. Although this report includes information and knowledge shared by Navajo officials and stakeholders, this project does not represent the official views or policy of the Navajo government.

Panorama of Monument Valley, Arizona-Utah (Utah at left, Arizona at center, and right). Photo: Wikimedia Commons, Kaveh.

CHAPTER 1
OVERVIEW AND CONTEXT

In this chapter we provide brief introductions to climate change, tribal climate change-related efforts taking place around the U.S., climate adaptation, and federal Indian law. We also provide an overview of the Navajo Reservation context. In Chapter 2, we present an example of one way to go about adaptation planning and implementation (also known as an adaptation planning process). Chapter 3 presents a synopsis of available information on climate changes and variability currently being observed in the southwestern United States (US) and on the Navajo Reservation and of potential future climate changes in the Southwest (SW). Chapters 4 through 12 focus on nine key sectors or resources: water, farming, range, health, tourism, biodiversity, forest, community infrastructure, and energy. For each sector or resource we provide information that is relevant for the adaptation planning process described in Chapter 2. This information includes: (1) an introduction to the resource; (2) potential climate change and variability impacts on that resource; (3) an assessment of legal, political, economic, and other vulnerability and adaptive capacity factors that may contribute to or lessen impacts; (4) potential adaptation strategies; and (5) an initial survey of funding options to facilitate adaptation planning and implementation efforts.

1.1 Introduction

In a 2013 report, the Intergovernmental Panel on Climate Change (IPCC) has concluded that "[w]arming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased." (IPCC, 2013). The IPCC also reported evidence of ocean acidification as well as changes in ocean salinity in various regions (IPCC, 2013). On land, the IPCC report observed more frequent warm days and nights and fewer cold days and nights (IPCC, 2013). There have also been observed decreases in the extent of Arctic sea ice and Northern Hemisphere spring snow cover over the past two decades as well as the continued shrinking of glaciers almost worldwide. Permafrost temperatures in most regions have increased since the early 1980s (IPCC, 2013) (additional climate science is discussed in Chapter 3).

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Climate change and variability are already being observed throughout the US, including in the SW (IPCC, 2007; Garfin et al. 2013). According to the 2013 Assessment of Climate Change in the Southwestern United States (SWCA), a report covering the states of Arizona, New Mexico, Utah, California, Colorado, and Nevada, between 1901 and 2010 annual average temperatures in the SW increased by 1.6 °F +/- 0.5 °F (Garfin et al. 2013). Also according to the SWCA, more heat waves occurred during 2001-2010 as compared to 20th century average occurrences, snowmelt and snowmelt-fed stream flow in many areas occurred earlier, and recent drought has been unusually severe when compared to other droughts over the last century (Garfin et al. 2013). All of these trends are expected to continue and could possibly be exacerbated in the future (Garfin et al. 2013).

In addition to broader climate change, in this report we also focus on climate variability. Climate variability is the way that climate variables such as temperature or precipitation fluctuate around a long-term average (Dinsey, 2011). For example, some winters are warmer than others, some years are wetter or drier than others. As part of climate variability, we experience extreme weather such as droughts or blizzards. Many of us are familiar with the El Nino Southern Oscillation as being a source of climate variability. As long as the long-term averages of climate variables do not change significantly, the climate is considered to be stable. Climate change involves changes in long-term averages or changes in the range of weather (Dinsey, 2011).

During the past decade, intertribal organizations around the US have started to recognize climate change and variability as a significant factor that can impact tribal resources, livelihoods, and cultures. The National Tribal Air Association (NTAA) calls climate change "perhaps the most pressing environmental issue of our time" and notes that "perhaps no other community of people [in the US] has experienced the adverse impacts of climate change more than the nation's Indian tribes." (NTAA, 2009) On June 11th, 2009, the Tribal Leaders of the Federally Recognized Indian Tribes in Michigan and the Governor of Michigan signed an *Intergovernmental Accord to Address the Crucial Issue of Climate Change*. Biannual meetings are held between the Michigan tribes and the State to discuss shared responsibilities and potential cooperative efforts (Cozzetto et al. 2013). The National Tribal Environmental Council (NTEC) and Council of Energy Resource Tribes (CERT) have also taken public positions on climate change (Cordalis and Suagee 2008). In April of 2013, the first national adaptation forum was held in Denver, Colorado. One outcome of the tribal sessions was the formation of National Tribal Climate Change Policy Working Teams, addressing adaptation, mitigation, and traditional ecological knowledge in native communities (personal communication, Sue Wotkyns, 2013)

Native communities face unique challenges but may also have access to additional federal, state and foundation funding resources when facing climate change. Recently, the SWCA and other reports have begun to acknowledge that the unique historical, legal and economic context of native communities has implications for the adaptive capacity of tribes (SWCA, 2013). Amongst special issues affecting tribes, SWCA cited "cultural and religious impacts, impacts to sustainable livelihoods, population emigration, and threats to the feasibility of living conditions." (SWCA, 2013) Additionally, adaptation strategies must be tailored to fit the needs, values and practices of native communities. For instance, one common problem identified in Navajo studies is that monitoring, forecasting and adaptation techniques "can sometimes ignore or be inconsistent with traditional Native values, knowledge, and practices." (Redsteer et. al 2010; SWCA, 2013)

On the ground, tribes are starting to take actions both to mitigate climate change by reducing greenhouse gas (GHG) emissions and to adapt to climate change. In terms of mitigating climate change, the Intertribal Council on Utility Policy (Intertribal COUP), composed of fifteen member tribes from the northern Great Plains, has taken a leading role in promoting the reduction of GHG emissions through tribal wind power development. In 2005, Intertribal COUP acquired a majority ownership interest in *NativeEnergy*, a corporation providing carbon offsets, renewable energy credits, and carbon accounting software. *NativeEnergy* provided the carbon offsets for *An Inconvenient Truth*, a book and film focusing on climate change (Cordalis and Suagee 2008). In 2006, the National Congress of American Indians, the oldest and largest intertribal organization in the US, adopted a resolution calling on Congress and the President to "move forward on a national, mandatory program to reduce climate change pollution and promote the development and adaptation of renewable energy within a time-frame that prevents irreversible harm to public health, the economy and the environment." (NCAI, 2006)

Native American communities have also started identifying how climate change and variability is specifically impacting tribes. A 2009 NTAA report on climate change impacts on tribes included input from representatives of sixty-five tribal nations as well as the EPA's Office of Air and Radiation (NTAA, 2009). In 2011, representatives from tribes in Arizona and New Mexico, including members of the Navajo Nation (NN), met as part of a joint Institute for Tribal Environmental Professionals (ITEP) and Forest Service Rocky Mountain Research Station Southwest Tribal Climate Change Workshop (Wotkyns, 2011). Tribes to the east in Oklahoma and southern Louisiana met in 2011 and 2012 to discuss the impacts of climate change at meetings held as part of the National Climate Assessment (NCA) process (Louisiana Workshop, 2012; Riley, 2012). Input from the Oklahoma and Louisiana meetings is being included in the forthcoming (2013) tribal chapter of the NCA, *Impacts of Climate Change on Tribal, Indigenous, and Native Lands and Resources* (Bennett et al. submitted). A special issue of the journal, *Climatic Change*, was published in October 2013 and is entitled "Climate Change and Indigenous Peoples in the United States: Impacts, Experiences, and Actions."

The remainder of this chapter provides a brief introduction to current tribal adaptation efforts and federal Indian law. We also include geographic, political, and socioeconomic background for the NN to provide context for adaptation planning efforts. Throughout the rest of the report, whenever possible we have included data specific to the NN. However, Navajo-specific or even Four Corners-specific data is not always available. The same is true for adaptation strategies; often studies have focused on more populated areas that have access to monitoring resources and additional resources to implement adaptation projects. In these cases, data and adaptation strategies for the SW or for similar ecosystems is considered. We offer this report as a tool and resource for Navajo and other stakeholders.

1.2 Climate Adaptation

Photo: Julie Nania.

Climate change and variability are already being observed in different geographic regions, sectors, and ecosystems, adding urgency to adaptation efforts. Adaptation can be thought of as actions taken to minimize harm or increase benefits in response to actual or anticipated changes. With advancements in the understanding of the scientific basis of climate change and predictive models, a body of literature has developed regarding how individuals, communities, and jurisdictions can adapt to, prepare for, and mitigate changes to come, reducing vulnerability and increasing resilience.

The adaptation planning process we discuss in Chapter 2 consists of seven phases, including: (1) scoping and engagement; (2) current vulnerability, adaptive capacity, and risk (VACR) assessment; (3) future VACR assessment; (4) option identification; (5) option prioritization; (6) pilot projects and implementation; and (7) monitoring and evaluation.

As is discussed more in Chapter 2, climate change adaptation is an opportunity not only to prepare for climate change, but also to think bigger about what kind of communities we would like to live in and what kind of world we would like to leave those who come after us. As we choose how to adapt, we can select adaptation strategies that also help us work toward that broader vision.

Many tribal communities are already preparing and planning for climate change. Amongst the most comprehensive of climate change adaptation plans are the Swinomish Climate Change Initiative Impact Assessment Technical Report (Swinomish, 2009) and Climate Adaptation Action Plan (Swinomish, 2010). Together, these documents provide a comprehensive look at potential climate change impacts to the Swinomish community, its lands and its resources. The report outlined response options, priorities, and recommendations for the Swinomish Tribe.

Photo: Julie Nania.

Other Northwest (NW) tribes have also begun to assess and prepare for the effects of climate change. The Tulalip tribes, for example, have developed a fact sheet on the impacts of climate change on tribal resources (Tulalip Nation) and created an interactive Native Climate Commons that tribes and tribal members can use as a forum to share ideas, experiences, and strategies when dealing with the effects of climate change and variability (Native Climate Commons).The Quinault Nation has issued a report titled *Climate Change Impacts on the Quinault Indian Nation* (Hansen, 2010). Together, these tribes also developed a 2009 Tribal White Paper on Climate Change Adaptation and Mitigation (ICCWG, 2009).

SW tribal communities are also assessing the impacts of climate change on their resources. Examples of this work are available on ITEP's Tribes & Climate Change website (ITEP, 2013). One such example is Dr. Margaret Hiza-Redsteer's dune studies, which provide insight into the impacts of drought on the NN and the Hualapai Tribe's drought mitigation efforts.

In addition to examples from tribal communities, many western states and counties have developed adaptation plans and strategies.[1] These regional plans may be useful resources for tribal governments interested in developing their own plans. Similarly, the federal government is engaged in a wide variety of adaptation efforts (C2ES, 2012) and is endeavoring to streamline adaptation planning through the Interagency Climate Change Adaptation Task Force (IPCC, 2007).

The NN already has important practices in place to facilitate successful climate change adaptation planning. The Nation has a well-developed water law and policy strategy and is working to settle its water rights claims. The Navajo Nation Department of Water Resources (NNDWR) has developed a formidable drought contingency plan. Additional strategic planning efforts include the Navajo Natural Heritage Program, the Navajo Integrated Weed Management Plan, the Navajo Veterinary Stockpile Plan, and priority species management plans. Individual departments have also already begun to address some of the most pressing concerns presented by climate change in a decentralized manner.

The NN has started to address the issue of climate change as part of Navajo governance. The Navajo

1 Reports include the following from: Colorado (Colorado Department of Public Health and Environment, Colorado Climate Action Plan (2007); Colorado Climate Action Panel, Final Report (2011)); Arizona(Arizona Department of Environmental Quality, Arizona Climate Change Action Plan (2006)); California (California Natural Resources Agency, 2009 California Climate Adaptation Strategy); and King County, Washington (King Country Climate Plan (2007)).

Department of Fish and Wildlife (NNDFW) has on its staff a part-time climate change coordinator. The April 2013 Fourth Annual Navajo Agricultural Conference, jointly sponsored by the Navajo Departments of Agriculture and Fish and Wildlife, had two themes; one was drought, the other climate change. Concerns over drought, water scarcity, and ecosystem changes have also been incorporated into other NN planning documents.

1.3 Federal Indian Law

Federally recognized Indian tribes may face particular constraints or have access to unique opportunities because of their status as sovereigns and their relationship with the federal government. Tribes may face certain restraints when managing natural resources because of federal oversight of lands or other trust resources. Conversely, opportunities for funding may arise which are only available to federally recognized Indian tribes. Below is a brief introduction to the federal-tribal relationship. Particular federal policies and practices are addressed in each resource chapter where relevant.

Tribes have a unique legal status as sovereigns. As stated in Cohen's Handbook of Federal Indian Law, "Perhaps the most basic principle of all Indian law . . . is that those powers which are lawfully vested in an Indian tribe are not, in general, delegated powers granted by express acts of Congress, but are rather 'inherent powers of a limited sovereignty which has never been extinguished." (Cohen, 2005) The United States Supreme Court, in a series of decisions in the first half of the Nineteenth Century, defined Indian nations as "domestic dependent nations" which had retained the sovereignty required to govern internal matters, including control of tribal members and tribal territory (Johnson,1823; Cherokee Nation,1831; Worcester, 1832). However, this sovereignty is limited; US courts have found that Indian nations lost the power to enter independently into international agreements with other foreign nations and to unilaterally transfer trust property title to non-Indians. Tribal powers over their members and their territory are limited by federal statutes, executive policies, judicial decisions, terms of treaties with the federal government, and by restraints implicit in the federal trust relationship. In all other respects, tribes have exclusive power over their members and their territory (Cohen, 2005).

The status of tribes as sovereigns is important in the climate change context because it provides tribes with a unique opportunity to address issues that implicate the management of tribal lands. Many native communities are intimately tied to the land and are often tied to unique ecological niches likely to be affected by climate change and variability (Kuhnlein and Receveur 1996; Smith et al. 2008; Green and Raygorodesky 2010; SWCA, 2013). For example, Navajos continue to gather traditional plants and medicines, engage in subsistence farming, and herd sheep. Sovereign authority to control certain aspects of resource management can help with the better management of these resources. The role of the NN government in managing these resources is discussed below where relevant.

Tribes also typically have unique reserved rights in water and natural resources on (and occasionally off of) their reservations. When tribes entered into treaties with the federal government establishing reservations, they reserved the water necessary to make the reservation livable (Winters, 1908). Additionally, many tribes have off-reservation hunting, fishing, and/or gathering rights secured by treaties, statutes or aboriginal use (Cordalis and Suagee, 2008). These rights may be affected by climate change and variability. Native communities and scholars are advocating for greater protection of tribal rights as part of national climate policy (Hanna, 2007). This advocacy has been primarily focused on the provision of federal funding opportunities to protect resources and to fund the settlement of resource claims. Throughout this report we will discuss the role that federal policies, laws, funding and agency engagement may play in Navajo climate adaptation efforts.

1.4 Reservation Overview and Setting

The NN Reservation includes a portion of the driest part of the traditional Navajo homeland (Redsteer, Kelley et al. 2010). It encompasses an area of over 27,000 square miles, including pieces of Utah, New

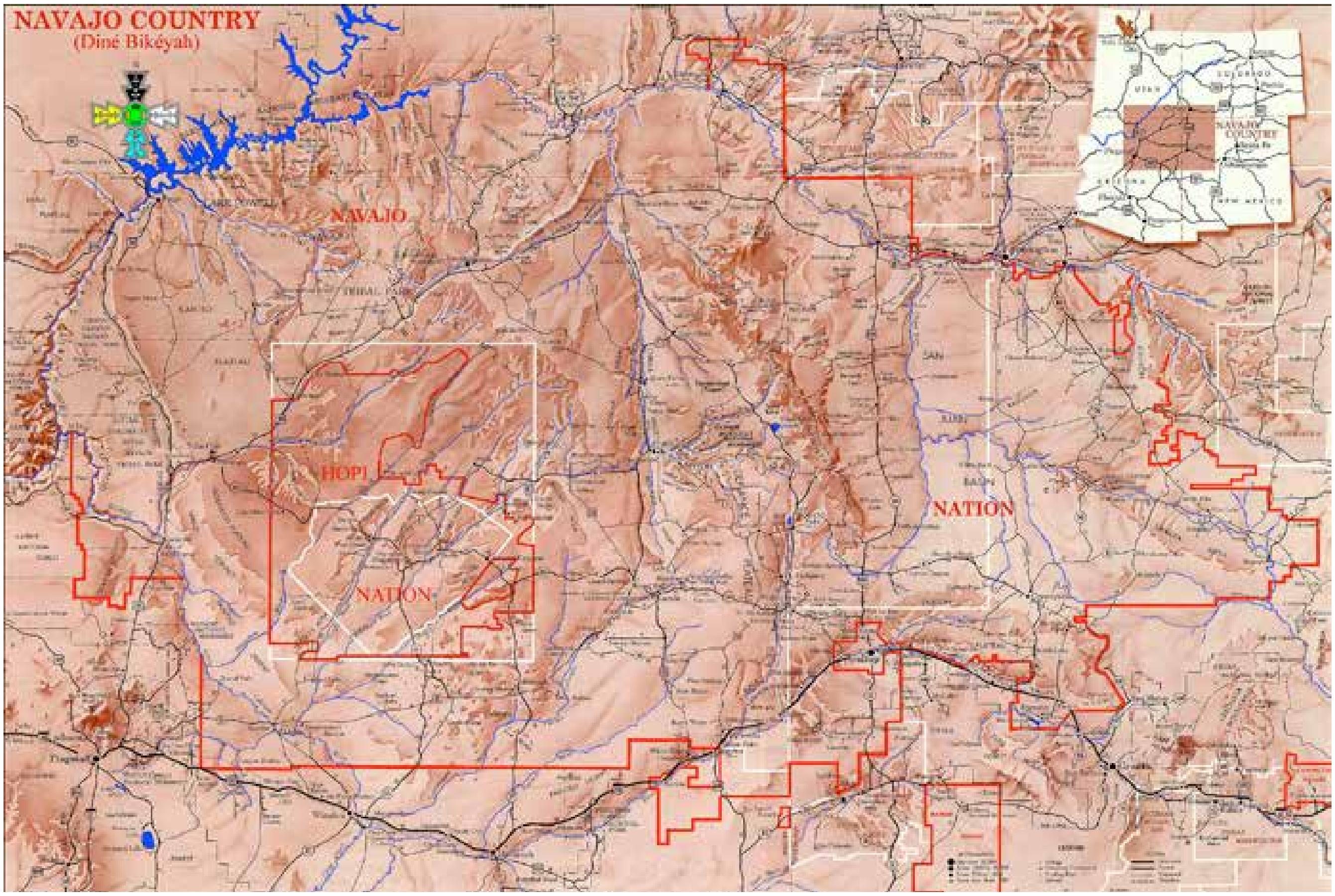

Figure 1.1. Map of Navajo Country, http://www.lapahie.com.

Mexico, and Arizona.[2] The entire reservation is about the size of West Virginia (IHS, n.d.). Although approximately 300,000 people claim full or partial Navajo ancestry (Donovan, 2012), only 173,667 Navajo reside on the Reservation (BIA, 2010).

Navajo lands are rich in natural resources. Energy resources on the Reservation include coal, uranium, and oil and gas deposits. Navajo forests have sustained a small-scale timber industry which harvests primarily ponderosa pines. Renewable energy resources, namely wind and solar, are abundant. Finally, the NN has substantial water rights claims and settled water rights to the Colorado River basin.

Management of natural resources on the Nation occurs at federal, national, and chapter levels. The political structure of the NN is a product of historical federal land divisions and Navajo governance structure. Originally, the Diné organized themselves into local bands (Wilkins, 2003) and the "fundamental political unit" was the natural community (Aubrey, 1970).[3] Chapters are the smallest political units of modern governance and were first folded into this central government structure in 1927. In total, there are 110 NN chapters (DIT, 2009).

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2 The four sacred mountains which structure the boundaries of the Reservation are Mt. Hesperus in Colorado, Mount Blanca in Colorado, The San Francisco Peaks in Arizona and Mount Taylor in New Mexico.

3 These communities centered around "one of more natural sources of water" for domestic and livestock uses. Each of the natural communities had its own social structure. Periodically, these local bands or natural communities would meet in non-binding regional tribal assemblies (Wilkins, 2003). The origins of the central government are traceable to a desire by outside companies to extract mineral resources from the Nation's territory (Maryboy and Begay, n.d.) and a business council created by the Department of the Interior to approve mineral leases (Wilkins, 2003). When questions arose about whether the business council truly represented the people of the Nation, the Commissioner of Indian Affairs established the mechanism by which the first Navajo Nation Council was seated in 1923 (Wilkins, 2003). For some people within the Nation, a centralized government "originates from Western political history and carries a contrasting experience to that of the Diné." (Diné Policy Institute, 2008)

Aerial over Monument Valley. Photo: Creative Commons, J Brew.

The Nation never adopted an Indian Reorganization Act [IRA] (1934) constitution, even though many other tribes succumbed to federal pressure to do so (Maryboy and Begay, n.d.).[4] In 1991, an internal reorganization process created Navajo legislative, judicial, and executive branches. In 1998, the revitalization of local governance began in earnest with the passage of the Local Governance Act (LGA), which granted chapters broader powers over local affairs (Maryboy and Begay, n.d.).

Today the Reservation is divided into five administrative "agencies" that correspond with the five Bureau of Indian Affairs (BIA) agencies that support the Nation.[5] The BIA agencies continue to provide various technical services under direction of the BIA's Navajo Area Office in Gallup, New Mexico, including coordination, management, planning, oversight, and monitoring of various Navajo natural resources. Presently, the Navajo Nation Council convenes with BIA representatives from each agency at the NN capital in Window Rock, Arizona (Begay, 2010). On December 15th, 2009, Navajo voters passed an initiative reducing the number of council delegates from 88 to 24 members.

NN laws are primarily codified in the Navajo Nation Code (NNC). Traditional or fundamental law also still serves as an important component of the NN judicial system. In 2002, the Council passed a resolution recognizing fundamental law as the guiding body of law for the Nation (Fonseca, 2010). Thus, fundamental law provides the "foundation of all laws" (1 NNC. 202f) and may guide strategies and priorities the NN selects when addressing climate change adaptation.

Most NN lands are held in trust by the federal government and administered by the Navajo government. Leases are made both to customary land users (for homes, grazing, and other uses) and to private and public organizations. A few private inholdings exist within the Reservation as a result of a historic federal policy which facilitated the allotment of tribal lands (Kerr-McGee Corp, 1985).[6]

In 2010, the NN general fund was $150 million (Division of Economic Development, 2010). The taxation of coal, oil, and natural gas extraction represent the Navajo government's single largest source of revenue (Tiller, 2005). Navajo workers are employed in the coal mines and power plants dotting the Nation and the boundary territories. Aside from extractive industries, much of the Reservation's economy and lifestyle are based on traditional practices such as livestock grazing (including sheep, cattle, and goats) and craft-making (including weaving, jewelry production and artistry). A 2004 study by the Navajo Division of Economic Development found that at least 60 percent of all families have at least one member working in the arts and crafts sector. Navajos also work for shops and businesses on the Reservation or in nearby towns. Additionally, the NN government employs thousands of tribal members and non-members in civil service jobs (Division of Economic Development, 2010).

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4 The voters rejected the IRA constitution in a referendum vote (Dine Policy Institute, 2008).

5 The five agencies include Chinle, Eastern, Western, Fort Defiance, and Shiprock.

6 Most of these inholdings are located in the Eastern Agency. Compared to other tribes, Navajo was relatively unaffected by allotment and much of the Nation remains tribal land.

Despite an abundance of natural resources, the NN has average unemployment levels of 15.6 percent (Census Bureau, 2010). Local unemployment rates range from as high as 57 percent to as low as 6 percent, depending on the community (NN Regional Partnership Council, 2010). The median annual income of households on the Reservation is $27,389 (Census Bureau, 2010) and 38 percent of all people on the Reservation are living below the poverty line (AFP, 2009).[7]

The social, political, cultural and economic context on the NN will have direct implications for adaptive capacity and constraints (see Chapter 2). Adaptation may occur at the central level, or on a chapter by chapter basis. The Nation may be able to leverage unique funding opportunities or at times may face constraints by the economic conditions on the Reservation. Ultimately, the unique sovereignty of the NN will enable the Navajo resource managers to address climate change in the most appropriate manner for the Nation.

7 In comparison, the average income in the US as a whole is $52,762 annually and there is a 14.3 percent average poverty rate (Census Bureau, 2010).

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Marble Canyon on the Navajo Bridge. Photo: Creative Commons, Paul Falardeau.

CHAPTER 2
AN ADAPTATION PLANNING PROCESS

Adaptation can be thought of as consisting of actions to minimize harm or increase benefits in response to actual or anticipated changes. It is, at its heart, a continual process of sharing ideas and learning, both from experience and from one another about what works, when, and why.

There are many different ways to go about adaptation planning. Here we present one possible method. However, we encourage you to develop a process that works for you. Your community has been adapting all along- what has worked and what has not?

Adaptation planning phases

The process we discuss below is depicted in Figure 2.1 and has seven different phases, including:

Phase 1 – Scoping and engagement

Phase 2 – Current vulnerability, adaptive capacity, and risk (VACR) assessment

Phase 3 – Future VACR assessment

Phase 4 – Option identification

Phase 5 – Option prioritization

Phase 6 – Pilot projects and implementation

Phase 7 – Monitoring and evaluation

As indicated in the figure, these phases are cyclical. The future will become the present; both climatic and non-climatic conditions will change; lessons will be learned and new information will become available. An adaptation plan is thus a living document. It should be continually updated and revised as the need arises (CIER, 2006 e). The phases discussed below may be iterative - in other words, while we are in a later phase in the cycle (such as option prioritization), we may realize that it could be helpful to revisit an earlier phase (such as a VACR assessment) to obtain more information.

Chapter citation: Cozzetto, K., Nania, J. (2014). Chapter 2 – An Adaptation Planning Process. In *Considerations for Climate Change and Variability Adaptation on the Navajo Nation*, edited by J. Nania and K. Cozzetto. University of Colorado, Boulder, CO.

How to use the information in the rest of this report

As we describe each of these seven phases below, we will point out how the information included in subsequent chapters of this report can be used in the planning process. For instance, information from Chapter 3 on *Climate, Hydrologic, and Ecosystem Changes in the Southwest and on the Navajo Nation* can be used in Phases 2 and 3. Various sections of Chapters 4 through 12 can be used in Phases 2, 3, 4, and 6. We indicate this in Figure 2.1 with text labeled "Chapter Section." In addition, as we discuss the seven phases, we will refer readers to additional resources for more in-depth information.

Although adaptation planning may occur in response to climate change, it can also be an opportunity to think bigger about what kind of community we would like to live in and what kind of world we would like to leave to those who come after us. We touch on that briefly in Phase 5 and encourage you to think about adaptation planning as a way to move moving towards that broader vision.

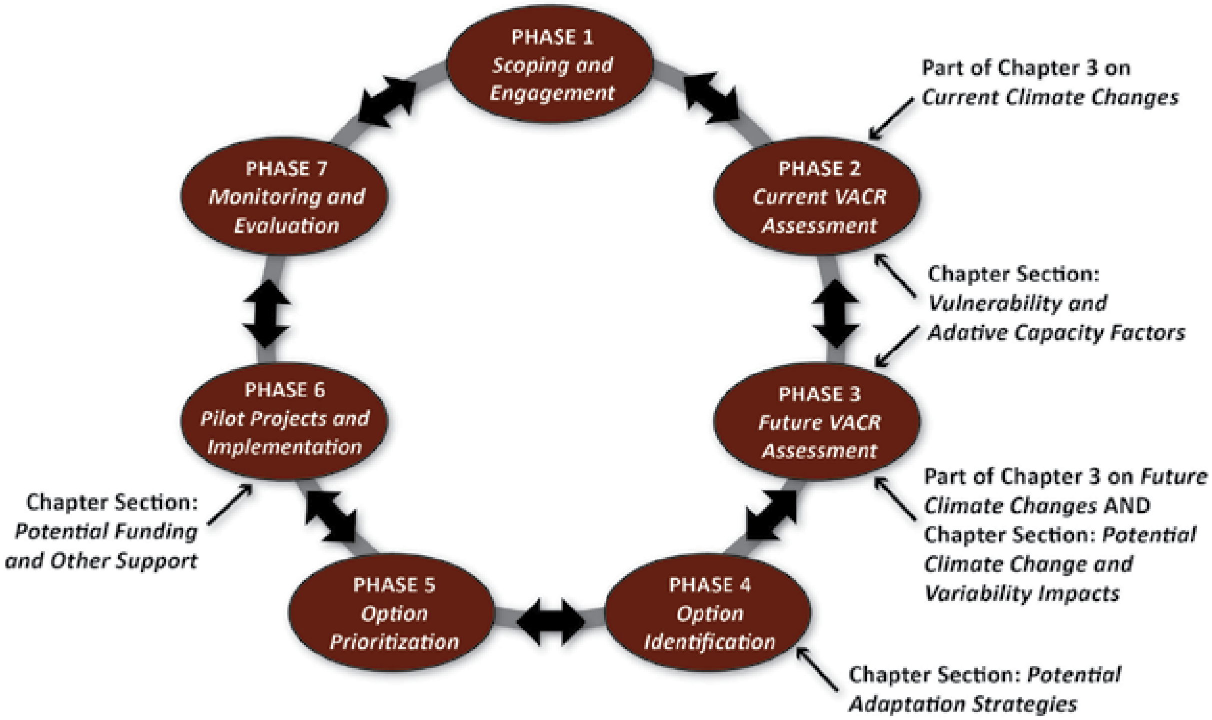

Figure 2.1. Visual representation of an adaptation planning process. Information in the different sections of this report can be used in different phases of adaptation planning. In the figure, we indicate this with text labeled "Chapter Section." The double arrows between the phases indicate that the phases may be iterative.

2.1 Phase 1: Scoping and Engagement

During the scoping and engagement phase, the emphasis is on determining:

- The focus of adaptation planning
- The timeframe over which the planning process will take place
- Identifying members of the project team
- Obtaining the support of decision-makers in the community

Focus of the adaptation planning

Adaptation planning can cover a wide variety of topics. Adaptation planning can focus on a particular sector (such as ranching or tourism) or on a particular resource (such as water or air). An adaptation plan can address a particular species, for example the Golden Eagle, or for a group of species, such as small mammals. Plans can focus on a specific hazard (such as drought or flooding) or on multiple hazards. This scoping phase is when you decide the topic of your planning efforts.

Golden Eagle Box 2.1: Scoping

20-year plan to protect Golden Eagle populations on the Colorado Plateau

Adaptation planning can also cover a variety of geographic and time scales. For example, you can prepare a plan at the Navajo chapter level or at a chapter level. Planning on a geographic scale could also involve focusing on a watershed (such as the Little Colorado River watershed) or a particular mountain range (such as the Chuska Mountains).

It is important to think about how far into the future you would like to plan. Plans can look five years, ten years, twenty years, or even 50 years into the future. Information, however, becomes less certain the further into the future you go. You will also want to think about how often you are likely to update your living adaptation plan as conditions change and new knowledge and experiences arise. As an example, the Canadian Centre for Indigenous Environmental Resources (CIER) recommends revisiting adaptation plans every 6 or 7 years (CIER, 2006 f). Adaptation planning can occur as a stand-alone effort or can be included in planning that is already occurring (for example an economic development plan or drought contingency plan).

To provide a consistent example throughout the various phases of the planning process, we are going to consider a scope in which we develop a twenty-year plan to protect Golden Eagle populations on the Colorado Plateau. We chose this example because the Golden Eagle has been designated a priority wildlife species by the Navajo Fish and Wildlife Department. We also have some initial background information on the Golden Eagle from a joint Navajo Department of Fish and Wildlife and Heinz Center *Climate Change Vulnerability Assessment for Priority Wildlife Species* (Mawdsely and Lamb, 2013) and from a Bureau of Land Management *Rapid Ecological Assessment for the Colorado Plateau* (BLM, 2012). Golden Eagle examples are indicated with a photo of a Golden Eagle (photo provided by the Navajo Nation Zoo). Please note that we are not wildlife experts. The Golden Eagle examples are presented to show how an adaptation planning process might work. They are not intended to be in-depth or to represent our views about what should be done to protect Golden Eagles on the Colorado Plateau.

Timeframe of the planning process

In the scoping and engagement phase we start considering some basic logistics of the planning process. You may want to consider:

- What is the timeframe over which you envision that the planning process will take place?
- Do you envision the process occurring over one year, two years, or perhaps longer?
- How frequently do you anticipate that the project team (see below) will need to meet?

This kind of information can be helpful when inviting people to be on the project team.

Identifying a project team

Often, five to ten people is an optimal number for a working group (CIER, 2006 a). In terms of team members, diversity is key. If possible, it is good to invite participants that represent a mix of ages. Consider including tribal elders who can contribute the wisdom they have gained over their lives as well as members of the youth who will experience impacts as climate changes become more pronounced in the future. It is also good to include a mix of men and women, as well as people with a variety of backgrounds and experiences (CIER, 2006 a). For example, it can be helpful for team members with different family histories to be involved. Ideally, members will have different job experiences as well. It would be beneficial for people involved to have backgrounds in various science fields or in policy or health areas. Farmers, ranchers, and business people could be important additions to adaptation planning teams. Depending on the focus of the plan, it may be useful to include both members who are involved at the Navajo national as well as at the chapter decision-making levels. If the geographic range of the plan is large, it can be important to include representatives from different regions. Essentially, the adaptation planning team should represent the communities, interests and expertise which will be necessary to put together a comprehensive plan. The greater the diversity you have on the team, the more diverse perspectives that will be furnished. This diversity can provide a more holistic view of both the challenges presented by climate change and the opportunities for climate change and variability adaptation.

Although the project team will be doing the bulk of the work, perspectives included in the adaptation planning process will not be limited to those of team members. Part of the work the team will be doing is to obtain an array of input from the broader community throughout the various phases of the adaptation planning process. For additional considerations when selecting a project team, we refer readers to *Guidebook 1 – Starting the Planning Process* in CIER's report series – Climate Change Planning Tools for First Nations (CIER, 2006 a).

Obtaining the support of decision-makers in the community

In the scoping and engagement phase it may be wise to obtain support from community decision-makers, particularly those who will need to be involved in the implementation of the adaptation plan. Gathering support can be done through meeting with various tribal leaders and may involve the passing of a tribal climate change resolution. The Institute for Tribal Environmental Professionals (ITEP) at Northern Arizona University has developed a template for such a resolution that will soon be available for download in a Resources Library Database on the ITEP website (http://www4.nau.edu/itep). The template is part of a larger Tribal Climate Change Adaptation Planning Toolkit that will also soon be available on the website.

2.2 Phase 2: Current Vulnerability, Adaptive Capacity and Risk (VACR) Assessments

The next phase in the adaptation planning process is to conduct a current vulnerability, adaptive capacity, and risk (VACR) assessment. VACR assessments are powerful tools that help us understand why impacts are occurring or may occur or why they may be lessened. VACR assessments also help us to understand how often impacts may occur and how severe they might be.

VACRs provide us with three important types of information that we can use in subsequent stages of the adaptation planning process. The three types of information include:

- Information to identify adaptation options
- Information to set priorities
- Information to help identify knowledge gaps

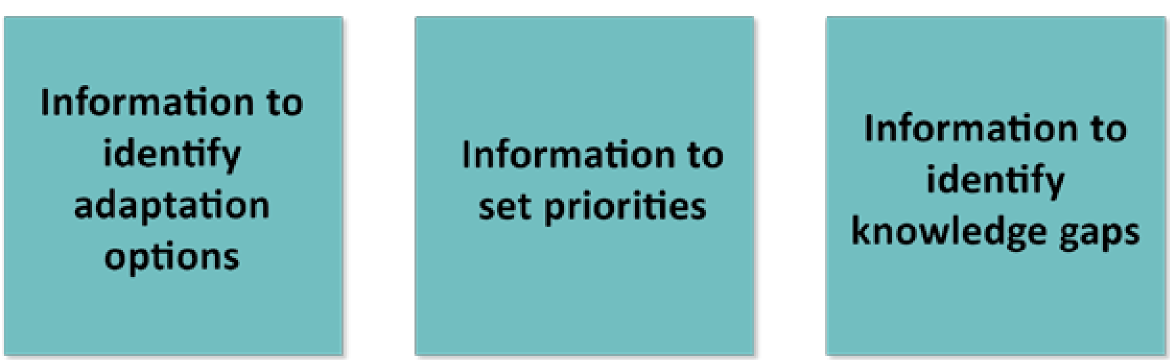

Figure 2.2. The three types of information provided by vulnerability, adaptive capacity, and risk assessments.

Current VACR assessments are, in effect, a systematic way of identifying lessons learned from past and current experiences. We conduct current VACR assessments to provide us with a solid foundation from which to understand the reasons why certain impacts occurred in the past. The VACR assessment can help us anticipate what future impacts may result if these vulnerabilities remain unaddressed.

In this section, we first describe vulnerability, adaptive capacity and risk. Then we provide a qualitative overview of current VACR assessments. We end with a discussion of methods. For more in depth discussion of current VACRs, a good resource is the *ACCC Resource Manual: Reflections on Adaptation Planning Processes and Experiences* (Street and Opitz-Stapleton, 2013).

What are vulnerability, adaptive capacity, and risk? How do they relate to impacts?

There are a variety of definitions used to describe vulnerability, adaptive capacity, and risk. In this report, we make use of definitions drawn from hazards and disaster risk reduction research (Cutter et al. 2010; Füssel and Klein 2006).

Vulnerability and adaptive capacity

The vulnerability and adaptive capacity part of a VACR assessment basically asks two questions.

1. Is a community or ecosystem exposed to a particular climate hazard?

2. What non-climatic factors (e.g., human, environmental) may contribute to or decrease an impact?

We refer to these questions in the text as questions #1 and #2.

Climate hazards can include things like droughts, floods, heat waves, blizzards, wildfires, rises in annual average temperatures, and more. A community or ecosystem may or may not be exposed to a particular climate hazard. As indicated in question #1, the vulnerability and adaptive capacity portion of the VACR assessment considers this potential for exposure. For example, because the Navajo Reservation is located inland, residents will not be exposed to a hazard such as sea level rise. Therefore, Navajo residents are not vulnerable to sea level rise. Conversely, Navajo residents will be exposed to a hazard such as drought. As another example, the location of a structure in the floodplain of a creek or arroyo may be indicative of whether or not people may be exposed to flooding due to overbank flow.

In addition to exposure, when trying to understand why impacts are occurring or may occur, it is also extremely important to consider the broader (non-climatic) context in which these changes are occurring (question #2). This broader context includes:

- *Socioeconomic factors* - examples include the size of a particular community, how dispersed the population is (rural vs. urban), access to education, gender and age inequality, and income levels.

- *Political factors* - examples include water rights, laws such as water quality regulations, and institutional capacity, flexibility, or inflexibility

- *Infrastructural/technological factors* - examples include water supply systems, roadways, and housing.

- *Environmental factors* - examples include patterns of land use, functioning wetlands that can provide storage of flood waters, and invasive species that may be changing historic ecosystems.

- *Spiritual and cultural factors* - examples include sacred springs or mountain ranges, such as the San Francisco Peaks, where impacts on these locations may have spiritual or cultural consequences.

These non-climatic factors are often called vulnerability and adaptive capacity factors. They are essentially a community's weaknesses (vulnerability) and strengths (adaptive capacity) with respect to handling changes (CIER, 2006 c). Although we have divided vulnerability and adaptive capacity factors into the five categories noted above for ease of conceptualization, on the ground, these factors are all interconnected.

For instance, when thinking about drought on the Navajo Nation (NN), a farmer who has access to irrigation water will not experience the same impacts as a farmer who does not have access to irrigation water. Irrigation infrastructure increases adaptive capacity. By way of further example, when thinking about some recent (2013) climate hazards that occurred elsewhere in the US, including flooding in Colorado, early warning systems that involved sending text messages or sounding emergency sirens were adaptive capacity factors that may have saved peoples' lives. In contrast, culverts that had not been cleaned of debris were vulnerabilities when it came to flooding.

In sum, one way to think about vulnerability and adaptive capacity is to think about it as community and ecosystem strengths and weaknesses with respect to handling a particular climate hazard to which they are exposed.

Risk

The risk part of a VACR assessment also asks two questions.

3. What are the characteristics of the climate hazard (e.g., likelihood that it will occur, intensity, duration, timing)?

4. How do vulnerability/adaptive capacity factors interact with the characteristics of the climate hazard to create impacts?

We refer to these questions in the text as questions #3 and #4.

When considering the characteristics of a climate hazard (question #3), we think about things like how frequently that hazard tends to occur. For example, on the NN, drought is a fairly common occurrence, while tornadoes are highly unusual. We also think about things like intensity. A heat wave with daily high temperatures above 90 °F is hot; a heat wave with daily high temperatures above 100 °F is more intense and may consequently have impacts that are more severe. Another characteristic to consider is duration. Droughts, for instance, can be both short (lasting a few months) and long (lasting multiple years). Timing can also be relevant – a drought occurring during the winter may have different impacts than one occurring during the summer. We want to think about possible interactions between different climate hazards occurring at the same time For example, drought impacts may be more severe if combined with elevated temperatures).

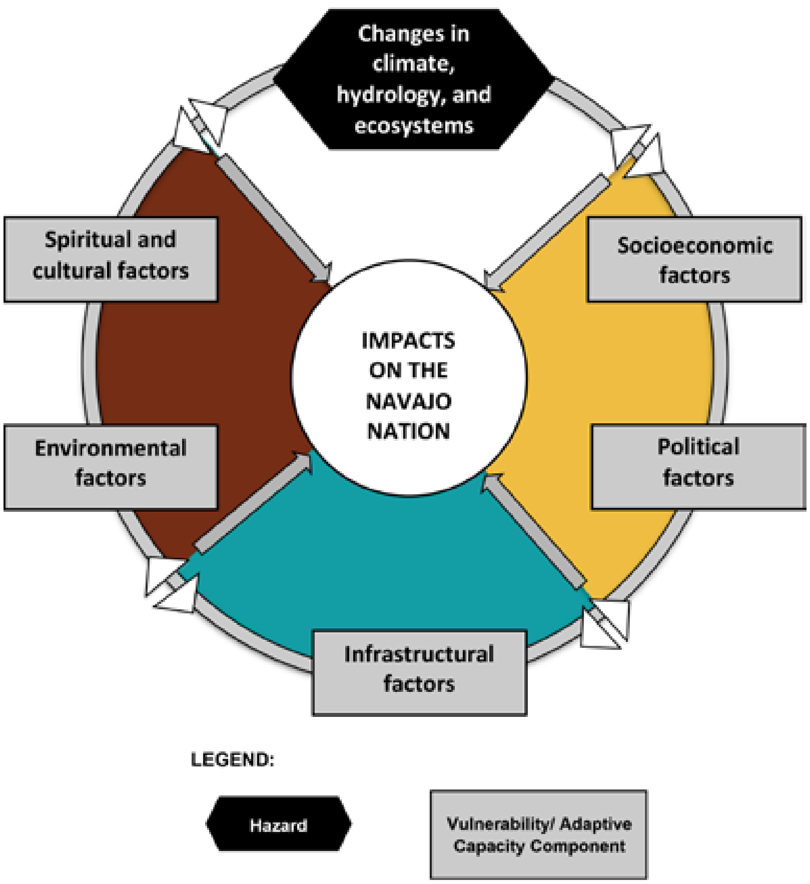

Figure 2.3. How vulnerability and adaptive capacity factors interact with changes in climate, hydrology, and ecosystems to create impacts. Adapted from Cozzetto et al. 2013.

Finally, we consider question #4, which

relates to the interactions between vulnerability and adaptive capacity factors and climate hazards. For example, drought may lead to a decrease in the amount of forage and water available for livestock. When combined with vulnerability factors such as invasive species, overgrazing, or the inability to pay for supplemental forage and water, impacts such as declining livestock health or even livestock deaths may result.

In sum, one way to think about risk is as a description of the impacts that we have experienced or might expect to experience given the interaction between vulnerability and adaptive capacity factors and climate hazards.

Current vulnerability, adaptive capacity, and risk assessment overview

Current VACR assessments are an opportunity to evaluate the kinds of impacts that we have experienced from various climate hazards and to understand why those impacts have occurred at a deep level. It is a chance to assemble a set of lessons learned and to reflect upon what has happened in the past, what has worked, what has not, and the reasons why. We can use this information to help us anticipate potential future impacts and as we identify and prioritize adaptation options.

When conducting a current VACR assessment, we are acting like investigative reporters gathering information and trying to get to the bottom of something. During this process we may ask questions like: Who or what was affected? How severely? Where? How frequently? And, the big question, why?

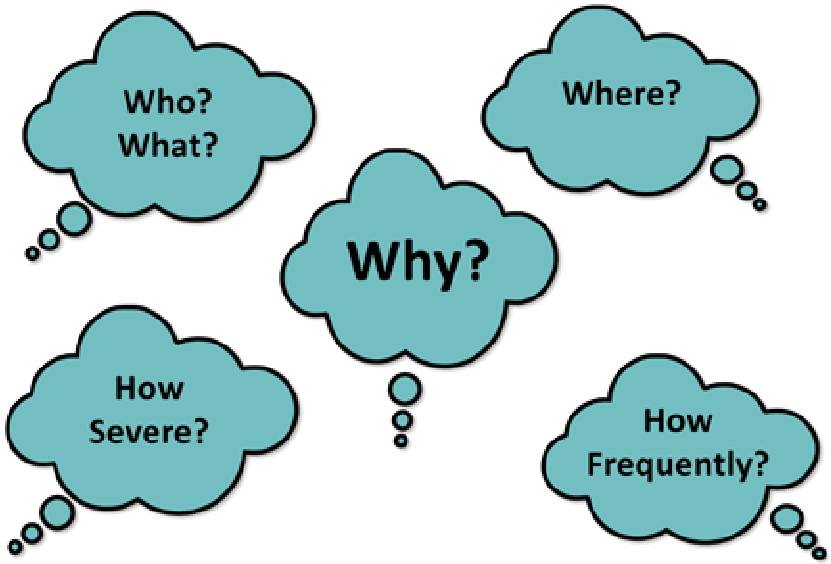

Figure 2.4. The kinds of questions asked in vulnerability, adaptive capacity, and risk assessments.

The information to answer these questions can come from a multitude of sources, including: climate, water, wildlife, forest, and grazing lands monitoring data, economic development plans, and emergency response reports. Information may come from one-on-one interviews with residents, or from focus groups or stakeholder meetings. Local ecological knowledge of people who have lived in the region for a long time can be extremely valuable and help to fill in gaps where instrumental data may be sparse. In Chapter 3 of this report we have summarized many of the climate variability and changes currently being experienced in the SW and on the Navajo reservation. Chapter 3 can thus serve as a broad basis for climate information when conducting a current VACR assessment.

A current VACR assessment will focus on the scope of our adaptation planning effort and can start with observations of impacts now occurring. If we continue with the Golden Eagle example discussed in Phase 1, we might start with the observation that Golden Eagle populations on the Colorado Plateau are declining. We might then ask questions #1 and 2 described above in an effort to get at why the decline is occurring.

The Golden Eagle population may be declining for a variety of reasons. Some of these reasons may have to do with exposure to climate hazards. For example, wildfires may be affecting open shrubland habitat, causing declines in eagle prey populations (see Box 2.2) (BLM, 2012). Invasive species may be contributing to the conversion of shrubland habitat (Mawdsely and Lamb, 2013).

Other factors contributing to the decline of populations are unrelated to climate (see box below). For example, eagles are dying because they are running into power lines and wind turbines, which are infrastructural factors (BLM, 2012; Mawdsely and Lamb, 2013). They are also dying because of secondary poisoning from consuming prey that has ingested rodenticide that has been killed by lead bullets (BLM, 2012). This can be considered an environmental/land-use factor and is not directly related to climate change impacts. In sum, while some eagle deaths are attributable to climate-related factors, quite a few other non-climatic factors (i.e., vulnerability and adaptive capacity factors) are also contributing to the impact of declining Golden Eagle populations.

As the project team goes through the VACR, they will delve deeper into why impacts are occurring and can ask additional questions. For example, when exploring how secondary poisoning is contributing to eagle deaths, they might ask if secondary poisoning is happening more in certain geographic areas as compared to others. For instance, when exploring how wildfires have affected eagle populations, the project team might gather information as to how effective wildfire response has been (see Box 2.2).

This exploration of vulnerability and adaptive capacity factors in a VACR assessment is the first place in the adaptation planning process where we can start to make use of the information found in subsequent chapters of this report. Each chapter covering a particular sector (e.g., tourism and recreation, energy) or resource (e.g., water, rangelands, forest) contains a section entitled vulnerability and adaptive capacity factors. These sections are not intended to be comprehensive descriptions of vulnerability and adaptive capacity factors that may influence a particular sector or resource. Rather, they are intended to be used by the project team as it goes through the adaptation planning process as a basis for brainstorming the non-climatic factors that may be interacting with climate hazards to create impacts.

As we move into the risk part of the VACR assessment, we consider questions related to the characteristics of climate hazards (question #3 above), including:

- How frequently have wildfires occurred in eagle habitat?
- How severe have they been?
- When have they occurred and where?

We also consider how vulnerability and adaptive capacity factors have interacted with climatic factors to create impacts (question #4 above). For example, the project team may try and gather information about the percentage of eagle deaths attributable to wildfire impacts on prey in comparison to eagle deaths attributable to collisions with power lines or wind turbines, etc. (see Box 2.3).

By the end of the current VACR assessment, we aim to have a solid and broad understanding of why an impact is occurring as well as what factors may or may not be more dominant. We may also have identified some areas in which we need to conduct further monitoring or research. One helpful goal can be to have a list of lessons learned from handling past situations.

Methods

There are a variety of methods for gathering information and conducting VACR assessments. A VACR assessment can be done qualitatively, quantitatively, or in a way that combines both qualitative and quantitative methodologies.

A qualitative VACR approach could involve a project team holding a workshop for a few days bringing together stakeholders with a variety of experiences and expertise to discuss the topic of the adaptation planning (e.g., conservation of Golden Eagle populations).

A current VACR could start with an observation of an impact that is occurring (e.g., Golden Eagle populations are declining in the Colorado Plateau). Alternatively, a current VACR could start with a discussion of a climate event that has occurred (e.g., the blizzard of 2010), followed by a discussion of impacts emanating from that climate event and the subsequent exploration of vulnerability and adaptive capacity factors that may have contributed to those impacts.

Golden Eagle Box 2.2: Current VACR Assessment Focus on Vulnerability and Adaptive Capacity

Observation: Golden Eagle populations are declining on the Colorado Plateau

Inquiry: What climatic and non-climatic factors are contributing to or lessening the decline of Golden Eagle populations?

- Wildfires are affecting open shrubland habitat and prey populations are declining ***(climate-related factor)***
    - How effective has wildfire response been in the past? What are community strengths and weaknesses with respect to fighting wildfires?
    - What fire prevention activities were in place? Were prescribed burns done?
- Habitat loss due to invasive species ***(climate-related/land-use factor)***
    - What kind of invasive species seem to be most problematic? Under what conditions?
    - Are any programs in place for invasive species control?
- Drought may be playing a role ***(climate-related factor)***
    - Is there more information on why this might be the case?
- Golden Eagles are dying because they are running into power lines and wind turbines ***(infrastructural factor)***
    - Is Golden Eagle mortality due to wind turbines collisions higher in certain regions?
    - Where eagle deaths are lower, have certain measures been taken to lessen eagle mortality?
- Loss of nesting and hunting grounds due to urbanization, agricultural development, and solar farm construction ***(land-use factor)***
    - Where is this occurring?
- Secondary poisoning when consuming prey that has ingested rodenticide or prey wounded with lead bullets ***(land-use/ environmental factor)***
    - Is such poisoning occurring in certain areas vs. others?
    - If so, are certain factors leading to less mortality?
- Although legally protected, sometimes eagles are accidentally shot by hunters or intentionally shot by ranchers ***(land-use/ regulatory factor)***
    - How many livestock deaths are due to eagle attacks?
    - Are there any related educational campaigns to prevent eagle deaths?

Sources: BLM, 2012; Mawdsley and Lamb 2013

A more in-depth quantitative approach could take longer and involve the project team meeting periodically during the timeframe that the VACR is occurring. The team would also have "homework" to carry out between meetings. This homework could involve various participatory activities to engage and gather information from a variety of stakeholders in the region. Additional information gathered can help to develop a more complete and holistic assessment of historic and current impacts.

Brief descriptions of some methods for gathering information for current VACR assessments are provided here below. Included with most descriptions is a reference for more information.

Literature review: A literature review involves project team members gathering data from monitoring networks, reports, and other sources that will help inform the VACR assessment. This can include meteorological and climate data such as temperature, economic data, census data, policy reports, topographic maps, and scientific articles (Macchi, 2011).

Historical timelines: Historical timelines can span ten to twenty years and show major events that have affected the wellbeing of a community or an ecosystem, including events such as natural disasters (e.g., droughts, floods, blizzards), changes in livelihood, diseases and political/regulatory milestones (Macchi, 2011).

Influence diagrams: Influence diagrams are flow charts that start with a climate event that has occurred in the past and use arrows to show the cascading consequences of these changes in a wide range of areas, including: the environment, livelihoods/socioeconomic consequences, infrastructural impacts, spiritual and cultural effects, and political implications (CIER, 2006 c).

Seasonal calendars: Seasonal calendars are visual representations of seasonally-varying phenomena including climate events, livelihood activities and disease occurrences (Macchi, 2011). They can be developed in the form of a matrix with the months of the year across the top of the calendar (noting that the year does not necessarily have to start in January) and with events, livelihood activities, etc. listed in a column on the left side of the matrix. They can be used to identify links between different seasonally-changing events, as well as to identify populations that are potentially vulnerable during different times of year.

Mapping exercises: Maps are visual representations of the lay of the land and can show both natural features (such as mountains, forests, rivers, lakes, wetlands, watersheds, species habitats) and human-made or societally important features (such as schools, hospitals, roads, water supply infrastructure, hunting grounds, areas to gather wood or medicinal plants, and recreational areas) (CIER, 2006 c). They can also be used to identify places where residents or resource managers have observed environmental or other changes occurring (including changes in wildlife habitat, vegetation composition, etc.). Maps may be digital and take advantage of GIS, aerial photographs, and satellite images. Or they can be handmade (CIER, 2006 c). Overlaying maps can show links between different community assets and observed changes.

Venn diagram of institutions: This is a visual representation of key decision-making levels and agents that demonstrates how they are interconnected (or not). Each circle in a Venn diagram represents some type of decision-making boundary. Decision-making entities can include, for example, household, chapter level, Navajo national level, US federal government level, or entities such as the Navajo Water Management Branch or the Bureau of Reclamation. These diagrams can be helpful to understand how decisions are made within a community. They may also illustrate institutional barriers or adaptive capacities that may be available institutionally (Macchi, 2011).

One-on-one interviews: One-on-one interviews can be carried out with a variety of individuals (for example resource managers, ranchers, farmers) to gain more in-depth information about the selected topic.

Focus groups: Focus groups involve talking with small groups of people to gain more information about the adaptation planning topic. Some of the methods discussed here – e.g., influence diagrams, seasonal calendars, mapping exercises – can be carried out by focus groups. Focus groups are good ways to collect input from people beyond the members of the project team.

2.3 Phase 3: Future Vulnerability, Adaptive Capacity and Risk (VACR) Assessments

Phase 3 in the adaptation planning process involves conducting a future vulnerability, adaptive capacity, and risk assessment (VACR). The future VACR assessment is where we conduct a more in-depth exploration of the potential future implications of climate change for our region up to a certain point in the future. In this phase we will gather information as to whether a community or ecosystem will likely be exposed to particular climate changes (question #1) as well as information about the nature of the climate changes or events (question #3) up to a certain year.

This type of information gathering can be done in a highly quantitative/technical fashion. For example, an analyst may download temperature and other climate variable projections for a particular geographic location. The analyst could then run these through a hydrologic model.

Gathering information on climate changes can also be done in a more qualitative fashion. For example,

Golden Eagle Box 2.3: Current VACR Assessment Focus on Risk

What are the characteristics of the climate hazards?

- Wildfires in eagle habitat
    - How frequently did they occur?
    - How intense were they?
    - When did they occur?
    - How long did they last?
    - Do we have information on shrubland fuel loads that may have contributed to wildfire spread? If not, is this an area where we might like to obtain more information?
    - How many of these fires were attributable to natural causes vs. human started ignitions?
- Droughts in eagle habitat
    - How frequently did they occur?
    - How intense were they?
    - When did they occur?
    - How long did they last?
- Did wildfires and/or droughts contribute to the spread of invasive species?

How do climate, vulnerability and adaptive capacity factors interact to create declines in Golden Eagle populations?

- Of documented Golden Eagle deaths, how many per year were attributable to electrocution from collisions with power lines, to collisions with wind turbines, to ingestion of rodenticides, and so on?
- By how much have prey populations declined? How much of this decline can be attributed to factors like wildfires or drought?
    - How are declines in prey populations estimated to have impacted Golden Eagle populations?
- What is the areal extent of nesting and or feeding ground habitat loss due to urbanization vs. conversion to agricultural land vs. solar farm construction vs. invasive species and by how much have these losses contributed to declines in Golden Eagle populations?
- According to the Heinz Center report, "of the Golden Eagles found dead in the early 1960s to the mid-1990s, 73% died from human-related causes." (Mawdsley and Lamb 2013)

a project team may use information pertaining to the general direction of changes expected (e.g., temperatures are expected to rise and droughts are expected to increase in frequency, severity, and duration).

It is up to project team members to choose what level of technical analysis they would like to undertake. In Chapter 3 of this report, we have summarized many of the climate changes anticipated for the Southwest (SW). Chapter 3 can thus serve as a basis for thinking about changes that may occur when conducting a future VACR.

The climate, hydrologic, and ecosystem changes discussed in Chapter 3 can have a variety of consequences (question #4). For example, in the SW, higher temperatures, increased drought, and longer fire seasons associated with earlier snowmelt are expected to lead to an increase in wildfire frequency and size (Brown et al. 2013). Fires are a natural feature of the landscape. However, in recent years, record-setting wildfires have occurred in both Arizona and New Mexico (see Chapter 10). Wildfire smoke contains particulate matter that could exacerbate respiratory conditions (see Chapter 7). Wildfires can also directly impact utility infrastructure, and retardants dumped by aircraft to combat fires can foul electricity transmission lines (Chapter 11). If we continue with our Golden Eagle example, increased wildfire frequency and size could potentially lead to more burning of shrubland habitat, greater declines in eagle prey species, and increased difficulties for Golden Eagles.

Other climate changes may also have potential effects (see Box 2.4). Each chapter following this one (Chapters 4 through 12) contains a discussion of the potential consequences of climate changes and variability for a particular sector/resource. These summaries are not meant to be comprehensive examinations of all possible impacts; rather, they are intended to serve as a basis for a project team to start to think about potential consequences of climate change as they go through the adaptation planning process and attempt to address question #4.

Vulnerability and adaptive capacity factors may also change in the future (question #2). Therefore, we also need to consider how these factors might change and interact with climate changes occurring to create impacts. Continuing with the Golden Eagle example, we might think about what kind of human population growth or decline we might expect in the region. Population growth may affect whether shrubland might be converted to agricultural land, or vice versa. We might also consider changes in renewable energy development and potential corresponding impacts on eagle populations (see Box 2.4). Again, as we consider future changes in vulnerability and adaptive capacity factors, we can make use of the vulnerability and adaptive capacity factor sections included in each of the sector/resource chapters in this report.

As we think about the future, there are sources of uncertainty as to the kinds of changes that may take place. For instance, there is uncertainty associated with scientific models. While some climate processes are well understood, significant difficulties remain in representing others, like clouds. We may also lack sufficient observational data.

There is also uncertainty associated with our behaviors. We do not know what human populations will be like in the future. Nor can we be certain of the kinds of choices that our societies will make, including choices about our energy sources, our energy usage, or how we may modify the land surface. All of these choices and many more will affect our greenhouse gas (GHG) emissions. This is why in future VACR assessments we try to identify potential impacts from not just one possible future, but from a range of possible futures.

One way to consider a range of futures is to utilize scenarios. If we are considering drought impacts on farming, we might consider impacts from a matrix of scenarios including situations in which drought occurrences are the same as now, in which droughts are 20% worse, and in which droughts are 50% worse. We may also include scenarios in which irrigation infrastructure is similar to now, in which irrigation infrastructure is in greater disrepair, and in which irrigation infrastructure has been improved to be highly efficient.

Pursuing our Golden Eagle example, we could also consider impacts from a matrix of scenarios. Scenarios could include ones in which shrubland area affected by wildfires is the same as now, is 20% greater, and is 50% greater. We may also consider scenarios in which the total area of shrubland habitat is 20% more than now, in which it is the same as now, and in which it is 20% less than now (see Table 2.1).

For more in depth discussion of future VACRs, a good resource is the *ACCC Resource Manual: Reflections on Adaptation Planning Processes and Experiences* (Street and Opitz-Stapleton 2013).

Methods

As noted in Phase 2 on current VACR assessments, there are a variety of methods for gathering information and conducting such assessments. The information presented now is somewhat repetitive of the information presented for Phase 2. However, the focus is on potential future conditions rather than current/historic conditions.

A qualitative VACR approach could involve a project team holding a workshop for a few days to bring together stakeholders with a variety of experiences and expertise (e.g., conservation of Golden Eagle populations). A future VACR could start with a discussion of an anticipated climate change (e.g., temperatures are expected to get warmer), followed by a discussion of impacts emanating from that climate event and an exploration of potential changes in vulnerability and adaptive capacity factors that could contribute to or lessen those impacts. Different scenarios would be considered.

A more in depth quantitative approach might take place over a longer timeframe, and involve the project team meeting periodically during that period and then having "homework" to carry out between meetings. This homework could involve the generation of model projections and the carrying out of various participatory activities.

Brief descriptions of some methods for gathering information for VACR assessments were provided in Phase 2 on current VACR assessments. In addition, we include some more information on participatory scenario building and model projections below.

Participatory scenario building: Scenarios, as noted above, are possible representations of what the future may be like. Participatory scenario building can involve a dialogue between climate researchers and stakeholders. Climate researchers can provide information as to what kinds of climate changes can be anticipated in the future. Stakeholders or other kinds of researchers may be able to identify plausible changes in vulnerability and adaptive capacity factors (PROVIA, 2012).

Information on climate changes can also be gathered from climate assessments and other reports. One method for coming up with different scenarios to consider is to ask each project team member to write down a few different scenarios and rank each according to probability of occurrence and severity of consequences on a scale of one to five (Eriksson and Juhl 2012). The team can then examine the different scenarios developed and choose which ones to analyze further so as to represent an array of possible futures. Scenario development could also be the topic of a focus group discussion.

Model projections: Characterizing future impacts often starts with coupled atmosphere-ocean general circulation models that provide projections of climate variables at relatively large spatial scales (typically greater than 150 km). These projections can then be run through a regional climate model or through statistical models to "downscale" output so that it is available at finer spatial scales such as 25-50 km. The downscaled output, in turn, can be run through a biophysical model such as a water evaluation and planning model or through an agricultural production or vegetation model. Or the downscaled output could be run through a socioeconomic model; for example, a multi-sectoral economic analysis model to examine impacts. Sometimes biophysical and socioeconomic models are linked to explore the connections in an integrated system.

Golden Eagle Box 2.4:
Future VACR Assessment

What climate, hydrologic, and ecosystem hazards will Golden Eagle populations be exposed to in the future? How will the nature of those hazards change? What impacts may these changes have on Golden Eagle populations?

- Wildfire frequency and size are expected to increase and wildfire seasons are expected to become longer. This could impact shrubland habitat and reduce Golden Eagle prey populations.
- Drought is expected to increase in frequency, severity and duration. Our current VACR assessment indicates that these could contribute to further impacts on Golden Eagle populations.
- Extreme temperatures may affect prey populations (Mawdsely and Lamb 2013).
- How may invasive species be affected under climate change? How could this potentially affect eagle nesting and feeding habitat?
- Do higher temperatures and potentially greater precipitation intensities have implications for eagle nestlings?
- Are prey populations expected to move in response to changing environmental conditions?

As part of a future VACR, a project team could choose to try and get more detailed information on the types of climate changes that may occur. For example, how much are average summer temperatures anticipated to increase by 2030?

How may vulnerability and adaptive capacity factors change in the future?

- How do we expect population in the region to change and potentially affect the conversion of shrubland to urban or agricultural uses or vice versa?
- How will renewable energy generation (wind and solar, in particular) change in the region? What types of regulations may help minimize impacts on Golden Eagles?
- How will wildfire management, wildfire response capabilities, and interagency cooperation change?

How will climate, hydrologic, and ecosystem changes and changes in vulnerability and adaptive capacity factors interact to create impacts on Golden Eagle populations?

	Area of shrubland habitat affected by fire same as now	Area of shrubland habitat affected by fire 20% greater	Area of shrubland habitat affected by fire 50% greater
Total area of shrubland habitat 20% greater	**Scenario 1** impacts	**Scenario 2** impacts	**Scenario 3** impacts
Total area of shrubland habitat same as now	**Scenario 4** impacts	**Scenario 5** impacts	**Scenario 6** impacts
Total area of shrubland habitat 20% less	**Scenario 7** impacts	**Scenario 8** impacts	**Scenario 9** impacts

Table 2.1. Possible scenario matrix for assessing impacts on Golden Eagle populations. Impacts become increasingly severe as the color darkens.

2.4 Phase 4: Option Identification

The next phase in the adaptation planning process is option identification. Here we want to review our current and future VACR assessments and scenarios, in particular the in-depth examinations of why impacts are or may occur. Because we have done a thorough analysis, we should be able to come up with a wide variety of adaptation tools for what we might think of as our adaptation toolbox. These could be so-called "soft options" such as regulatory tools, educational tools, or economic tools, or "hard options", such as infrastructural or technological approaches.

In the option identification stage, we are trying to get as many tools as possible in our toolbox. We are not yet selecting which tools to use; that will come in the prioritization part of the process. So let the creative juices flow. In each of the resource/sector chapters (Chapters 4 through 12), we have included a section on potential adaptation strategies. These chapter sections can be used as a basis for starting to brainstorm adaptation options that would be most relevant for the NN.

If we continue with the Golden Eagle example that we have been using, one potential climate change that may contribute to declines in Golden Eagle populations is increased wildfire frequency and size affecting shrubland habitat. Potential adaptation strategies include: educating the general public to reduce fires started by humans and improving monitoring to identify wildfires once they start. Additional possible adaptation strategies are noted in Box 2.5.

One vulnerability factor contributing to Eagle deaths are collisions with power lines and wind turbines. Potential adaptation strategies include: burying utility lines near eagle nesting locations and employing bird flight diverters on overhead power lines. Additional possible strategies are provided in Box 2.6.

Eagle mortality is also being caused by eagles getting secondary poisoning by ingesting prey that have consumed rodenticides or by consuming lead bullet fragments in prey that have been wounded with lead bullets. Potential adaptation strategies include: educating land owners on methods to control rodents that do not involve rodenticides and educating hunters about non-toxic bullet alternatives to lead shot. For more adaptation options, please see Box 2.7

We could consider all the additional climatic and non-climatic factors identified in the VACR assessment that are contributing to declining eagle populations and brainstorm even more adaptation options. This brainstorming could be done by the project team during a meeting or during several meetings. It is also

Golden Eagle Box 2.5: Identifying Adaptation Options

Climate factor – increased wildfire frequency and size

- Educate the general public to reduce fires started by humans.
- Improve monitoring to identify wildfires once they start.
- Conduct assessments of fuel loads in shrublands to identify locations where catastrophic fires are more likely to occur.
- Fire is a natural feature of the landscape so conduct strategic prescription burns to manage the fuel load.
- Increase number of personnel able to carry out such strategic burns.
- Identify diverse water sources for fighting fires in various regions.
- Increase the number of personnel trained to fight fires.
- Improve interagency cooperation to address fire response.
- Start a nursery to revegetate shrublands that have burned.
- Purchase additional equipment for fighting shrubland fires.

Golden Eagle Box 2.6: Identifying Adaptation Options

Vulnerability factor – eagle collisions with power lines and wind turbines

- Stop building wind turbines (we'll consider the advantages and disadvantages of this option below)
- Consider eagles when choosing where to locate wind turbines, in particular roosting and feeding areas.
- Consider burying utility lines near eagle nesting locations.
- Employ bird flight diverters on overhead power lines.
- Work with wind turbine owners to follow the 2012 USFWS *Land-Based Wind Energy Guidelines* to minimize impacts on birds.
- Breed eagles in captivity for release in the wild to help increase populations.

desirable to hold community meetings so that stakeholders can contribute adaptation ideas– the more people thinking about adaptation, the more adaptation options that will be identified!

2.5 Phase 5: Option Prioritization

Once we have identified a list of potential adaptation options, we need to think about which ones we would like to work on and in what order we would like to pursue them. If there are many different options, we might want to make use of a screening process to select options that we will then examine more in-depth (CCS, 2011). The project team may want to undertake the initial screening. It may decide to involve experienced leadership at this stage to get input as to what they consider to be feasible (CIER, 2006 d).

The more in-depth analysis of options may include decision-making approaches such as: social impacts analysis, environmental assessments, cost-benefit analysis, cost-effectiveness analysis, multi-criteria analysis, regrets analysis, portfolio management and more. During the more in-depth analysis it is desirable to get as much community input as possible (CIER, 2006 d). Everyone will be affected by climate change/variability as well as by climate adaptation strategies (CIER, 2006 d), though not everyone will be affected equally or in the same manner. In addition, as pointed out by CIER in their Guidebook 4: Identifying Solutions, "when more people are involved in discussing the future plans in the community, the chances of people supporting these actions when they are implemented increase, and people also often want to be involved in making these actions successful" (CIER, 2006 d).

Golden Eagle Box 2.7: Identifying Adaptation Options

Vulnerability factor – secondary poisoning

- Create education campaigns on the potential dangers rodenticides pose to Golden Eagles.
- Educate homeowners/ landowners on methods of controlling rodent pests that do not involve rodenticides.
- Educate hunters about non-toxic bullet alternatives to lead shot.
- Encourage hunters to retrieve wounded prey.
- Pass regulations mandating the use of non-lead shot in areas known to be Golden Eagle feeding grounds.
- Establish raptor recovery centers where sick eagles might have the chance to be rehabilitated.

As part of the prioritization process, a community or organization will need to define the criteria that it would like to employ when prioritizing options. Below, we present potential criteria that could be used. Criteria should be considered both during the initial screening process and during the more in-depth analyses.

For additional information on the in-depth decision-making analyses we noted above, we refer readers to:

- Chapter 5 of the Center for Climate Strategies [CCS] Adaptation Guidebook (CCS, 2011)
- Chapter 3 of the United Nation's Programme of Research on Climate Change Vulnerability, Impacts, and Adaptation [PROVIA] Draft Guidance on Assessing Vulnerability, Impacts, and Adaptation (PROVIA, 2012)
- Chapter 4 of the National Research Council's report, Adapting to the Impacts of Climate Change (NRC, 2010)
- ACCC Resource Manual: Reflections on Adaptation Planning Processes and Experiences (Street and Opitz-Stapleton, 2013)

For ideas on how to engage stakeholders in prioritization, we refer readers to CIER's *Guidebook 4: Identifying Solutions* (noted above) (CIER, 2006 d).

Helpful prioritization criteria

Community visions for future: Climate change adaptation planning is an opportunity not just to adapt to climate change but to think bigger about our values and the kind of communities and environments that we would like to live in and the kind of world we would like to leave to those who come after us. Adaptation options selected should further this vision.

Visioning exercises can be done with focus groups (see Phase 2) or during larger stakeholder meetings. Once again, including a range of stakeholders with different experiences and perspectives is important in this process. Visioning can include social, economic, environmental, cultural, and other considerations. For example, a community vision may include things like well-paying stable jobs, re-vegetation of lands, decreasing toxic pollution, respect for others and ourselves, and more basketball courts. Although we mention visioning during Phase 3, it can also be done at each phase in the adaptation planning process. For more discussion of community visioning, we refer readers to the CIER's Guidebook 3 in their series, *Climate Change Planning Tools for First Nations* (CIER, 2006 c).

Vulnerable subpopulations: Certain populations/habitats/species/crops/livestock may be more vulnerable to certain climate changes. For people, potentially vulnerable populations often include: children, the elderly, pregnant women, people with pre-existing medical conditions, people who work outside, those who live in poor housing conditions, and those with mental illness or with post-traumatic stress disorder (Houser et al. 2000). However, the specifics of which populations may be more vulnerable will vary with the particular climate change being considered. For example, asthma sufferers may be particularly vulnerable to climate change-related effects on air quality, while those with diabetes may be more susceptible to heat stress (see Chapter 7). Vulnerable subpopulations should be examined as part of the VACR assessment. Decision-makers may want to prioritize strategies that help vulnerable subpopulations adapt.

Benefits (including co-benefits) and potentially adverse impacts: If a strategy has been proposed for adaptation, it should provide some benefit in terms of adapting to a particular kind of climate change. One consideration is the degree of the benefit provided by the strategy. If we consider our Golden Eagle example, we might think about the magnitude of the decline in eagle mortality to which a particular strategy might contribute.

We also want to think holistically and consider the adaptation benefits that a particular strategy might provide for other sectors, how that strategy may further our societal, economic or environmental goals, or how a strategy may contribute to the reduction of GHG emissions (Kinney, 2008; UKCIP, 2007). These additional or multiple benefits are sometimes called “co-benefits.” For example, one impact of rising temperatures may be increasing demands on our energy supply systems for the cooling of buildings. Increasing energy efficiency may lessen energy demands. It can also help homeowners save money on energy bills, an economic benefit. Depending on the energy source, energy efficiency can help contribute to reductions in GHG emissions. It could also help decrease air pollutant emissions, which could contribute to improved public health. These tangential benefits are co-benefits.

We also want think holistically about the potential adverse impacts of a particular strategy on different populations, on the environment, across sectors and resources and across generations (CCS, 2011; NRC, 2010). For example, an adaptation strategy that may be beneficial for one sector or resource may be harmful or maladaptive for another. Desalination, for instance, can be a good adaptation option for diversifying the water supply. Desalination, however, can also be quite energy intensive and could increase stresses to the energy system.

Distribution of benefits and adverse impacts: As well as considering the benefits and adverse impacts of a strategy, it is also important to think about how benefits and costs are distributed (CCS, 2011). Consider: Do certain groups receive a disproportionate amount of the benefits or bear a disproportionate amount of the costs? Are social inequalities exacerbated further by an option?

Strategy feasibility: Strategy feasibility considers questions such as: What kinds of decisions need to be made to implement the strategy (CIER, 2006 d)? What kinds of actions are needed (CIER, 2006 d)? What kinds of financial, technical, legal, administrative and other resources are needed (CIER, 2006 d)? Is the political and social will in place? Have others implemented this strategy? What has worked well, what has not worked?

Strategy feasibility can be considered in conjunction with the benefits provided by the strategy. If the potential benefits are high, it may still be worth pursuing a strategy that may be more difficult to implement. If, for example, funding is an issue, initial steps could focus on trying to identify alternative funding mechanisms. If, the political/social will is not currently in place, perhaps the initial focus could be on education and building support.

Financial Costs: Financial resources on the NN can be scarce (see Chapter 1). Thus, costs are a necessary consideration for any undertaking. It is important to consider not only the costs for implementing the strategy, but also the long-term costs related to maintaining the strategy (CCS, 2011). During the screening process, the costs of different options can be ranked qualitatively. For example, an educational option may be relatively low cost while options involving the installation of large-scale infrastructure might be high cost. During the more in depth analysis of adaptation options, concrete cost estimates can be developed and funding sources identified.

Natural/manmade reset opportunities: In terms of implementation, it may be possible to make use of natural or manmade opportunities to reset conditions. This can both help ease transitions and decrease costs; in this way, it is related to the financial costs criterion noted above (Luers and Moser 2006; Millar et al. 2007). Routine infrastructure upgrades can be opportunities to retrofit highway or bridge expansion joints to accommodate higher temperatures. Upgrades can also present opportunities to install larger culverts that both allow for potential increased precipitation intensities and accommodate wildlife passage to connect landscapes. As new infrastructure is constructed, potential climate changes can be considered in design. Natural reset opportunities include flooding or wildfires. For example, post-flooding recovery could possibly include relocating structures out of floodplains (Millar et al. 2007).

Timeframe of impacts addressed: Different impacts may occur on different timescales. Some strategies may address shorter-term impacts, while others may address impacts that are anticipated to occur further in the future (UNECE, 2009).

Flexibility: Because of increasing uncertainty about future climate conditions, consideration should be given to the flexibility of a strategy. Flexibility refers to the ease with which a strategy can be adjusted or changed if different conditions arise than those anticipated (PROVIA, 2012). Increased flexibility can permits us to course correct if new information arises about an adaptation strategy (Millar, 2007; UKCIP, 2007). Flexibility includes the ability of a strategy to be reversed and/or the ability of a strategy to be implemented incrementally (Millar, 2007; UKCIP, 2007). Flexibility is just one consideration among many so this is not to say that a less flexible strategy should not be implemented but rather that the implications of choosing such a strategy should be fully understood.

Examples of flexible strategies include: promoting policies that allow decision-making to be more readily adjusted as environmental conditions change, investing in insurance, making use of parks or other conservation areas to perform double duty as flood management areas, and incrementally introducing new agricultural crops that are more in line with projected climate changes (UKCIP, 2007). Although infrastructure is typically thought of as a less flexible adaptation strategy than institutional or regulatory options (soft as opposed to physical options)(PROVIA, 2012), there may be ways to enhance infrastructure flexibility. Examples include floatable water treatment plant intake systems that can rise or fall as reservoir levels change and bridges that can be raised if flows beneath them rise (Weeks, 2013).

Risk preference: Risk preference varies from community to community and takes into account factors such as the severity of an impact, the likelihood that it will occur and what the community wants to do about it. An example often used to explain risk preference is that of an asteroid hitting the earth. The likelihood of this occurring is extremely low; however, if one did, the severity of the impact would be extremely high. A decision-maker might think that since the likelihood of such an occurrence is so low, it is not worth spending any time or money towards addressing a potential asteroid strike. Alternatively, a decision-maker might think that the potential consequences of such an impact would be so catastrophic that such a threat should be addressed. Thus, the choice as to whether or not to use resources to adapt to a potential asteroid strike is a value judgment.

The severity of a potential impact can be discussed in qualitative terms. Severity may be extremely limited, limited, serious, extremely serious, or catastrophic. Severity, for example, can also be discussed in quantitative terms that will vary depending on the impact. This type of information will emerge from the current and future VACR assessments and will be reflected upon during options prioritization. In the case of our Golden Eagle example, severity might be discussed in terms of eagle mortality per year.

In similar fashion, likelihood can be discussed in qualitative terms. Likelihood could be ranked for example as very low, low, medium, high, or very high. Sometimes the likelihood of an impact can be described in terms of quantitative probabilities based on model results, statistical sampling, or expert judgment. An impact may be described, for instance, as less than 5% likely, between 5 and 33% likely, between 33% and 66% likely, between 66% and 95% likely, and over 95% likely.

A degree of confidence may be attributed to either a severity or likelihood of occurrence. The degree of confidence (e.g., low, medium, high) will depend on the level of evidence (uncertainty) and the level of agreement among the evidence (confidence). Adapting to a change that has a higher confidence of occurring may take priority over adapting to one which may occur but for which the degree of confidence is lower.

Redundancy: Redundancy has different meanings in different contexts. For example, in our efforts to streamline systems and make them more cost effective, sometimes redundancy is targeted as a bad thing to be eliminated. However, redundancy can also mean having alternative ways for accomplishing critical functions during emergencies (e.g., personnel, infrastructure) so that one part of a system can fail without there being many cascading consequences causing the entire system to fail. If you have a backup hard drive, that is an example of redundancy (CCS, 2011; Wilbanks et al. 2012). Given anticipated increases in extreme events, redundancy in critical systems can be important for minimizing damage, hardship, and loss of life.

In the context of transportation, redundancy might involve having more than one route and/or modes of transport between critical destinations (Wilbanks et al. 2012). In the context of water supply, redundancy could involve having generators to provide backup power at pumping facilities in the case of a power outage, having spare pipes and fittings on hand in case of line breaks, or having diverse water supply sources in case of drought (USEPA, 2011). Redundancy, thus, is a kind of adaptation strategy in itself. We mention it in the context of prioritization in that it can be good to include approaches that involve redundancy for critical systems.

Safe-to-fail: Traditionally, when it comes to infrastructure, engineers try to design structures so that they are "fail-safe," that is designed not to fail at all unless a particularly rare event occurs. With climate change comes both the potential for increasing extreme events and also increasing uncertainty (Weeks, 2013). Designing structures for more extreme events can increase costs significantly. Furthermore, higher uncertainty in the types of events that may be experienced by structures means that they could still potentially fail, even if designed to more extreme standards (Weeks, 2013).

To address this, some engineers are proposing a shift in design standards from "fail-safe" to "safe-to-fail." Safe-to-fail means designing a system so that if one part of the system fails, the results would not be catastrophic (Weeks, 2013). An example of such a design would be one in which if floodgates breaks, waters would overflow into uninhabited flood zones, possibly causing property damage but protecting human life (Weeks, 2013). Such designs could be less expensive but still preserve public safety.

No regrets options: No regrets options are adaptation strategies that would provide benefits even if climate change was not occurring. Such strategies, however, make even more sense to undertake given climate change (Luers and Moser 2006; UKCIP, 2007). An example of a no regret option is to decrease leakage for water infrastructure.

Low regret options: Low regret options are adaptation strategies that provide benefits that are primarily realized in a future with climate change but that incur low or modest costs and risk (CCS, 2011; UKCIP, 2007). Such options may include incremental adaptation measures (see flexibility description). Examples include: monitoring the effectiveness of adaptation measures so as to learn lessons, promoting the preservation of lands to conserve biodiversity, and incrementally introducing new agricultural crops that are more in line with projected climate changes (UKCIP, 2007).

Win-win options: Sometimes people discuss "win-win" options, which are also known as co-benefit strategies. These are strategies that provide adaptation benefits for multiple sectors or resources or provide adaptation benefits while addressing other social, economic, or environmental goals (Kinney, 2008; UKCIP, 2007). Options that reduce GHG emissions in addition to providing adaptation benefits are considered win-win options as well. We discuss co-benefits above in the *Benefits and potentially adverse impacts* section.

Community support: After gathering community input on adaptation priorities, it may be evident that certain strategies have widespread support. These strategies can be good strategies to start with, as approaches with community support are often more successful (CIER, 2006 e).

Diversity: Because of increasing uncertainty under climate change, consideration should be given to implementing a diverse array of adaptation options as opposed to focusing on a single solution (CCS, 2011; Millar, 2007; NRC, 2010). This is sometimes called a portfolio approach. Some strategies may work well under certain climate and social change scenarios, while others work better under different scenarios. Thus, it is more likely that a portfolio approach will be able to address the particular sets of conditions that may arise (CCS, 2011).

A diverse array of approaches would include both structural/technological and non-structural strategies such as those that involve education and increasing awareness, economic instruments, regulatory measures, and other social and behavioral approaches (NRC, 2010; UNECE, 2009). A mix of strategies will also include measures that address short-, medium-, and longer-term impacts as well as ones that can be accomplished more rapidly and ones that take more time. Strategies that address community visioning goals and development needs in addition to climate change would also be included (CIER, 2006 e).

Diversification itself can be an adaptation strategy. For example, diversifying water supply sources (e.g., surface water, groundwater, desalination, etc.) or diversifying crops planted so that they thrive under different climate regimes are both ways to spread risk and increase the likelihood that at least one water source or crop will do well under the conditions that arise (CCS, 2011).

We encourage you to add to or take away from the list as best fits your needs. Before we move on though, we show in Box 2.8 how some of the criteria noted above might relate to some of the adaptation strategies that we came up with for our Golden Eagle example. At the end of the option prioritization process, we will have a set of adaptation strategies we would like to implement.

Golden Eagle Box 2.8: Prioritizing Adaptation Options

Linking priority setting criteria to adaptation strategies

- Educate the public to reduce accidental fires started by humans.
    - No regrets
    - Low cost
    - Very feasible – not too many decision-making levels and low cost
    - Co-benefit – improved public safety
- Conduct assessments of fuel loads in shrublands to identify locations where catastrophic fires are more likely to occur.
    - Medium cost – might involve more personnel
    - Feasibility – do we have the trained personnel to conduct such assessments? If not, what resources do we have for training?
    - Vulnerable subpopulations – Golden Eagle populations hunting in habitats with high fuel loads may be more vulnerable to wildfire impacts.
- Fire is a natural feature of the landscape. One strategy could be to conduct strategic prescription burns to manage fuel loads.
    - Not flexible/reversible
    - Adverse impact – could worsen air quality while fires occur
    - Benefits – could help prevent large catastrophic fires and air quality might be worse during such fires as opposed to during prescribed burns.
    - Feasibility – do we have the trained personnel to conduct the burns? What is the process for getting approval to conduct such burns?
    - Medium/high cost – would likely involve more personnel. Would also need equipment to manage/contain fires.
- Do not build wind turbines
    - Community visioning – as part of community visioning we would like long-term sustainable jobs. Given that several Colorado Plateau states have renewable energy portfolio standards, wind could be a good option for meeting these. Seems likely that fuel economy will continue to switch more towards renewables in the future
    - Co-benefits – would reduce GHG emissions, could reduce air pollutant emissions and improve public health
    - Might focus on ways to minimize Golden Eagle deaths from wind turbines rather than eliminating wind turbines as option entirely

2.6 Phase 6: Pilot Projects and Implementation

Once strategies have been sorted through and prioritized, it is time for implementation. One thing to think about at this stage is whether to test the strategy out at a small-scale (i.e., through a pilot or demonstration project) or whether to implement it at a full-scale. As part of the implementation process, it can be helpful to develop a work plan. Such a plan can contain a variety of elements, including: milestones, roles and responsibilities, detailed timelines, budgets, and measures of success (CIER, 2006 e). These elements are described below.

Milestones: Each broad strategy or project can be divided into a series of key smaller steps or milestones. These steps will differ depending on the strategy, but should be able to be tracked and linked to a timeline (CIER, 2006 e). Steps that may comprise milestones include:

- Finding out if others on the Navajo Reservation are already working on some aspect of the strategy and should be involved in its implementation.
- Completing any approval processes necessary to start the project or including funds for the project in an organizational budget.
- Identifying and obtaining outside sources of funding.
- Conducting research on whether others have tried the strategy and on what has worked or not worked.
- Building capacity to complete the work either within the organization or hiring outside consultants.
- Designing the project – for example if the strategy is a regulation - forming language for the regulation; if the strategy is a structure - completing the structure design.
- Establishing measures of success so that the project can be monitored and evaluated.
- Establishing maintenance procedures for the project.
- Constructing the project/releasing the project.
- Maintaining the project.
- Sharing information about the project with the community.

Box 2.9 points out some potential milestones for an educational strategy to reduce human-caused wildfires.

Roles and responsibilities: Once milestones have been established, people need to be identified to complete each step. The tasks each person is expected to accomplish need to be clarified. If a task is shared between more than one person/group, it can be helpful to clarify who will be leading and keeping track of task completion (CIER, 2006 e). It can also be helpful to identify an individual who will keep track of progress being made on the strategy as a whole.

Detailed timelines: Timelines will be related to project milestones (CIER, 2006 e). Timelines will involve determining the number of hours each individual will contribute to project tasks, timeframes for regulatory and budgetary cycles, and proposal deadlines for outside funding. Appropriate times for project implementation also need to also be considered. For example, construction projects may not be able to take place during winter months. Planners should also think about whether a strategy as a whole needs to be implemented by a specific deadline (CIER, 2006 e).

Budgets: Budget considerations include: hourly wages; the purchase of new equipment or technology;

costs pertaining to the installation of infrastructure; costs for long-term maintenance of the project; costs for monitoring and evaluation of the project; and costs for communication (e.g., telephone, internet access, etc.) including those related sharing information about the project with the wider public.

Measures of success: Certain measures help us evaluate whether an adaptation strategy was effective or not. These are sometimes called measures of success. CIER points out in its Guidebook 6 that developing these measures is not always straightforward (CIER, 2006 f). If the strategy involves holding

Golden Eagle Box 2.9: Implementation

Examples of milestones for a strategy to educate the public to reduce accidental human-caused fires

- Approvals
    - Have project and budget approved by department director
    - See if some other departments can contribute funds
- Design the campaign
    - Complete background research
        - Research causes of human induced fires
        - Investigate whether any in-house organizations or agencies are already conducting such a campaign – e.g., Dept. of Forestry
        - Investigate whether such campaigns have been conducted by outside organizations and find out what worked or what did not work
    - Determine the scope of the educational campaign
        - Select the target audiences
        - Select the communication methods to be used (e.g., radio ad, fliers, website, attending social events)
        - How many years will campaign last? Will there be more activities during first year or two and then scaled back activities later?
        - When should the campaign be released?
    - Build capacity to complete the work
        - Have in house capacity to complete radio ad; hire graphic artist for flier and/or web designer
    - Plan out campaign
        - Radio
        - Flier
        - Website
        - Determine which social functions would like to attend over specified geographic area and contact organizers.
    - Establish measure(s) of success so know if project was effective
    - Establish campaign maintenance
        - Continue messaging for five years
        - Evaluate campaign using measure(s) of success and adjust campaign accordingly
    - Establish how will share info about campaign effectiveness with resource managers and general public
- Release and maintain educational campaign
    - Do so at start of fire season for each of five years and continue messages throughout fire season
- Share information about campaign effectiveness

a workshop, for instance, on improving community health, one possible measure to use is the number of people attending the workshop. While this is valuable information to record, it doesn't really indicate whether people started to make use of the information in their daily lives. A more effective measure of success might involve following up with participants a few months after the workshop and learning about the kinds of meals they are preparing and exercises that they are doing (CIER, 2006 f). Monitoring and measures of success are discussed in more detail in the section on Phase 7.

On-going community participation: As the project is being implemented, it is important to let people know what is going on, both what is working well and what is not. This is important from the point of view of being transparent about what is being done. In addition, engaging the community can be an opportunity to celebrate what has been achieved (CIER, 2006 e). Sharing information can be accomplished through a variety of means including participating in radio programs, distributing newsletters or household fliers, posting information on a website, by hosting meetings and open houses, or by attending social gatherings (CIER, 2006 e).

2.7 Phase 7: Monitoring and Evaluation

The final phase is monitoring and evaluation. This process is actually important throughout the entire adaptation process. Monitoring can involve measures from a variety of fields, including: climate, hydrology, soil sciences, biology, public health, economics, demographics and legal information.

Monitoring can also serve a wide variety of aims. For example, it can provide baseline data to help us understand how the climate and environment are changing, data on impacts, data for use as model inputs, and data to test models. In the context of adaptation planning, monitoring can supply information that can help us identify adaptation strategies and prioritize which strategies to implement (CCS, 2011). It can also help us assess the progress of strategy implementation and aid us in evaluating whether or not the implemented strategies are achieving the intended results, or flag any unintended consequences (CIER, 2006 f).

Unintended consequences may occur as a result of uncertainties associated with future climate changes/variability and uncertainties in how vulnerability and adaptive capacity factors may change. This latter type of monitoring may thus allow us to course correct and promote strategies that are providing effective adaptation while allowing us to minimize/avoid maladaptation. Here we focus on monitoring related to strategy implementation and effectiveness.

Measures of implementation progress

In terms of assessing implementation progress, measures can indicate whether milestones for the various strategies are being achieved on time, whether budgets are sufficient, and whether people have the capacity to complete the tasks that they were assigned (CIER, 2006 f). CIER recommends checking in and evaluating progress at least every six months. As noted in Phase 6 under roles and responsibilities, certain people on the implementation team can be designated to keep track of implementation progress (CIER, 2006 f). It can also be helpful if the project team writes down reflections on both challenges and successes in the implementation process to help improve implementation (CIER, 2006 f).

Evaluating strategy effectiveness

There are a variety of methods that can be used to evaluate strategy effectiveness. A basic level of evaluation may involve establishing measures of success. These can either be quantitative (i.e., numerical), qualitative (i.e., perceptions) or both. Once selected, these measures can be monitored and used to assess strategy/plan effectiveness (CIER, 2006 f).

Measures of adaptation effectiveness will vary depending on the strategy (CCS, 2011). CIER provides some criteria for selecting measures of success in its Guidebook 6 (CIER f, 2006).

These criteria include considering whether the measure is:

- "Valid (is it in fact measuring the result)"
- "Reliable (consistent over time)"
- "Sensitive (to changes so that it is connected to the results)"
- "Simple (easy to collect and analyze)"
- "Useful (will help us make decisions)"
- "Affordable (can the indicator be measured within the existing budget)"

Golden Eagle Box 2.10: Measure of Success

Example of a measure of success for a strategy to educate the public to reduce accidental human-caused fires

- Collect data on causes of wildfires and assess whether there is an overall decrease in the number of wildfires attributable to human causes.

As CIER points out, developing a measure that is valid is not always straightforward (CIER, 2006 f). The example CIER uses (and that we mentioned in Phase 6) considers a strategy that involves improving community health by holding workshops. One possible measure is the number of people attending the workshop. While this is valuable information to record, it doesn't really tell whether people started to make use of the information in their daily lives. A more effective measure might involve following up with participants a few months after the workshop about the kinds of meals they are preparing and exercises that they are doing (CIER, 2006 f).

In terms of the simplicity criterion, the selected measure should not take an inordinate amount of staff time to collect and analyze (CCS, 2011). In terms of usefulness, this could include providing information as to whether or not an adaptation strategy needs to be adjusted and possibly information as to how the strategy should be altered to improve it. Another criterion for effectiveness noted by CIER is whether the strategy is helping the community move towards its overall vision. We refer readers to CIER's Guidebook 6 (CIER, 2006 f) and to Chapter 4 of the Center for Climate Strategies' Adaptation Guidebook (CCS, 2011) for additional discussion on evaluation metrics.

In addition to a basic evaluation of adaptation strategies, somewhat more formal methods exist as well. One, the *Most Significant Change* method, is a participatory method in which stakeholders are interviewed and asked what they consider to be the most significant changes resulting from a particular strategy or from the plan as a whole (PROVIA, 2012). One benefit of this method is that it continues to engage stakeholders in the adaptation process. Another advantage is that it is one way for unanticipated changes to be revealed (PROVIA 2012). Another method, *Outcome Mapping*, is a method that takes into account that adaptation strategies occur in complex contexts and that simple cause and effect linkages may not be occurring (PROVIA, 2012). We refer readers to Chapter 3 of the United Nations' Programme of Research on Climate Change Vulnerability, Impacts, and Adaptation's (PROVIA) *draft Guidance on Assessing Vulnerability, Impacts, and Adaptation* for more in depth discussion and additional examples of evaluation methods (PROVIA, 2012). Additionally, there are toolkits and frameworks for developing evaluation processes. These include the United Kingdom Climate Impact Programme's AdaptME toolkit and the World Resources Institute's Making Adaptation Count framework. Again, we refer readers to PROVIA's draft guidance for more information and additional frameworks (PROVIA, 2012).

In terms of who does the monitoring and evaluation of project success, it can be helpful to get some input from outside the implementation team to help assess strategy effectiveness (CIER, 2006 f).

Adjusting the adaptation plan

Every year or two, the project team can meet to evaluate the adaptation plan and strategies to determine whether any adjustments should be made to make them more effective (CIER, 2006 f). As noted above, this type of course correction is an important component of managing under increasing uncertainty. In addition, every so often, it will be necessary to revisit the plan and go through a version of the planning cycle again.

Celebrating achievements

One final phase noted in the CIER guidebooks is remembering to celebrate achievements (CIER, 2006 e). It has probably taken you considerable time to read this chapter or even a part of it. If you have embarked on an adaptation planning process, you have probably contributed even more time and effort to climate change adaptation planning. Congratulations on the steps you have already taken; hopefully there are many more to come.

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Over Monument Valley, a region of the Colorado Plateau characterized by a cluster of vast and iconic sandstone buttes. Photo: Creative Commons, Pauk.

CHAPTER 3
CLIMATE, HYDROLOGIC, AND ECOSYSTEM CHANGES IN THE SOUTHWEST AND ON THE NAVAJO NATION

Key Points: Current SW Temperature

The 2001-10 decade as compared to 20th century averages:

- warmest decade
- greater temperature increases during spring and summer
- decreases in number of cold waves and increases in number of heat waves
- increases in growing season length

Climate variability and global warming are currently resulting in or are likely to result in changes to climate (e.g., temperature; precipitation timing, duration, intensity, and frequency), to hydrology (e.g., snowmelt timing; streamflow), and to ecosystems (e.g., species geographic distributions and population sizes). This chapter summarizes climatic and hydrologic changes currently being observed in the Southwest (SW) and on the Navajo Nation (NN), paleoclimatic information, and projected future climatic and hydrologic changes for the SW region. It also provides examples of ecosystem changes currently being observed and anticipated to occur as global warming continues.

We rely heavily on the *Assessment of Climate Change in the Southwestern United States* (Garfin et al. 2013), which we refer to below as the SWCA. The SWCA is a review by experts in the region of the current state of climate change science and impacts and was prepared as part of the National Climate Assessment (NCA) process. We also make use of other reports and scientific papers and present NN-specific information whenever possible. For additional references and discussion of climate changes in the region, we refer readers to the SWCA.

3.1 Current Climate and Hydrologic Changes

Changes in climate are already being observed in the SW and on the NN.

Chapter citation: Cozzetto, K., Nania, J. (2014). Chapter 3 – Climate, Hydrologic, and Ecosystem Changes in the Southwest and on the Navajo Nation. In *Considerations for Climate Change and Variability Adaptation on the Navajo Nation*, edited by J. Nania and K. Cozzetto. University of Colorado, Boulder, CO.

Temperature averages and extremes

In the SW region

According to the SWCA, temperatures in the SW are warming. As noted in Chapter 1, between 1901 and 2010, annual average temperatures in the region increased by 1.6 °F (+/- 0.5 °F) (Hoerling et al. 2013). Of the eleven decades from 1901-2010, the 2001-2010 decade was the warmest, both for the region as a whole, and for the states of Arizona, New Mexico, and Utah individually (Hoerling et al. 2013). During the same 2001-2010 decade, temperature increases in the SW region have been greater during the spring and summer as compared to winter and fall, fewer cold waves and more heat waves have occurred, and the length of the average annual freeze-free growing season was seventeen days longer (all as compared to 20th century averages) (Hoerling et al. 2013). All paleotemperature records for the SW region indicate that the modern time period from the 1950s onward has been the warmest of any comparable time period in the last 600 years. Most but not all records indicate that the modern period has also been the warmest in the past 2,000 years (Hoerling et al. 2013).

On the Navajo Reservation

For the NN, analyses of University of Oregon PRISM[1] temperature data as part of a Navajo Nation Drought Contingency Plan (DCP) technical review indicate that since approximately 1995 the Nation has consistently experienced annual average temperatures warmer than the 1905-2011 long-term average (Crimmins et al. 2013).

Key Point: Current NN Temperature

- Warmer annual average temperatures since 1995 as compared to 1905-2011 average

Precipitation averages and extremes

In the SW region

For the SW region as a whole, between 1901 and 2010 there is not evidence for significant trends in total annual precipitation or in precipitation extremes (Hoerling et al. 2013). Of the eleven decades from 1901-2010, the 2001-2010 decade was Arizona's driest decade on record (Hoerling et al. 2013). In contrast, for Utah, 2001-2010 was one of the wetter decades. For New Mexico, 2001-2010 was fairly average in terms of total annual precipitation (Hoerling et al. 2013).

Key Point: Current SW Precipitation

- No significant trends between 1901 and 2010

On the Navajo Reservation

For the NN, analyses of University of Oregon PRISM precipitation data by Crimmins et al. (2013) indicate that from 1905 to 2011, the Nation experienced two distinct wet periods, one in the early 1900s and the other in the 1980s. It also experienced a pronounced dry period in the 1950s. Tree-ring precipitation reconstructions by Faulstich et al. (2013) which focus on Navajo and Hopi lands also show that the 1905-23 and 1978-93 periods were wet, while the 1950s were marked by a cool-season (October through April) precipitation deficit. Analyses of precipitation data by Redsteer et al. (2011) from seven meteorological stations[2] on or near the NN for approximately the 1905-2010 time period also show above normal precipitation during the early 1900s

Key Points: Current NN Precipitation

- Wet periods during the early 1900s and 1980s, with extremely wet individual years only before 1950
- Dry period during the 1950s

1 PRISM is the Parameter-elevation Regressions on Independent Slopes Model climate mapping system run by a group at Oregon State University. PRISM combines observational data with modeling to produce continuous, gridded estimates of temperature and precipitation, at a 4 km scale.

2 Meteorological stations were located at Betatakin, Canyon de Chelly, Ganado, Leupp and Moenkopi Plateau, Shiprock, Tuba City, and Winslow (Redsteer et al. 2011).

and 1980s and below normal precipitation in the 1950s. However, the authors also note a trend in which all extremely wet years (i.e., years with more than 1.5 times the average precipitation) occurred before 1950.

Drought

Droughts are caused by precipitation deficits and can last from weeks to years or even decades. As they persist, they can result in decreases in streamflow, deficits in soil moisture, and lowering of groundwater tables. Warmer-than-average air temperatures can exacerbate drought severity. Other factors such as wind and humidity can also influence drought conditions.

In the SW region

Key Point:
Current SW Drought

- During the past 2,000 years, there have been droughts more severe and longer than droughts in modern times

For the SW, analyses of summertime (June-August) drought from 1901-2010 using the Palmer Drought Severity Index (PDSI)[3] indicate that the 2001-2010 decade had the second largest area affected by drought after the 1951-60 decade. The analyses also show that 2001-2010 had the most severe average PDSI (Hoerling et al. 2013). The paleodrought record for the SW indicates that, in the past 2,000 years, multiple droughts have occurred that are more severe and longer-lasting than droughts observed since 1901 (e.g., the 1950s, 2000s droughts) (Hoerling et al. 2013). A distinction of the recent (2000s) droughts is that temperatures have been significantly warmer than during other droughts in the 20th century, contributing to the observed drought severity expressed in the PDSI.

On the Navajo Reservation

Key Points:
Current NN Drought

- Between 1905-2011, the NN experienced severe drought during the 1950s and other periods
- Since 1994 until the present time, there has been an overall long-term drought coupled with brief periods of shorter-term wetness
- The current drought/wet fluctuations are associated with higher than average temperatures
- Although the Navajo reservation has experienced severe droughts during the 20th and 21st centuries, during the preceding three centuries, droughts have been more severe and longer lasting

Crimmins et al. (2013) analyzed drought for the NN using a 24-month Standardized Precipitation Index (SPI)[4] based on PRISM precipitation data from 1905-2011. They found evidence of severe drought in the 1950s. They also found that since 1990, the Nation has experienced rapid swings between periods of intense drought and periods of unusual wetness. This rapid switching between dry and wet conditions contrasts with patterns in precipitation variability in the early to mid-20th century when more years had precipitation conditions that were closer to average. While relatively short-term periods of wetness may help improve short-term drought conditions, at least temporarily, they do not necessarily help alleviate the impacts associated with long-term drought (Crimmins et al. 2013).

The Redsteer et al. (2011) study assessing recent drought on the NN through 2010, suggests that the Nation was in a drought from 1994 to 2009 with brief respites in 2004-5 and 2010, making the 1994-2009 drought longer than any other NN drought of the 20th century. The study found that the drought may have originated in the drier western lowlands of the Reservation and then spread. The authors note that the warmer temperatures may have exacerbated drought impacts. Since the Redsteer et al. (2011) study was published, the NN has reaffirmed its drought state of emergency in 2011, 2012, and most recently in July of 2013, indicating that the drought continues.

3 PDSI is an index that takes into account the effects of both precipitation deficits and temperature on soil moisture.

4 The SPI is a drought index based solely on precipitation.

A study by Faulstich et al. (2013) used tree ring data to reconstruct cool season (October-April) and warm season (July-August) precipitation over Navajo and Hopi lands for a 412-year period from 1597-2008 and to examine multiyear drought characteristics.[5] For the modern period from 1900-2008, Navajo and Hopi lands experienced nine cool season, multiyear droughts and 12 warm season, multiyear droughts.[6] The 1900-2008 period contained the fewest seasonal, multiyear drought events of any of the centuries. In addition, the authors examined dual season multiyear droughts during which precipitation during both the cool and warm seasons of the same year were below the long-term average. They found that sustained, 3-4 consecutive year dual season droughts are absent from the modern period. Yet such sustained droughts occurred six times during the pre-modern centuries and included a cluster of three dual season droughts taking place during the first half of the 18th century. Thus, although severe droughts occurred between 1900 and 2008, in the past, due to natural climate variability, more severe and longer drought events have taken place.

Hydrologic changes

In the SW region

According to the SWCA, hydrologic changes being observed across the West include: declines in mountain snowpack, more winter precipitation falling as rain rather than snow, and trends towards earlier snowmelt. The assessment also reviewed studies of near-natural or naturalized streamflows for four hydrologic basins in the SW, including the Upper Colorado River and the Rio Grande (Hoerling et al. 2013).

Naturalized streamflows are best estimates of what river discharges would have been without human influences such as diversions. Observed streamflow changes are thus more likely to be attributable to climate change. During the 2001-10 decade, below normal streamflows were observed in the Upper Colorado River and the Rio Grande. For the Colorado River at Lee's Ferry, 2001-2010 river flows were 16% lower than the 1901-2000 average and were the second lowest out of the eleven decades from 1901-2000. For the Rio Grande at El Paso, 2001-2010 river flows were 23% lower than the 1941-2000 average even though precipitation in the basin was 3% above normal. As noted above, 2001-10 was an unusually warm decade and this may have contributed to the decreased discharges.

Key Points: Current SW Hydrology

- Declines in mountain snow pack
- More winter precipitation falling as rain rather than snow
- Earlier snowmelt
- Both the Upper Colorado River and the Rio Grande experienced below normal streamflows between 2001-2010

On the Navajo Reservation

To learn about long-term environmental changes taking place on the Reservation, Redsteer et al. (2011) interviewed 50 Navajo elders. Significant changes noted include: declines in amounts of snowpack over the past century (100% of interviews) and decreases in surface water features and water availability (85% of interviews). Many elders had also observed the disappearance of springs.

Key Points: Current NN Hydrology

- Declines in snowpack
- Declines in more than 30 surface water features
- Worsening water quality in some locations

5 For the study, cool season, multiyear droughts were defined as any period during which the precipitation for two or more consecutive cool seasons was below the associated long-term (1597-2008) mean. Warm season, multiyear droughts were similarly defined. Seasonal, multiyear droughts were ranked according to a combination of magnitude (cumulative precipitation deficit over a given time period), duration (number of consecutive years the drought lasted), and intensity (magnitude divided by duration i.e., average magnitude) (Faulstich et al. 2013).

6 Three cool season, mulityear droughts for the modern period - 1950-1951, 1953-1957, and 1976-77 - were ranked 5th, 9th, and 6th, respectively in terms of all cool season, multiyear droughts over the 1597-2008 time period. One of the warm season, multiyear modern droughts - 2002-2006 - was ranked 8th among all (1597-2008) warm season, multiyear droughts.

In addition to interviewing Navajo elders, Redsteer et al. (2011) examined historic reports with observations on reservation surface water features such as streams, lakes, and springs. The authors also analyzed USGS stream gauge data for the Reservation. They found significant declines in more than 30 major surface water features, supporting the observations of Navajo elders discussed above. For example, many stream reaches observed to be perennial (i.e., flowing all year) in the early 1900s have since become intermittent (i.e., flowing for only part of the year) and many stream reaches observed to be intermittent in the mid-1900s have since disappeared entirely (Redsteer et al. 2011, 2013). Moenkopi Wash and the lower reaches of Chinle Wash, for instance, became intermittent after 1960, and the Little Colorado River on the southern border of the Reservation became intermittent at Holbrook in 2007 (Redsteer et al. 2011). Declining snowpack and earlier snowmelt due to warmer temperatures may be contributing to these declines in perennial flow (Redsteer et al. 2011). Changes in surface water features do not seem to correspond to water development in the region (Redsteer et al. 2013).

Changes in water quality are also being observed. For example, the water in some of the wells in the Greasewood Springs area of the southwestern NN have become so saline that the water is unusable for livestock and has corroded the piping and equipment used for bringing the water to the surface (Redsteer et al. 2011). Declining recharge and overutilization seem to be contributing factors to water quality decline (Redsteer et al. 2011).

3.2 Future Climate and Hydrologic Changes

In the future, many of the trends currently being observed are expected to continue and, in some cases, be exacerbated.

Key Points: Future SW Temperature

- Warmer annual average temperatures
- Early 21st century warming of +1-4 °F
- Late 21st century warming varies with emissions scenario: 2-6°F and 5-9°F
- Greater temperature increases in summer
- Increases in the length of the annual freeze-free growing season
- Increases in heat wave frequency, severity, and duration
- Decreases in cold wave frequency but not necessarily severity

Brief background on climate projections

Here we discuss some of the model projection results for the SW reported in the SWCA (Cayan et al. 2013).[7] Two greenhouse gas (GHG) emissions scenarios were considered – B1 (low emissions) and A2 (high emissions) (IPCC, 2007). These scenarios were established by the Intergovernmental Panel on Climate Change (IPCC) in their 2000 *Special Report on Emissions Scenarios* in preparation for the Fourth IPCC Assessment Report, published in 2007. Models were run for both a historical or reference time period (e.g.,1971-2000) and for various future time periods (e.g., 2021-50). Differences in a particular climate variable (e.g., annual average temperature) between simulated future and historical time periods constitute the projected changes. For more details on the models and analytical methods used, we refer readers to Chapters 6 and 7 of the SWCA.

Temperature averages and extremes

All model simulations presented in the SWCA showed temperatures in the SW progressively warming throughout the 21st century. Projected increases in annual average temperatures range from 1-3 °F for 2021-50 for the low emissions scenario to 5-9 °F for 2070-99 for the high emissions scenario (Table 3.1). In the

7 Projections of future climate conditions are obtained through the use of Global Circulation Models (GCMs). These models produce climate output at large spatial scales (e.g., 90 to 400 miles/ 150-600 km). GCM output is thus often downscaled to smaller spatial scales (e.g., 15-30 miles/ 25-50 km). This is typically accomplished through the use of statistical or dynamical downscaling methods or some combination of both. In statistical downscaling, statistical relationships are established between GCM climate output and local historical observational data. In dynamical downscaling, GCM output is run through a regional climate model. The downscaling methods each have their advantages and disadvantages, and we refer readers to Chapter 6 of the SWCA for additional discussion (Cayan et al. 2013).

early 21st century, differences in warming between the low and high emissions scenarios are not great. However, by the late 21st century significant differences between the two scenarios are evident.

Simulations under an A2 (high emissions) scenario were also done to evaluate seasonal temperatures, growing season length, and heat and cold waves in the future (Cayan et al. 2013; Gershunov et al. 2013). Model projections show that temperature increases are anticipated to be greater in summer and least in winter, with model mean summer increases of 3.5, 5.5, and 9 °F and model mean winter increases of 2.5, 4, and 7 °F for the early-, mid-, and late-21st century, respectively (Cayan et al. 2013). Simulations also show increases of at least seventeen days in the length of the annual freeze-free growing season by the mid-21st century for the SW as a whole (Cayan et al. 2013).

	Low Emissions Scenario	High Emissions Scenario
2021-50	**+1-3 °F**	**+2-4 °F**
2041-70	**+1-4 °F**	**+2-6 °F**
2070-99	**+2-6 °F**	**+5-9 °F**

Table 3.1. Ranges of temperature increases across the SW from sixteen statistically downscaled Coupled Model Intercomparison Project (CMIP3) models (Cayan et al. 2013; SWCA, 2013).

Heat waves, as defined according to current climate, are expected to increase in frequency, severity, and duration during the 21st century with nighttime heat waves increasing at a faster rate than daytime heat waves (Gershunov et al. 2013). Cold waves, as defined according to current climate, are expected to decrease in frequency, but not necessarily in severity (Gershunov et al. 2013).

Precipitation averages and extremes

For the SW region as a whole and for the Colorado River basin in particular, the projections reported in the SWCA showed little change in total annual precipitation over the 21st century under either the B1 or the A2 emissions scenarios (Cayan et al. 2013). However, precipitation in the SW is more difficult to model than temperature. The North American Monsoon (NAM), which provides approximately 45% of total annual precipitation on the NN between July and September (Redsteer et al. 2010) is particularly challenging to simulate (Cayan et al. 2013). Precipitation projections for the region are thus less certain and, in the SWCA, are categorized as having medium-low confidence (Cayan et al. 2013). For example, in simulations for the SW region as a whole there was considerable variability among the simulations for a given emissions scenario/future time period, with some models showing decreasing precipitation, while others showed precipitation increases. The median value for the various simulations showed little change for the Colorado River basin.

Key Points:
Future SW Precipitation

- Little change in total annual precipitation in the Colorado River basin (medium-low confidence)
- More extreme precipitation events and storms (medium-low confidence)

Given the ability of air to hold more moisture under warmer temperatures, models project increases in extreme precipitation events even in areas where decreases in mean precipitation are anticipated (Gershunov et al. 2013). However, the effects of climate change on the NAM are not yet clear; thus, associated effects on NAM-related precipitation extremes are also uncertain (Gershunov et al. 2013). Again, the SWCA categorizes projections in precipitation extremes as having medium-low confidence (Gershunov et al. 2013).

Drought

According to the SWCA, "climate change is slowly tipping the balance in favor of more frequent, longer lasting, and more intense droughts." (Gershunov et al. 2013) One study, based on the high

Key Point:
Future SW Drought

- Increases in drought frequency, severity, and duration in the Colorado River basin emissions scenario, suggests that the current SW drought (which is roughly a once per century or 100-year drought) will become commonplace during the second half of the 21st century and that future droughts will be much more severe (Cayan et al. 2010, Gershunov et al. 2013). Projected Colorado River streamflows that were used as a proxy for assessing drought, also under the A2 high emissions scenario, show a similar pattern reflecting more intense, more frequent and longer-lasting droughts than have been observed in the modern instrumental time period. Colorado River drought conditions were not necessarily attributed to precipitation deficits; rather, drought conditions were associated with warmer temperatures and other factors such as the effects of decreased snowpack and increased evapotranspiration on reducing soil moisture (Gershunov et al. 2013).

Key Points:
Future SW Hydrology

- More winter precipitation as rain, not snow
- Lower spring snowpack
- Earlier snowmelt
- Snowpack increasingly confined to smaller, higher elevation areas
- Decreases in the frequency and intensity of spring/early summer snowmelt-driven floods
- Decreases in late spring through late summer runoff
- Lower soil moisture by early summer
- Possible decreases in Colorado River flows

Hydrologic changes

Current hydrologic changes that are projected to continue into the 21st century due to warmer temperatures include: more winter precipitation falling as rain rather than snow, lower spring snowpack, earlier snowmelt, and snowpack being increasingly confined to smaller, higher elevation areas, (Cayan et al. 2013). More winter precipitation falling as rain rather than snow will likely lead to decreases in the frequency and intensity of spring and early-summer snowmelt driven floods (Gershunov et al. 2013). More winter rain than snow, earlier snowmelt, as well as lower precipitation in some areas, are expected to contribute to less runoff in the late spring through late summer (Cayan et al. 2013; Udall et al. 2013). Lower soil moisture by early summer is expected to result from a combination of decreased runoff and increased evapotranspiration due to warmer temperatures and a reduced period of snow cover leading to a longer period of exposed vegetation and ground (Cayan et al. 2010; Painter et al. 2010). In addition, by the mid-21st century, changes in temperature and precipitation are projected to possibly decrease Colorado River flows by between 5% and 20% with possible reductions of roughly 3-16% per 1 °F warming and 1-2% per 1% reduction in precipitation (Cayan et al. 2010).

3.3 Current and Future Ecosystem Changes

Changes in climatic and hydrologic conditions can, in turn, lead to ecosystem changes that will interact with one another.

Key Point:
Future NN Sand Dunes

- Increases in sand dune destabilization and movement

Sand dunes and dust storms

Sand dunes extend over approximately one-third of the Reservation (Redsteer et al. 2013). Droughts in the 20th century have caused significant changes in sand dune mobility and areal coverage. During the 1950s drought, sand dunes began to occur downwind of dry rivers and washes, which supplied fine-grained materials for sand dune formation. During the drought period between 1996 and 2009, the areal extent of dunes in one monitored site increased by about 70% (Redsteer et al. 2010). These dunes are moving at rates of approximately thirty-five meters per year (Redsteer et al. 2010). Dunes are covering housing, causing transportation problems, contributing to the degradation of grazing and agricultural lands, contributing to the loss of rare and endangered native plants, and contributing to poor air quality when dust storms occur (Redsteer et al. 2010; 2011; 2013). Under conditions during which temperatures warm and droughts increase in frequency, severity, and duration, dunes currently stabilized by vegetation may become mobile as they no longer have enough moisture to support plant life. Once mobile, it is difficult for dunes to restabilize because plants have difficulty establishing themselves in moving soils (Redsteer et al. 2013; Yizhaq et al. 2009). In addition, flood events may transport new fine-grained sediments to ephemeral streams and washes, providing more materials for sand dune formation (Redsteer et al. 2011; 2013).

Moving dust may potentially land on snowpack. This decreases the snow's albedo (reflectiveness) and increases the absorption of solar radiation, which can contribute to earlier snowmelt and exacerbate any impacts from warming temperatures (Painter et al. 2010). Furthermore, early snowmelt leads to earlier exposure of vegetation and soils, which can increase evapotranspiration losses as compared to snow-covered conditions. One study modeling the effects of dust on snow for the Colorado River has shown that a longer snow-free season decreases annual runoff totals (Painter et al. 2010).

Wildfires

Between the 1970s and 2005, wildfires in the western US as a whole increased by more than 300% (Wilder et al. 2013). Reduced precipitation, along with land management practices and past practices of wildfire suppression, has contributed to fires of unprecedented size throughout the SW during the past decade (Steenburgh et al. 2013). In particular, Arizona experienced record-setting fires in 2002 and 2011, and New Mexico experienced record setting fires in 2011 and 2012 (Steenburgh et al. 2013).

Key Points: Future SW Wildfires

- Longer fire seasons
- Increases in wildfire frequency and areal extent

Higher temperatures, increased drought, and longer fire seasons associated with earlier snowmelt are expected to increase wildfire frequency and size (Brown et al. 2013). According to one study, a 1.8 °F increase in temperature would be expected to result in a 380% increase in area burned in the mountains of Arizona and New Mexico and a 470% increase in area burned on the Colorado Plateau (NRC, 2011; Fleishman et al. 2013).

Water quality changes

Recent studies have examined potential climate change impacts on water quality. Rising air temperatures, decreased runoff, lower flows from drought, and potentially increasing reservoir evaporation can contribute to rising stream and lake temperatures (Delpla et al. 2009; Kaushal et al. 2010; Murdoch et al. 2000; Udall, 2013). Warmer water, in turn, holds less oxygen and could thus lead to decreases in dissolved oxygen concentrations in aquatic ecosystems (Murdoch et al. 2000). Climate changes will also likely result in altered stratification and eutrophication, with specific changes depending on the particular characteristics of the aquatic ecosystem (Murdoch et al. 2000; Tillman and Siemann 2010). Rising temperatures and CO_2 levels, for example, could cause accelerated eutrophication and excess algal growth in lakes with adequate nutrient and oxygen supplies (Murdoch et al. 2000).

Greater turbidity and sedimentation may result from increasing precipitation intensities and greater wildfire frequency and areal extent (Cromwell et al. 2007). More intense storms and flooding could also contribute to higher pollutant loadings as heavy rains wash nutrients, contaminants, waste and sediments into surface waters and if flooding overwhelms wastewater treatment plants (USEPA, 2014).

Storms that follow long dry periods could potentially cause high

Key Points: Potential Water Quality Changes

- Warmer water temperatures
- Lower dissolved oxygen concentrations
- Altered stratification and eutrophication
- Increased turbidity and sedimentation associated with more intense rainfall and greater wildfire frequency and areal extent
- Higher pollutant loadings associated with more intense rainfall
- Higher occurrences of waterborne diseases associated with more intense rainfall
- Alterations in organic carbon characteristics of waters due to vegetation changes
- Potential groundwater salinization

sediment loadings. Heavier precipitation events could also lead to more occurrences of waterborne diseases due to pathogens such as *Cryptosporidium* and *Giardia* transmitted through drinking water or recreational use (Karl et al. 2009). Potential alterations in organic carbon characteristics of waters could occur as a result of changes in vegetation (Cromwell et al. 2008). Temperature and chemical composition of aquifer waters can also be impacted by climate change (van Vliet, 2007). Shallow aquifers may experience increases in temperature as a result of increasing air temperatures. In arid areas such as the NN, rising temperatures may cause increased evapotranspiration, which could lead to groundwater salinization (van Vliet, 2007).

Other ecosystem changes

Changing climatic and hydrologic conditions are leading to and have the potential to lead to ecosystem changes in addition to those related to sand dune mobility and wildfires. Some of these changes are listed in table 3.2 below. Examples are provided in subsequent chapters on individual resources, particularly in Chapter 9 on Biodiversity.

Potential Ecosystem Changes
• Changes in nutrient cycling and productivity [1]
• Changes in community composition, competition, and survival [a, 1]
• Habitat loss and conversion [1, 2, 3]
• Increased spread of invasive or non-native species [1, 2, 3]
• Shifts in species geographic ranges (often polewards or along elevation gradients) [1, 2, 3]
• Changes in phenology (timing of life history events) and development [1, 2, 3]
• Changes in population sizes [a, 2, 3, 4]
• De-coupling of ecological relationships (e.g., plant-pollinator) [2, 3]
• Increased spread of parasites, wildlife diseases, and zoonoses [3]

a – Population refers to a group of individuals from one species living in a particular area and community refers to all the organisms interacting and living in a specific area (Molles Jr. 2008)

b – Zoonoses refer to diseases that can be transmitted from animals to humans

1 – Tillman and Siemann 2010; 2 – NFWPCAP, 2012; 3 – Mawdsley et al. 2009; 4 – NPS and CAW 2007

Table 3.2. Potential ecosystem changes.

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San Juan River. Photo: Wikimedia Commons, Finetooth.

CHAPTER 4
WATER RESOURCES

Water is perhaps the most important resource for the Navajo Nation (NN) because access to water has implications for all other sectors on the Reservation. The San Juan River, one of the largest tributaries of the Colorado River, bisects the Reservation. Nonetheless, over 70,000 Navajo, roughly one-third of the Reservation population, do not have access to running water. Without running water, families must haul water to meet their domestic and livestock needs (KNME Productions). Despite substantial domestic supply issues, the NN has significant settled and unsettled senior water rights in the Colorado River basin. Securing domestic access to clean water through recognition and development of these rights is therefore a national priority.

4.1 Background Information on Navajo Water Resources

Water is generally scarce on the NN where lands range from arid to semi-arid. The wetter areas of the Reservation include the higher elevation regions of the Lukachukai and Chuska Mountains (both approaching 10,000 ft at crest) and Black Mesa (6,500-7,200 ft). Average total annual precipitation in these regions ranges from ten inches to greater than sixteen inches in the Chuska Mountains. The driest locations on the Reservation include the lowlands (3,900-4,900 ft) west of the Lukachukai Mountains and the areas east of the Lukachukai Mountains in New Mexico (Redsteer et al. 2010). For instance, total annual precipitation in Tuba City, west of the Lukachukai Mountains, averages about seven inches (NDWR, 2003).

Water sources and usage

Surface water and groundwater are integral to domestic, agricultural and industrial activities on the Reservation. The Nation has rights to the San Juan River, the Colorado River, and the Little Colorado River, as well as to ephemeral washes within Reservation boundaries (NDWR, 2011). For municipal public water systems, Navajo residents and businesses rely heavily on groundwater underlying the Nation, including the Coconino, Dakota, Navajo, Mesa Verde, and Morrison aquifers, as well as numerous alluvial aquifers (NDWR, 2011).

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An estimated 25-40% of Navajo households cannot access public water systems and thus must haul water (NDWR, 2003; NDWR, 2011). The distances to access water resources and the fuel and water costs associated with water hauling efforts are substantial. According to one study, the average household's one-way trip was fourteen miles (ITFAS, 2008) and longer trips were up to forty miles (NDWR, 2003). Hauled water may cost twenty times more than water for non-water haulers in neighboring communities (NDWR, 2003). In addition, some households may also haul water from non-potable sources, including private wells, livestock wells, and spring sources. The potential implications of relying on non-potable water sources are discussed further in Chapter 7.

Individual water use on the Reservation is substantially less than surrounding areas, due largely to the lack of water infrastructure development. According to the Navajo Drought Contingency Plan (DCP) (NDWR, 2003), in 2003 per capita water use for residents on Navajo Tribal Utility Authority (NTUA) public water systems was approximately 100 gallons per day. For residents on non-NTUA systems, per capita use ranged from 20-100 gallons per day. Water haulers use substantially less water; according to one 1981 study, per capita water use by residents hauling water was estimated at ten gallons per day. In comparison, the average urban resident in Phoenix uses approximately 183 gallons of water per day (Western Resource Advocates, 2010). Water haulers are likely to be highly dependent on groundwater because their hauling points tend to be wells (NDWR, 2011).[1] Although water use on the NN will undoubtedly increase with the development of domestic water resources infrastructure, the baseline water use of NN residents is far below other SW communities.

In addition to domestic uses, agriculture activities, particularly ranching and farming, require a substantial amount of water. On the Reservation, water for livestock comes from approximately 1,200 livestock wells that tap shallow alluvial aquifers and an estimated 7,500 stock ponds supplied by surface water runoff (NDWR, 2011). The Navajo Department of Water Resources (NDWR) Technical Construction and Operations Branch is responsible for maintaining many of the windmills associated with the livestock wells.

The Navajo Agricultural Products Industry (NAPI) is the largest Navajo farming operation. NAPI is supplied by the Navajo Indian Irrigation Project (NIIP), which has rights to over 500,000 acre-feet (af) of San Juan River water stored in the Navajo Reservoir (Robertson, 2006)[2] (see Chapter 5). The Nation also has almost 90 smaller irrigation projects. These projects receive water from the San Juan River, alluvial wells and springs, surface water stored in reservoirs, and smaller rivers with no reservoir storage. Due to a lack of management capacity and inadequate funding for operation and maintenance, some of these systems have deteriorated and are not currently in use (NDWR, 2003) (for more details see Chapter 11).

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1 According to the draft Water Resource Development Strategy for the NN (NDWR 2011), the "C-Aquifer underlies most of the reservation in the Little Colorado River Basin. It is recharged from outcrops on the Defiance Plateau, the Mogollon Rim, and the San Francisco Mountains. The communities of Cameron, Leupp, Ganado and Chinle, among others, depend on the C-Aquifer for much of their municipal water supply... The N-Aquifer has less storage than the C-Aquifer, but overall it has better water quality. The communities of Kaibeto, Kayenta, Pinon, Tuba City, and the Peabody Coal Mine, among others, depend on the N-Aquifer. The D-aquifer is on the eastern portion of the reservation. Although the aquifer is considered to have poor water quality, the communities of Tsayatoh, Sanostee, Smith Lake, and Casamera Lake, among others, rely on it as their primary source of water." The Morrison Aquifer provides water for the communities of Crownpoint, Tohatchi, and Sanostee, and the Mesa Verde Aquifer provides water for several communities in the Eastern Agency including Coyote Canyon and Two Grey Hills. In addition, "the communities of Fort Defiance and St. Michaels receive 70% of their water supply from the Black Creek alluvial aquifer, which recharges rapidly. Dilkon, Cameron, and Lower Greasewood also rely on alluvial systems. Typically, these aquifers have very limited storage capacity and development potential, and are more prone to droughts. Furthermore, water quality problems such as high dissolved solids limit use."

2 The NIIP is one of the largest water development projects on the Navajo Reservation. NIIP and the San Juan Diversion were jointly authorized in 1962 through Public Law 87-483. The public law authorized the Secretary of Interior to construct, operate, and maintain NIIP primarily to provide irrigation water to approximately 10,630 acres of land. NIIP was allotted 640,000 af in a 1956 State Water Use Permit and received approval to divert up to 508,000 af of water in a 1974 contract with the Secretary of Interior.

Case Study: Energy Justice, the Energy-Water Nexus, and the Black Mesa Dispute

The adaptive capacity of communities is often impacted by the historical development of those communities. Water management decisions on the Black Mesa have had direct implications for the local community. Beginning in 1882, the federal government redistricted the Navajo and Hopi reservations on the Black Mesa, creating conflict between the two nations (for more discussion, please see Chapter 11). In the midst of this dispute, Peabody Coal Company began extensive surface mining operation to access rich coal deposits buried below Black Mesa.

Peabody's operations have extracted billions of gallons of ground water from the N-Aquifer. Although the NN historically received royalties for both the coal and water extracted by these operations, the royalties received were often far below the market value of leased resources. Peabody's coal slurry operation supplying the Mohave Generating Station, consumed 44 billion gallons of groundwater from the N-Aquifer, at a rate of 3.8 million gallons per day until the closure of the plant in 2006. Although groundwater withdrawals decreased by 70% when the coal slurry operation ceased, the Kayenta Mine, which supplies coal to power the Navajo Generating Station continues to use ground water at an average rate of 1.1 million gallons per day.

The implications of pumping N-Aquifer water for coal extraction have been hotly debated. Several studies have indicated that the operation of the coal slurry pipeline has damaged the pressure head and the quality of the N-Aquifer and contributed to the drying up of traditional springs. The DOI's Office of Surface Mining and Peabody have countered with their own studies that the N-Aquifer will eventually recover from the continued operation of the Kayenta Mine and any drawdown caused by the coal slurry operations. An independent study by Dr. Daniel B. Higgins, who holds a Ph.D. in Arid Lands Resource Science, found that water levels at several surveyed locations have not recovered, but have instead continued to decline following the cessation of the coal slurry operation. Dr. Higgins noted that it is entirely possible that the impacts of Peabody's operations are "time lagged," meaning that the N-Aquifer may not have yet display the full extent of impacts from these operations.

The quality and availability of N-Aquifer water is essential to the health of Black Mesa residents who rely on the N-Aquifer for water. A lack of infrastructure, coupled with the drying of traditional water sources, has forced Black Mesa residents to haul water from distant sources to their homes. Certain springs of Black Mesa are sacred, and groundwater holds a sacred place in Navajo tradition and culture. Groundwater drawdown has harmed the spiritual and traditional practices of many Black Mesa residents

Coal mining operations on the Reservation have pros and cons and supporters and opponents. Coal mining is a major revenue source for the NN; Peabody pays over $37.2 million each year in royalties and fees for coal mined from Black Mesa. The benefits of Peabody's operations to the NN extend beyond its royalty payments: for example, Peabody pays the NTUA approximately $9.9 million in electrical fees, and the Kayenta Mine and NGS provide over 800 jobs for Navajo tribal members. Nonetheless, one of the objections of Navajo members to formerly proposed LCR Settlement agreements was the extension of Peabody's operations on Black Mesa, potentially enabling the continued drawdown and contamination of the N-Aquifer.

In total, the NN has over twenty reservoirs (NDWR, 2011). Many of these provide water for agricultural irrigation, and some recharge alluvial aquifers and provide wildlife habitat and recreational opportunities for fishing, hunting, and boating for Navajo residents and tourists alike (NDWR, 2011).

Industrial water use activities on the Reservation include coal mining, oil recovery, and power generation. The Peabody Kayenta Coal Mine uses water from the Navajo Aquifer, and the Navajo Coal Mine uses water from the San Juan River. Five oil companies on the Reservation use mainly non-potable groundwater for secondary or tertiary petroleum recovery. The Four Corners Generating Station uses water from the San

Juan River, and the Navajo Generating Station (NGS) draws water from Lake Powell. Two additional power plants, located near but not on the Reservation (Cholla and Escalante), rely on groundwater (NDWR, 2011).

In order to satisfy the Nation's growing water requirements for domestic, agricultural and industrial uses, water resource developments are currently being planned and implemented, including a number of regional water supply projects. The goal of these supply projects is to provide municipal water to 67 of the 110 Chapters and 80% of the projected Reservation population by 2050. The Bureau of Reclamation (BOR) is working with the NDWR and NTUA to provide planning and implementation of several of these projects (NDWR, 2011).

Institutional involvement in water management on the Reservation

Many institutions are involved with water management on the Reservation by providing planning support and/or funding. These entities include: the Indian Health Service (IHS), the BOR, Bureau of Indian Affairs (BIA), the United States Environmental Protection Agency (USEPA), the states, and the US Army Corps of Engineers. The IHS is one of the main agencies involved in planning and funding local municipal supply projects and works in collaboration with the NDWR and NTUA (NDWR, 2011). Once a water supply project is completed by the IHS, the NTUA generally takes control of operation and maintenance.

The NTUA is a non-profit enterprise of the NN that supplies drinking water, wastewater treatment, grid-electricity, natural gas, solar energy, and internet services to individuals and businesses throughout the Reservation. It is the largest supplier of drinking water on the Reservation and currently operates over 100 public water systems (PWS) serving an estimated 75% of the Reservation population. Other operators on the Reservation include the NDWR (~25 PWSs), the BIA (~60 PWSs for BIA schools and school-related housing) and a variety of missions, trading posts and private commercial operators (combined ~50 PWSs) (NDWR, 2011). Non-NTUA systems are typically smaller than those run by the NTUA and are often not metered. As NDWR systems are upgraded, operation and maintenance is often turned over to NTUA. The agency in charge of ensuring that PWS operators supply safe drinking water to the public is the NN Environmental Protection Agency's (NNEPA) Public Water System Supervision Program, which inspects and monitors PWSs, and enforces the Safe Drinking Water Act (SDWA).

Regulatory framework for water management

Regulating water resources on the Reservation involves a combination of tribal and federal authority. Although most water sources within the Nation's boundaries are governed by the Navajo Nation Water Code (NWC)[3], surface waters flowing into the Reservation are also governed by federal law and congressional settlements (see discussion below). Ground and surface waters may also be subject to a limited degree of state regulation, depending on the nature of the water source and the settlement agreements implicating that source.

The NWC is comprehensive and includes provisions to guide the issuance of water use permits on the Reservation. The code establishes a priority order of uses from: 1) domestic and municipal uses; 2) stock watering uses; 3) agricultural uses; 4) instream needs for fish, wildlife conservation and recreational uses; 5) economic development uses including industrial and power uses; and 6) other uses (22 NNC. 1501d).[4]

The Navajo Nation Division of Natural Resources (NNDNR) is the primary entity charged with administering the NWC. The NNDNR is responsible for permitting water use on the Reservation in accordance with the "long-term best interests of the Navajo People" through the Water Code Administration (WCA) (NNWCA, 2013). The NDWR and the NNEPA also play substantial roles in administering the code.

3 We refer readers to Chapter 12 for a discussion of the legal implications of the NWC on energy development.

4 See also 22 NNC. 1101: "In order to provide for a permanent homeland for the Navajo People; to protect the health, the welfare and the economic security of the citizens of the Navajo Nation; to develop, manage, and preserve the water resources of the Navajo Nation; to secure a just and equitable distribution of the use of water within the Navajo Nation through a uniform and coherent system of regulation . . . the Navajo Nation hereby asserts its sovereign authority over all actions taken within the territorial jurisdiction of the Navajo Nation which affect the use of water within the Navajo Nation."

Discharges into navigable bodies of water on the NN are subject to the regulation of municipal and industrial discharges under the Clean Water Act (CWA) (Copeland, 2008). Additionally, Navajo water resources are subject to the requirements of the SDWA (42 USC 300f, 2012). The NN became the permitting entity for the SDWA (42 USC 300j, 2012) in 2000 (Grant, 2007) and for the CWA in 2006 (33 USC 1377, 2012; 33 USC 1252, 2012). To obtain authority to administer these acts, the Nation was required to adopt water quality standards at a minimum as stringent as federal standards.

Water rights and settlement issues

Determining the Nation's reserved water rights is essential to secure sufficient long-term water supplies to support an expanding population with expanding water infrastructure needs. In the 1908 *Winters v. United States* decision, the United States Supreme Court determined that Indian tribes have reserved water rights dating back to the date of the establishment of their reservation (Winters, 1908). When the waters of the Colorado River were apportioned between the states, these Indian claims were recognized, but not quantified. The Supreme Court case *Arizona v. California* (1963) later condoned the quantification of tribal water rights under the practicably irrigable acres (PIA) standard (*Arizona*, 1963). The quantification of Indian federal reserved rights is now often based on the practicably irrigable acreage standard.

Under the PIA standard, potential NN water rights claims are huge. The NN has claims to substantial quantities of water from the Colorado River basin (Winters, 1908) and encompasses an area of roughly seventeen million acres (Kraker, 2004). Most of the NN's rights have not been quantified.[5] The priority date for these rights will likely be 1868, originating from the Navajo's treaty with the federal government creating the Reservation. This means that in times of drought, the Navajo's water rights, if developed, would take priority over the rights of large western cities like Phoenix, Las Vegas and Los Angeles (Jenkins, 2008).

Because water rights are adjudicated by basin, Indian tribes must settle their federal reserved rights claims for each water basin in every state that the basin touches. The NN has water rights claims in three states and several different river basins (see Appendix A at the end of this chapter). Thus, the process of settling these claims will involve numerous settlement efforts in different states. The Nation settled its claims in New Mexico with the 2010 Navajo-San Juan Settlement. It is currently negotiating with Utah to settle its claims to Upper Colorado River. Past negotiations with Arizona to settle its claims to the Lower Colorado River have been extremely contentious and recently stalled. Additional information about Navajo water rights claims is provided in Appendix A.

4.2 Potential Climate Change and Variability Impacts on Water Resources

Climate change and variability has the potential to seriously impact water resources. Observed and predicted changes in hydrology on the Reservation were discussed in Chapter 3. These observed and potential hydrologic changes in the Southwest (SW) and on the Reservation are summarized again in Tables 4.1 through 4.3 below. Key observations include declines in at least thirty surface water features on the Reservation and a long-term drought that has persisted since 1994 and has been punctuated by brief periods of wetness.

5 In 2004, the Tribe settled with New Mexico for 326,000 af of water from the San Juan River, a major Colorado River tributary. The settlement authorized $800 million in federal and state money to build a pipeline to the eastern side of the Reservation. In March 2009, President Obama ratified the settlement by signing an Act authorizing the construction of the Navajo-Gallup Water Supply Project, an $870 million water delivery system for Navajo communities from Shiprock to Gallup. In addition to the settlement with New Mexico, the Navajo have put the federal government and the seven Colorado River basin states on notice that they could justifiably use 336,856 af in Arizona (Jenkins, 2008). The Tribe believes it could also claim 80,000-100,000 feet in Utah. While these are the estimates of the Navajo's water rights lawyer, Stanley Pollack, some tribal members believe the amount of water due to the Navajo is much greater. Peter MacDonald, the former Navajo Chairman, estimated that the tribe has rights to over 50 million af of water, including water from other river basins, including the Rio Grande.

The impacts of drought on the NN have been widely acknowledged. The NWC reported that "[t]he lack of rainfall and snowfall on Navajo rangelands has resulted in severe drought conditions" (22 NNC. 52, 2012). Key potential future changes include earlier snowmelt, decreases in late spring through late summer runoff, and increases in drought frequency, severity, and duration.For more in depth discussion of the changes noted in the tables and for associated references, we refer readers to Chapter 3.

Observed Hydrologic Changes on the Navajo Reservation
• Declines in snowpack
• Declines in at least thirty surface water features
• Poorer water quality in some locations
• Wet periods during the early 1900s and 1980s, with extremely wet individual years only before 1950
• Severe drought during the 1950s, and other periods
• Between 1994 and 2014 there has been overall long-term drought coupled with brief periods of shorter-term wetness
• Although the Navajo Reservation experienced severe droughts during the 20th and 21st centuries, the droughts during the preceding three centuries tended to be more severe and longer-lasting

Table 4.1. Observed hydrologic changes on the Navajo Reservation.

Potential Climate Change and Variability Impacts on Hydrology and Water Demands
• More winter precipitation falling as rain rather than snow
• Reduced spring snowpack
• Earlier snowmelt
• Decreases in the frequency and intensity of spring/early summer snowmelt-driven floods
• Decreases in late spring through late summer runoff
• Lower soil moisture by early summer
• Increases in drought frequency, severity, and duration in the Colorado River basin
• Potential effects of climate change on the North American Monsoon are not clear
• Little change in total annual precipitation in the Colorado River basin (medium-low confidence)
• More extreme precipitation events and storms (medium-low confidence) possibly resulting in greater flooding

Table 4.2. Potential climate change and variability impacts on hydrology and water demands in the Southwest.

In addition to impacts on water quantity, climate change and variability will likely affect water quality as a result of rising air temperatures, changing precipitation regimes, fires, and forest die-off. Potential water quality changes in the SW were discussed in Chapter 3. These changes include warmer water temperatures, increased sedimentation, and higher pollutant loadings associated with precipitation events of increasing intensity. Changes in water quality have implications for water and wastewater utilities. Some of these are briefly noted in Table 4.3.

Potential Climate Change and Variability Impacts on Water Quality	Implications for Water and Wastewater Utilities
• Warmer water temperatures • Lower dissolved oxygen concentrations	Could affect the assimilation capacity of waters receiving wastewater treatment plant or cooling water discharges.
• Altered stratification and eutrophication	Excess algae could pose problems for water filtration processes.
• Increased turbidity and sedimentation associated with more intense rainfall and greater wildfire frequency	Could disrupt water filtration processes and cause losses in the water storage capacities of reservoirs.
• Higher pollutant loadings associated with more intense rainfall • Higher occurrences of waterborne diseases associated with more intense rainfall	Could affect the ability of water and/or wastewater treatment plants to meet regulatory standards.
• Alterations in organic carbon characteristics of waters due to vegetation changes	Could affect the formation of disinfection byproducts, some of which are known carcinogens (Mikkelson et. al 2012).
• Potential groundwater salinization	Could increase treatment requirements.

Table 4.3. Potential climate change and variability impacts on water quality and implications for water and wastewater utilities in the Southwest.

4.3 Water Resources as a Super Sector on the Navajo Nation

The changes in NN water resources due to climate change and variability are far reaching, as noted in tables 4.1, 4.2, and 4.3. The Assessment of Climate Change in the Southwest United States (SWCA) describes water as a "super sector" because changes in water availability and timing will affect all other sectors (SWCA, 2013). A summary of how hydrologic changes could affect the other sectors on the NN is introduced here (listed according to the associated chapter). Each chapter has additional information tailored to the resource described.

Chapter 5 – Farming

Farming is particularly sensitive to water availability, soil quality and erosion. Warmer temperatures, combined with associated longer growing seasons, could increase agricultural water demands, while areas that depend on snowmelt for irrigation could be impacted by changing winter precipitation patterns. Lower soil moisture by early summer followed by more frequent, more severe and longer droughts could pose difficulties for water provision to crops. According to Navajo elders, a lack of available water is already a leading cause for the decline in the ability to grow corn and other crops (Redsteer et al., 2011; Garfin et al., 2013). Longer drought punctuated with rainfalls of increased intensity can increase soil erosion. In addition, increased rainfall intensity could cause decreases in water quality by carrying agricultural chemicals and nutrients into surface waters. More subtle precipitation patterns and timing also have direct implications for crops and are discussed more in Chapter 5(D'Antonio, 2006).

Chapter 6 – Rangeland Resources

For rangeland resources, prolonged drought and variability in precipitation patterns could interact with warmer temperatures to affect forage, water supplies for reservation livestock, and disease susceptibility. Predicted increases in average and extreme temperatures may decrease soil moisture content, stressing plants (Schwinning, 2008). Increased drought may bring a decline in native vegetation and increase erosion and desertification (ITEP, 2009). Warming tends to amplify the effects of drought by increasing plant stress and mortality (Robles and Enquist, 2011). In some locations in the SW, changes in precipitation patterns have already resulted in areas of arid grassland converting into desert shrubland (McCarty, 2001).

As noted above, most Navajo rely on stock ponds, wells drawing from alluvial aquifers, and intermittent streams to satisfy their domestic and livestock water needs. Stock ponds are already often dry during the summer and during droughts (NDWR, 2003). Stock ponds will likely dry up more frequently due to anticipated rises in temperature and increases in drought frequency, severity, and duration.

Chapter 7 – Human Health

Community health is also affected by water resources. Climate events, such as increased drought and flooding, could affect the population numbers and geographic distribution of diseases and disease vectors (Gubler et al., 2001). Climate events can also affect subsistence farming and nutrition, water supply, wastewater, stormwater, transportation, communication, and other infrastructure in ways that disrupt access to safe water, food, and healthcare and contribute to associated health impacts (Houser et al., 2001). Water quality issues often have direct implications for residents relying on wells as their primary source of drinking water.

Changes in long-term precipitation and soil moisture could potentially reduce groundwater recharge (Udall, 2013; Earman and Detinger, 2011) and this may reduce the availability of groundwater. Reductions in groundwater could be of particular concern to water haulers, especially during times of drought. Increased reliance on water hauling has substantial implications for the health of Navajo communities. Families hauling water must often drive long distances to obtain potable water (see discussion above). During drought, distances traveled to find PWSs with available water may increase and the cost of water hauling can double (NDWR, 2003). The extra time and expense required to get water from a PWS, can lead families to drink from livestock ponds or other non-potable water sources closer to home.

Chapter 8 – Tourism and Recreation

Lake-based tourism and recreation on the NN could be affected by increased drought occurrences. During the current drought, several reservation lakes have completely or partially dried up. For instance, To'ahidiilíinii, or Many Farms Lake, used to be a source of fish and a gathering place for local residents and wildlife alike. Now, it is described as "an abandoned murky pond with no fish, useful only to dragonflies" (Jimmy, 2013). Disappearing lakes, which once served as sources of water, fish and communal areas, will affect tourists, residents and wildlife. Additionally, extreme temperatures and weather events may limit tourist activities on the Reservation.

Chapter 9 – Fish, Wildlife, Plants, and Biodiversity

Climate changes to aquatic ecosystems may include changes in nutrient cycling, productivity, stratification and eutrophication, warmer stream temperatures, and lower dissolved oxygen concentrations. These changes can affect the population numbers and geographic distributions of species as well as the timing of life cycle events. Hydrologic changes can lead to lower water levels in lakes and streams with potentially dire consequences for fish and other aquatic species. In terrestrial ecosystems, droughts can impact forage, predator-prey relationships, and population numbers. If water sources become scarcer, conflict interactions between wildlife and livestock or people may increase.

Chapter 10 – Forestry

Forests play important roles in the hydrologic cycle. They help regulate the timing and amounts of runoff to surface and groundwaters, can protect or improve water quality, can provide shading to reduce stream temperatures, and can provide stormwater and thus flooding control (NFWPCAS, 2012). Climate change impacts that affect forest health can thus affect the hydrologic cycle.

Anticipated increases in drought can directly affect forests by creating water stress, possibly affecting reproduction, and, if conditions become intense enough, by increasing tree mortality (Dale et al., 2001; Redmond, 2013). Anticipated longer fire seasons and increases in fire frequency and areal extent (see Chapter 2) could contribute to larger-scale tree dieoffs and potentially to habitat conversion (Dale et al., 2001). Additionally, high intensity fires can create water repellant post-fire soils that lead to increased runoff and subsequent debris flows that decrease water storage capacity (Glick et al., 2011; Moench and Fusaro, 2012). Both effects can, in turn, contribute to increased flooding. Insect and disease outbreaks could also be altered and lead to large-scale tree mortality. Some research has shown faster snowmelt rates in pine beetle impacted areas (Pugh and Small, 2002).

Chapter 11 – Infrastructure

Changing environmental conditions can affect the condition, effectiveness, and costs associated with water supply, stormwater, wastewater, transportation, communication, and housing infrastructure. A reservoir system's ability to meet water supply needs could be affected by changes in the timing of runoff. Additionally, an increased volume of runoff could flood the reservoir system's control functions. If droughts contribute to falling surface and groundwater levels, water supply intake locations may no longer be suitable. Droughts could also lead to lower stream flows, resulting in higher concentrations of pollutants in water that could affect the ability of treatment plants to meet safe drinking water standards (CDC et al., 2010).

Storms with high precipitation intensities could wash out road foundations, weaken bridge supports, or delay or disrupt road, rail, and air travel and associated freight operations through flooding or landslides (Niemeier et al., 2013). Intense rainfall events could also damage some navigation instruments used in air transportation (Niemeier et al., 2013). Communications infrastructure could be damaged by flooding of underground equipment or impacted by power outages from severe storms.

Dunes on the NN are already covering housing and other structures and causing transportation problems. Increasing aridity can lead to a decrease in vegetation and increase dune mobility (Redsteer et. Al, 2011; Garfin et. al., 2013). If precipitation intensities increase, floodplains could expand to homes and other structures that are not currently in floodplains. Flooding can block access to hospitals, contribute to mold infestations in buildings, and overload sewage treatment plants. Possible increases in the magnitudes and frequencies of floods could also pose additional risks for aging dams and levees, necessitating further actions to ensure safety (Brekke et al., 2009). Finally, potential climate-related water quality impacts could affect the effectiveness and costs of water supply and wastewater treatment.

Chapter 12 – Energy

Sustainable energy production is limited to the available water supply, particularly in times of water shortages. When nations lack access to water, they lack access to an essential component of energy generation and fuel production. Warmer air and water temperatures may result in increased water demands from the energy sector, for example, water used for cooling. At the same time, anticipated runoff decreases in late spring through late summer, and increased frequency, severity, and duration of droughts, may stress water supplies.

Just as water is needed to provide energy, energy is needed to treat and move drinking water and wastewater. For example, a large quantity of electricity is needed to pump raw water over long distances, as is done in the Central Arizona Project that supplies water to cities such as Phoenix (Ojima et al. accepted). Shortages could result both from climate change and other factors (such as population growth) (Drobot, 2011). [6]

These are just a few examples of the role water resources play across various sectors on the Reservation. Each section below includes a more in-depth discussion of how water and hydrologic changes impact that sector.

4.4 Vulnerability and Adaptive Capacity Factors

Changes in the hydrologic cycle will impact socioeconomic, legal, institutional, infrastructural, technological and other vulnerability and adaptive capacity factors (Chapter 2) to enhance or diminish the ability of the NN to ensure that adequate water is available for municipal, farming, livestock, industry, and ecosystem uses.

Socioeconomic and land use factors

Non-climatic factors can contribute to changing water demands. For instance, if population increases and as more Navajo become connected to public water systems, per capita municipal water demands will likely rise. The creation of long-term, sustainable livelihoods is of utmost importance on the Reservation.

6 For instance, between the years of 2000 and 2030, the population of Arizona is projected to increase by 108.8%.

The types of economic development chosen to take place on the NN will also affect the degree of new water demands for which the Nation must prepare. Land use factors may affect water quality, including nonpoint pollution coming from urban, industrial, and agricultural lands.

Legal and planning factors

Legal and other political and institutional factors will also shape the impacts of climate change on the hydrologic cycle. As noted above, the NN has claims to substantial quantities of water from the Colorado River basin and beyond.

The NWC provides sufficient flexibility to adapt to changing conditions and legal considerations on the Reservation. First, the NWC includes a variety of provisions designed to address emergency drought conditions. Specifically, the NWC includes provisions for water trucking during drought (22 NNC. 52, 2012) and for the development of new community water resources and wells (22 NNC. 123A, 2012). Second, the NWC permits the flexible allocation of water resources, including the ability to obtain water rights for wildlife purposes. Finally, the NWC protects habitat and ecological values by requiring that rivers, streams, lakes and ponds within the NN are retained substantially in their natural conditions, with base flows and water levels necessary to provide for preservation of traditional and religious, recreation, wildlife, fish, scenic, aesthetic, and other environmental values (22 NNC. 1503A, 2012).

Other NN projects and programs could be used to support climate adaptation efforts. The NDWR has undertaken two large water resource-planning efforts. In 2003, the NDWR, working with the BOR, BIA, and the Navajo Department of Emergency Management, completed a drought contingency plan (DCP) (NDWR, 2003). The plan addresses drought monitoring, declaration, and emergency response, and identifies actions that the Nation can take to mitigate drought impacts. The DCP also provides guidance for the development of more localized, chapter-level drought contingency plans. The monitoring portion of the plan has undergone an outside review the results of which could be incorporated into a DCP update (Crimmins et al., 2013). Updating the DCP has taken on particular urgency given the ongoing drought and anticipated increases in drought frequency, severity, and duration.

The NN is also working on a large-scale water development strategy. In 2011, the NDWR completed an update of a 2000 draft Water Resource Development Strategy (NDWR, 2011). The document describes current and projected water demands, identifies infrastructure deficiencies, presents a multi-component strategy for addressing those deficiencies, and states broader water resource management goals summarized in Table 4.1 below.

Elements of the Water Resource Development Strategy for the Navajo Nation
1. The development of several large regional water supply projects
2. The rehabilitation and development of local projects to convey water from the proposed regional projects to homes, businesses, and farms
3. Identification of methods to improve water access for water haulers
4. The preparation of chapter and regional water plans to systematically identify the full scope of need on the Reservation and to prioritize projects
5. Completion of the Navajo Indian Irrigation Project
6. Addressing deficiencies in aging dam system infrastructure
7. Implementing drought mitigation projects
8. Establishing flood hazard maps (those for Window Rock and Chinle were completed in 2010)
9. Restoring Navajo watersheds
10. Establishing technical advisory committees for major projects and initiatives

Table 4.4. Elements of the Water Resource Development Strategy.

As the Nation starts to address different objectives, climate change and variability considerations could be included in various ways. For example, when establishing flood hazard maps, consideration could be given as to the timeframe of data used and to potential increases in precipitation intensity. Additional considerations are addressed below in the discussion of water resources adaptation strategies.

Diverse data gathering and information sharing efforts are also underway. The NDWR produces monthly drought status reports to inform resource managers about drought conditions on the Reservation. These reports are made available on the Water Management Branch website (http://www.frontiernet.net/~nndwr_wmb). The NDWR also operates a hydroclimate network that includes nine stream gauges, nine automated climate stations, fifteen recording precipitation gauges, an extensive network of rain cans, a network of monitoring wells, and nine snow survey site (Aggett et al. 2011).

The NDWR has made the precipitation data that it collects available online in a searchable database. The department would also like to make the groundwater data it has available online as well, which could be extremely helpful in any planning and future modeling efforts that the NN undertakes. This will entail digitizing records and conducting quality assurance and control on the data. Finally, the Navajo Nation Water Quality Project (available at http://navajowater.org) is a web-based outreach campaign providing Navajo water quality information which emphasizes the water quality of drinking wells and springs near old uranium mines on the NN.

Infrastructure

Development of water resources on the Reservation is often impeded by a lack of infrastructure due to historical conditions. As described above in Chapter 11, the congressional Bennett Freeze prohibited development (including the development of water resources) in the Black Mesa area on the Reservation while boundary disputes between the Navajo and Hopi reservations were resolved. Black Mesa area water resources were intentionally disassembled in an attempt to promote relocation. BIA employees and Hopi rangers capped off, fenced off, dismantled, and bulldozed working wells (Forgotten People, 2011). The development of water infrastructure is impeded by a lack of funding and low population densities in certain areas of the Reservation, which can make the per capita costs of infrastructure development prohibitively high. Nevertheless, the NDWR and other departments are working tirelessly to improve water infrastructure on the Reservation.

The NN government has various small-scale water supply projects underway and is working to develop several large-scale projects (see Appendix A). The Navajo-Gallup pipeline is a large-scale water delivery project which will provide the eastern section of the NN, the southwestern part of the Jicarilla Apache Nation, and the city of Gallup with a reliable source of water by the year 2040 (USBR, 2012). The project will divert 37,764 af of water per year from the San Juan River and deliver this water to communities currently dependent on groundwater sources. It will serve 203,000 people in forty-three chapters across the NN.[7] Work on the pipeline began in December 2012. The Department of Interior (DOI) predicts that some Navajo customers could receive water as soon as 2015 (Donovan, 2013).

Due to the various barriers to developing infrastructure on the Reservation, 25%-40% of the population relies on water hauling to provide for their everyday needs. Water hauling disproportionately impacts certain areas. Homes that lack access to a public water supply range from 19% in the relatively urban Kayenta Chapter to over 75% in the remote Shonto and Forest Lake Chapters (NDWR, 2003).

The economic costs of water hauling are incredibly high; the cost to haul water on the NN is estimated at $133 per 1,000 gallons (NDWR, 2011). Hauling water can trap residents in a circle of poverty (NDWR, 2003). In comparison, residents in Phoenix pay less than $2 for the same amount of piped tap water (NDWR, 2011). Water hauling costs are estimated to double in times of drought because tribal members often have to drive over miles of washboard roads to access more remote water sources. Because of the hardships presented by water hauling on Black Mesa, the NDWR, the USEPA, and grassroots community

7 There has been some concern over how the pipeline will impact these communities, particularly from habitat interruption and disruption of local grazing practices.

groups are currently collaborating to provide alternatives to individual water hauling (EPA, 2012 b). These programs require significant financial and human resources and rely entirely on groundwater.

4.5 Potential Adaptation Strategies for Water Resources

The tools needed to develop water capacity for a changing climate are often the same or similar to tools currently used in general management practices (Gleick, 2000). Modifying systems for possible reduced water resource availability is an essential piece of climate change planning. Securing the availability of high-quality, reliable water will become increasingly difficult as water resources are reduced or altered by a changing climate. To effectively manage reservation resources, managers will need to consider future changes in the water cycle and the resulting effects on ecosystems. The NN already has taken measures to help adapt water resources to further pressures. When planning water resource adaptation strategies, the NN can rely partially on existing programs and institutional resources.

In a 2011 Southwest Tribal Climate Change Workshop (SWTCCW), participants provided an array of water resource adaptation suggestions (Wotkyns, 2011). The DCP also contains numerous recommendations for drought mitigation across a variety of sectors (NDWR, 2003). We mention select strategies from these and a few other sources in this section. We also refer readers to those sources for further details and additional strategies.[8]

Water resource adaptation strategies fall into a wide range of categories including: water demand management, water supply management, protecting and improving water quality, infrastructure management, improving drought risk management, improving flood risk management, managing landscapes for water resources, managing aquatic ecosystems, monitoring and research, and integrated water resources management planning (Hanak and Lund 2008; Brekke et al. 2009). We separate the strategies into categories for convenience here, but strategies may fall into more than one category.

Adaptation approaches may be structural and non-structural. Non-structural approaches make use of policy, legal and pricing reforms, better coordination among water purveyors, increased management flexibility and the like (D'Antonio, 2006). While some adaptation strategies may involve new practices, other strategies are continuations of practices currently implemented.

Water demand management

Water demand management includes water efficiency and conservation measures as well as reallocation or water transfers. Suggestions by SWTCC workshop participants on improving agricultural water efficiency include switching from flood irrigation to drip irrigation, using ditch liners or pipes to prevent loss of water during irrigation and constructing underground aqueducts to reduce evaporation for farming systems (Wotkyns, 2011). Additional strategies related to agricultural water efficiency and conservation include changing crop cycles to use less water and using automated sprinkler systems that sense environmental conditions (USDOI, 2005). Improved efficiency can decrease water costs while potentially improving crop yields.

It is important to note, however, that various methods may have indirect consequences. For instance, the SWCA notes that that greater efficiency may mean less water is available for groundwater recharge or

8 The federal government and many states are starting to plan for climate change impacts on water resources. The NN may want to consider water adaptation strategies proposed by other SW governments and federal agencies. For instance, the New Mexico Office of the State Engineer and the Interstate Stream Commission has compiled a report assessing the possible impacts of climate change on New Mexico's water supply and proposing potential adaptation strategies (D'Antonio, 2006; Arizona Climate Change Advisory Group, 2006). In 2008, the Public Policy Institute of California put out a report, *Adapting California's Water Management to Climate Change* (Hanak and Lund 2008). In 2009, the USGS published, *Climate Change and Water Resources Management – A Federal Perspective* (Brekke et al. 2009). In 2011, the consulting firm CDM completed a *Climate Change Handbook for Regional Water Planning* prepared for the USEPA Region 9 and the California Department of Water Resources. Similarly, the National Oceanic and Atmospheric Administration's Regional Integrated Science and Assessments program could provide additional information (NOAA, 2011).

Key Points: Water Demand Management

- Improve water conservation in buildings
- Use water efficient technologies
- Test toilets for leaks or install low-flow toilets
- Use Water Sense products
- Incentivize efficiency in codes

for surface water return flows which could have implications for downstream riparian ecosystems that depend on return flows. Furthermore, reductions may have implications for downstream uses and could be regulated by settlement or water delivery terms (Frisvold et al. 2013). In Chapter 2 we discuss how to balance adaptation strategies with other considerations.

SWTCCW participants suggested improving water conservation in buildings (Wotkyns, 2011). Adopting specific water conservation technologies, particularly in new developments, could create more sustainable development. Many NN communities are still developing; once the Navajo-Gallup pipeline and its delivery components are completed, some communities will be accessing piped water sources for the first time. Using water-efficient technologies will give communities an opportunity to develop in a sustainable manner. The USEPA suggests several methods to improve domestic water use efficiency including: testing toilets for leaks or replacing/installing low-flow toilets; replacing appliances with WaterSense approved products; minimizing landscape watering and/or choosing native and low water use plants; and using storm water for watering vegetation (EPA, 2012). Creating incentives to replace older appliances may encourage retrofits which can greatly lower both water and energy usage (Hanak and Lund 2008). Finally, leakages in water distribution systems can waste water. Programs that regularly monitor and address leakage in water distribution systems on a large-scale can be important water conservation measures (Western States Water Council, 2011).

The draft Navajo Water Resource Development Strategy (NDWR, 2011) strongly encourages water conservation. However, the Strategy notes that per capita water usage on the Nation is among the lowest in the region. Most Navajo currently do not have irrigated lawns or water-intensive appliances such as dishwashers or clothes washing machines. Per capita water use will likely increase with the development of the Navajo-Gallup pipeline and other domestic delivery systems.

Navajo communities have a right to develop basic community and domestic infrastructure. However, emphasizing water conservation measures while communities are developing will encourage sustainable long-term growth and results in long-term energy and water savings. Developing alternatives to water intensive industries could greatly help reduce potential climate change impacts. Because of the links between energy and water use (see Chapter 12), energy conservation measures in any sector often translate into water conservation.

Water supply management

Water supply adaptation strategies include: settling water rights, creating more diverse water supply portfolios to spread risk, identifying and developing alternative water sources, integrating surface water and groundwater management, and rehabilitating or developing additional storage capacity.

Strategies incorporated into the settlement of water rights can potentially be climate adaptation strategies. Water rights settlements are important for ensuring water quantity and availability for the future. One of the most effective ways to prepare for potential water shortages on the NN may be to complete water rights settlement negotiations with Utah, Arizona and New Mexico as quickly as possible. Every year, the SW population grows, long-term drought endures, and policymakers attempt to compensate for the limited supply of SW water resources (Hundley, 2009).[9] Similarly, many state water rights users are already reliant on unutilized senior tribal waters. If these tribal waters were to be put to use it would usurp state users. This growing dependency could make it politically difficult for SW tribes

9 The SWCA cautions that the Lower Colorado River basin is "currently relying on unused water from the Upper Basin to which it has no long-term right. If this surplus of unused water were to cease to be available because of climate change or increased Upper Basin use, the Law of the River would force water shortages almost entirely on Arizona." (Udall, 2013)

to obtain full recognition of their water rights.

As water supply pressures increase, the NN's chance of full realization of its water rights will likely diminish. Moreover, negotiated water rights settlements could provide water supply projects and other funding that could help to meet water supply infrastructure needs (Hundley, 2009). Thus, settlement agreements could quantify the Nation's rights and permit it to build the infrastructure necessary to meet domestic, livestock and industrial needs on the Reservation.

Working towards a settlement agreement does not mean that the NN should accept a settlement proposal which does not fairly represent its rights or meet the needs and future needs of Navajo communities. In addition to quantifying these rights, it is important to carefully consider how the Nation may use these rights once quantified. Because settlement agreements can restrict tribes to using water for particular uses or in a particular place, it is important to consider climate change when agreeing to any restrictions on water use or delivery. Once the Nation settles for a particular quantity and agrees upon additional settlement terms, it will likely require legislation to change any of the settlement provisions. The finality of these agreements emphasizes the need to consider their long-term implications under various potential climate change scenarios.

Settlements can, to a certain extent, incorporate the potential future pressures of climate change. If a delivered water supply comes from a reservoir that may experience reduced levels, it is important to consider where the intake infrastructure will be positioned. Settlements may contain provisions for sharing during times of shortage. With the potential for increased future shortages with climate changes, these provisions should be carefully considered. Important cultural resources can be protected explicitly in settlements. For example, development buffers around culturally important springs can prevent drawdown. This was one of the terms in the proposed 2010 Navajo-Hopi Little Colorado River settlement. Finally, flexibility in water supplies will better enable the NN to meet unanticipated challenges. Leases which restrict the NN's ability to allocate water resources should be carefully considered for their long-term implications.

Developing alternative water sources is another water supply management strategy. This could involve matching water sources to particular needs. For example, higher quality waters could be saved for drinking purposes, while lower quality waters could be used for irrigation. Feasible options put forth by SWTCC workshop participants suggested developing alternate water sources by rainwater harvesting, developing alternate well sites, retrofitting buildings with gray water systems, and encouraging water reuse (Wotkyns, 2011).

Water reuse involves reusing treated wastewater for non-potable purposes such as agricultural irrigation, industrial purposes, and toilet flushing. In cooperation with the BOR, the NN has already implemented some water reuse projects including the use of wastewater treatment plant sewage lagoon water to irrigate riparian areas near the Hubbells Trading Post by Ganado and to supplement water in wetlands near Pinion. Additional water reuse project ideas include the use of sewage lagoon water to irrigate a golf course in the LeChee Chapter and to irrigate Kerley Valley and Many Farms. The Navajo Mountain Chapter would like to incorporate water reuse into a new high school (NDWR, 2011). The DCP noted that the reuse of sewage lagoon water could extend the effective capacities of wastewater treatment plants whose lagoons are approaching their limits (NDWR, 2003).

Key Points: Water Supply Management

- Continue working to settle NN water rights claims
- Consider shortage provisions as part of settlements
- Create buffers for culturally sensitive water resources
- Consider the placement of intakes for drought conditions
- Consider the implications of long-term leases
- Save high quality water for drinking water
- Reuse water for appropriate applications
- Enhance storage capacity in certain systems
- Carefully consider what settlement terms may entail in the long term

Key Points: Enhancing Storage

- Add storage water tanks to PWSs
- Add wind breaks around stock ponds
- Develop underground water storage facilities
- Enhance groundwater recharge with rock dams, dikes, gabions and catch basins

There are obvious advantages to establishing alternative water sources, particularly in terms of drought mitigation. In the case of water reuse, if nutrient-laden, treated wastewater is used for agricultural irrigation, reuse can lessen nutrient loadings of waters and improve water quality (NRC, 2011). There are tradeoffs to be considered, however. Gray water usage may involve additional costs in terms of supplementary piping. The drilling and pumping of water from new wells may affect water levels in nearby wells. Thus, precautions must be taken to ensure that the degree of pumping will not cause unsustainable aquifer depletions. If water is being pumped from deeper depths, this could lead to increased energy demands and costs (Ojima et al. accepted). Although reuse sometimes improves water quality, if irrigation application rates exceed the ability for plants to uptake the nutrients, then reuse could lead to excess nutrient levels in waters (NRC, 2011).

Irrigating with treated wastewater can produce excess salinity levels in soils that can be detrimental to plant growth (Denver Water, 2011). Desalination can be quite energy intensive, which can result in additional GHG emissions. To address this later issue, the University of Arizona and the BOR are developing a solar-powered desalination plant in the southwestern corner of the Reservation. The plant will use solar photovoltaic energy to pump groundwater from a brackish aquifer and solar thermal panels to heat the water and pass the heated water through membranes that filter out contaminants (Bruggen, 2013).[10]

Rehabilitating or enhancing storage capacity in water supply distribution systems can increase the ability of a system to handle greater precipitation variability (Hanak and Lund 2008). Opportunities for storage enhancement exist for both surface and underground storage. The DCP includes NDWR recommendations to add additional storage tanks to public water systems as a drought mitigation strategy. Adding wind breaks around stock ponds for livestock can also decrease water loss to wind-driven evaporation. Aboveground storage tanks can be added to livestock watering systems in certain locations to reduce evaporative loss from stock ponds (NDWR, 2003).

In the draft Navajo Water Resource Management Strategy, the NDWR notes that some of the larger regional water supply projects will require new surface storage reservoirs (NDWR, 2011). SWTCC workshop participants also suggested developing underground water storage facilities and groundwater recharge, pumping, and storage facilities. SWTCC workshop participants also recommended improving groundwater recharge and storage through the use of "small rock dams, dikes, gabions, catch basin[s]" (Wotkyns, 2011). This can be a low cost strategy implemented at the community level. For instance, to help restore a sacred spring that had dried up in the Zia Pueblo in New Mexico, the Tribe, a restoration ecologist, and volunteers used rock dams to help catch runoff and sediment from the sandstone bluffs and clay hills above the spring (Rio Grande Return).

Integrated surface water-ground water management, or conjunctive management, is another water supply management strategy (Brekke et al. 2009). Water can be stored underground during wet periods for use during drier periods (Hanak and Lund 2008). According to studies conducted for California, shifting the State's drought storage from surface reservoirs to underground aquifers can decrease evaporation losses and help the state adapt to a combination of climate change, population growth, and urbanization. In areas with widely dispersed populations such as the Navajo Reservation, groundwater resources provide a decentralized water source. It is important to note that shifts from surface reservoir to underground storage could require changes to water rights agreements, changes in reservoir operating rules, and additional groundwater recharge and pumping facilities. Changes in reservoir operating rules can sometimes require an Act of Congress (Hanak and Lund 2008). Greater tribal participation in any planning that takes place on a broader regional scale may also be needed.

10 For more in depth discussion of water reuse considerations we refer readers to a National Research Council report on water reuse (National Research Council, 2011).

Protecting and improving water quality

> **Key Points: Protecting Water Quality**
>
> - Cap wells to protect water quality
> - Use waddles and straw to prevent erosion
> - Use riparian buffers to reduce non-point pollution

One main climate change adaptation strategy is to minimize stressors that may exacerbate climate change impacts. To protect ground and surface water quality, SWTCC participants suggested: developing 'other water sources to combat water pollution such [i.e.] arsenic", minimizing "exposure of wells to outside pollution by capping any drill wells and dug wells, putting boulders on them, and filling them to protect from contamination", and using "waddles and straw to reduce erosion flow" (Wotkyns, 2011). Protecting recharge areas can also reduce ground water contamination (CDM, 2011). The NNEPA is developing Source Water Area Protection Plans for public water system wells. These plans include inventories of potential well contamination sources and management strategies for minimizing such contamination. In arid environments, the salt and salinity levels of aquifers must be managed (CDM, 2011). Riparian buffers can also help minimize contamination by helping to prevent nonpoint source pollution from entering surface waters. Finally, targeted fire management around reservoirs could potentially reduce fire-related erosion increasing sediment levels entering reservoirs.

Infrastructure management

Maintenance and rehabilitation of water infrastructure is important to ensure its effectiveness. One anticipated impact of climate variability is an increase in extreme hydrologic events such as floods and droughts. It is therefore important to assess whether existing infrastructure will withstand the extreme and more frequent events that may be associated with climate change (D'Antonio, 2006). Extreme drought conditions that create shifting soil moisture contents could cause pipes to rupture (Royal Academy of Engineering, 2011; Houston City Council, 2011). Increasing precipitation intensities may pose additional risks to certain structures such as dams. As infrastructure is upgraded or constructed, engineering designs should anticipate the potential effects of climate change. For example, open space designs in residential or commercial areas or storm sewer designs may need to be altered to accommodate potentially higher flows.

Drought risk management

Given anticipated increases in drought frequency, severity, and duration in the SW, improved drought risk management will be important to adaptation on the Reservation. The DCP contains an extensive discussion of potential drought mitigation measures that the Nation can undertake (NDWR, 2003). We note some of these as bullet points below in Table 4.5.

Recently, the NDWR partnered with a group of university reviewers to do a technical review of the monitoring portion of the DCP. Currently, the NN uses what is known as a 6-month Standardized Precipitation Index (SPI), established by the Western Regional Climate Center, to determine the Nation's drought status (i.e. normal, drought alert, drought warning, or drought emergency). Changes in status are triggered by changes in SPI values. For example, when the 6-month SPI is between -1 and -1.49, the drought status is at a warning level. When the 6-month SPI becomes less than -1.49, then the status changes to drought emergency. The 6-month SPI index is very useful, but drought can occur at different time and spatial scales, and different resources may be affected at different scales. To better reflect this complexity, reviewers came up with a series of recommendations that could potentially improve drought monitoring and declaration on the NN.

Navajo Drought Contingency Plan Drought Mitigation Measures	
Drought Monitoring	• Establish a NN drought information website • Improve the NN hydroclimate network
Domestic Water Hauling	• Construct cisterns for rain water capture to augment water supply • Install household filters and other onsite treatment systems • Install automated "pay per fill" watering station pilot projects at trading posts and schools • Implement a drought gasoline voucher program • Create a water hauling truck service
Public Drinking Water Systems	• For systems that rely on alluvial wells, add non-alluvial wells to diversify sources • Add additional storage tanks to systems with inadequate storage • Establish rural water users circuit riders program to assist with system maintenance • Consider regional water projects for systems using alluvial or deeper aquifer wells that have reached their sustainable limits
Irrigators, Dryland Farmers and Ranchers	• Develop a water conservation and management plan for each irrigation project • Repair and overhaul livestock wells • Establish circuit riders to assist chapters with the development of drought plans and establishing water user groups
Recreation, Wildlife and Forestry	• Establish minimum reservoir levels to prevent catastrophic fish kills • Encourage the Navajo Department of Fish and Wildlife to apply for water use permits from the Navajo Water Code Administration to ensure adequate environmental flows • Install a well to provide supplemental water to the Toadlena Fish Hatchery for drought conditions • Conduct forest thinning and prescribed burns to prevent large catastrophic fires • Identify forest fire suppression water sources that need to be protected during droughts • Improve access points for fire equipment such as trucks and helicopters to reach fire suppression water sources

Table 4.5. Navajo Drought Contingency Plan Drought Mitigation Measures.

The reviewers' recommendations, discussed in the DCP Technical Review, involved deriving better drought information from the 6-month SPI, evaluating trigger-point thresholds based on drought impacts of most concern, and assessing the number of months the 6-month SPI must be at a particular value before the drought status is changed. Other recommendations considered additional drought metrics and included: incorporating a longer-term metric (e.g., a 24-month SPI) that could potentially warn about impacts on groundwater and vegetation like trees that are less likely to be affected by shorter-term drought; incorporating a shorter-term metric (e.g., a 3-month SPI) that could potentially help warn about impacts on surface waters or alluvial aquifers earlier than the 6-month SPI; consulting higher-resolution data than the broad climate divisions that could include calculating an agency-scale 6-month SPI such as the NDWR has started to do; incorporating temperature and soil moisture as indicators in drought monitoring; and establishing a drought impacts reporting system. The latter recommendation would emphasize impacts that are of particular importance to Navajo communities. For instance, a monitoring plan could focus on vegetation conditions, livestock watering sources, or changes in water hauling and water quality. Navajo staff members could potentially incorporate some of these monitoring activities to their routine job duties. Data scarcity poses challenges to drought monitoring. A final recommendation was to increase the NN precipitation observer network by relying on local community members to reliably report precipitation. For more information on the suggestions described above as well as other recommendations, we refer readers to the DCP monitoring technical review (Crimmins et al. 2013).

Flood risk management

Strategies to improve flood risk management that consider potential climate change impacts can include non-structural options such as: floodplain mapping, flood warning and evacuation procedures and education, zoning codes that limit construction in floodplains, building codes that incorporate flood-proofing in areas prone to flooding, and flood insurance. Structural options include: increasing levee heights; creating channel bypasses, flood walls and doors; assessing dam, levee, and other infrastructure for risks that may be posed by increasing precipitation intensities; increasing flexibility in reservoir operating rules to incorporate improvements in flood forecasting; and including higher precipitation intensities in designs and upgrades of storm sewer infrastructure (Hanak and Lund 2008). Additionally, floodplain/wetland protection and restoration can help increase the volume of natural flood storage (CDM, 2011).

Landscape management

As noted above, forests play important roles in the hydrologic cycle. Overgrazing can affect the hydrologic cycle by increasing soil compaction and decreasing water infiltration. Floodplain and wetland restoration can help regulate flooding, and wetland restoration and recharge area protection can help improve water quality. Selection of crop varieties that have lower water requirements can reduce overall agricultural water usage. Thus, water resource stewardship that can include watershed management, recharge area protection, and forest, rangeland, and cropping management is an important water resource adaptation strategy (CDM, 2011).

Aquatic ecosystem management

Water for aquatic ecosystems must be included in the overall scope of water resource management. Some adaptation strategies include: establishing dry year agreements to ensure flows for critical habitats and maintain water quality and changing reservoir releases so that they mimic natural flow regimes as much as possible. If reservoir levels change significantly, for example because of drought, it may be necessary to adjust dam outlet heights so that downstream water quality measures such as temperature are maintained. Floodplain restoration allows for overbank flows, which are important for organisms, biogeochemical processes, and groundwater recharge (Palmer et al. 2009). One strategy noted in the DCP includes establishing minimum reservoir levels to prevent catastrophic fish kills (NDWR, 2003).

Monitoring and research

Monitoring and research will guide sound decision-making by informing priorities and timelines (D'Antonio, 2006). Monitoring and research can be related to surface water, groundwater, other resources, socioeconomic factors, potential impacts, and to the effectiveness of any adaptation strategies implemented. SWTCCW participants identified strategies for improving ways to monitor and research water supply including "conducting water resources inventory to identify high-risk water resources" and partnering with universities on watershed studies (Wotkyns, 2011). Monitoring and research can take considerable time and resources. Collaboration among Navajo departments and among state, federal, and other tribal governments could improve the efficiency and lower the costs of monitoring. The AMEC consulting firm produced a report for the NDWR identifying ways to streamline the Navajo hydroclimate monitoring network to maximize the efficient use of personnel time (AMEC Consulting, 2011).

Integrated water resources management planning

Planning is integral to many of the potential water resource adaptation approaches. It can be more effective to create water resource adaptation strategies for anticipated future conditions than to respond to events and conditions as they arise. Certain aspects of a water resources system are much more difficult to adapt to in a reactive manner. In particular, long-term infrastructure development, such as water pipelines and large-scale delivery systems, are important areas of early consideration. The NN is presently strategizing on how to develop reservation water infrastructure.

The NN has the potential to plan development to adapt to changing climatic conditions. Water resource managers are already required to make decisions based on uncertain projections of the future. Water managers must decide on responses that give a project the flexibility to change with new data and changing conditions due to potential climate impacts. When developing and planning for water resources, dividing goals and strategies into short-term, medium-term, and long-term goals can facilitate planning for adaptation efforts. When faced with a lack of financial and institutional resources, selecting low-cost and easily implemented adaptation strategies can be an effective place to start. Most importantly, planning for climate change is a continuous process. We refer readers to Chapter 2 on adaptation for additional information on how policy makers may choose to prioritize these uses.

Some suggestions for planning include water management plans, reservoir management plans, flood plans and drought plans. Because water is a "super sector" that has implications for all sectors, water resource planning can also be incorporated into plans for other resources/sectors including forest management plans, energy, economic development plans, etc.

Integrated Water Resources Management Planning (IWRM) is one form of planning that takes into account that water transcends sectors. The Global Water Partnership defines the IWRM as "a process which promotes the coordinated development and management of water, land and related resources in order to maximize economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems and the environment." (GWP, 2012) IWRM thus considers both surface water and groundwater together, incorporating the integrated surface water-ground water management noted above. It simultaneously considers water for people, food, nature, industry and other uses, including the energy sector.

Because of hydrologic linkages to landscapes, IWRM includes land management in conjunction with water management (Brekke et al. 2009). It considers both water quantity and quality, and tries to involve a variety of stakeholders from all levels (GWP, 2012). By considering the linkages of various stakeholders and taking advantage of a participatory approach, IWRM will hopefully make more adaptation options available and contribute to the equitable and efficient use of water resources (Cromwell et al. 2007; GWP, 2012).

4.6 Potential Funding and Other Support

A number of federal programs, most notably from the United States Department of Agriculture (USDA), provide assistance to drought-affected communities. Some of these programs deal with emergency situations, while others offer assistance for long-term planning and precaution against drought. The USDA provides drought resources, but according to the Navajo Drought Water Report, it has been difficult for tribes to utilize these resources (NDWR, 2003). [11] Nonetheless, there may be opportunities to successfully use many of the programs outlined below not only for drought adaptation but for other kinds of water resource adaptation as well.

11 For instance, the metrics require using median household income instead of per capita income. Many family members live within the same house thereby artificially increasing the "median household income" when a per capita metric would reveal much lower income levels.

Funding Opportunity	Area of Focus	Source	Enablement and website
Emergency Community Water Assistance Grants	Assistance to communities facing substantial decline in water resources	USDA	Title V of the Disaster Assistance Act of 1989. http://www.rurdev.usda.gov/UWP-ecwag.htm
Resource Conservation and Development	Technical and loan assistance to community programs, including water conservation	USDA	Subtitle H of Pub. L. 97-98, Food and Agriculture Act of 1981, Section 1528-1538. http://www.rcdnet.org
Watershed Restoration and Enhancement Agreement Authority	Grants and agreements to protect and restore watersheds and habitat to better withstand natural disasters	USDA	Forest Service https://www.cfda.gov/?s=program&mode=form&tab=step1&id=3f77d4df8b9d660908187c0fbb640689
Reclamation States Emergency Drought Relief Act of 1991	Assistance to governments (including tribal) in minimizing the effects of drought	DOI	Reclamation States Emergency Drought Relief Act of 1991, Pub. L. 102-250, 106 Stat. 53 http://www.usbr.gov/mso/aamd
Water Resources on Indian Lands	Support for tribal water management plans	DOI	Bureau of Indian Affairs https://www.cfda.gov/?s=program&mode=form&tab=step1&id=a4282e5a120f60bacbe8da5bff46c6fa
Indian Tribal Water Resources Development, Management, and Protection	Assistance developing water management and protection of tribal water resources	DOI	Bureau of Reclamation https://www.cfda.gov/?s=program&mode=form&tab=step1&id=132e2dcf002d2ffc1f6b1319d1cc9c91
Reclamation Rural Water Supply Program	Provides framework to conduct water feasibility studies	DOI	Bureau of Reclamation https://www.cfda.gov/?s=program&mode=form&tab=step1&id=f972b7eab4b04c388b667e5baa3288e9
Cooperative Watershed Management Program	Aid to protect, conserve, improve quality, and ecological stability of water resources	DOI	Bureau of Reclamation https://www.cfda.gov/?s=program&mode=form&tab=step1&id=917078eb9c762f80b93ed64c91ec5262
Targeted Watersheds Grants	Support for water planning which improves water quality and reduces pollution	EPA	Office of Water https://www.cfda.gov/?s=program&mode=form&tab=step1&id=6826b33f7ea20a3111ccd356fd14185d

Table 4.6. Federal assisted programs for drought-affected communities.

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APPENDIX A. Water on the Navajo Nation

The Navajo reservation and is bounded by the San Juan River to the north, the Little Colorado River to the south, and the main stem of the Colorado River to the west.[12]

Water resources

The NN has claims to waters from the Upper Colorado River basin (including the San Juan River), the Lower Colorado River basin and the Rio Grande basin. Major rivers include the San Juan River, the Colorado River, and the Little Colorado. The Nation also has claims to a series of ephemeral washes that flow within the Reservation boundaries.[13] In addition to these surface water resources, the Nation relies on groundwater from the Coconino Aquifer, the Dakota Aquifer, the Navajo Aquifer, and several others.[14]

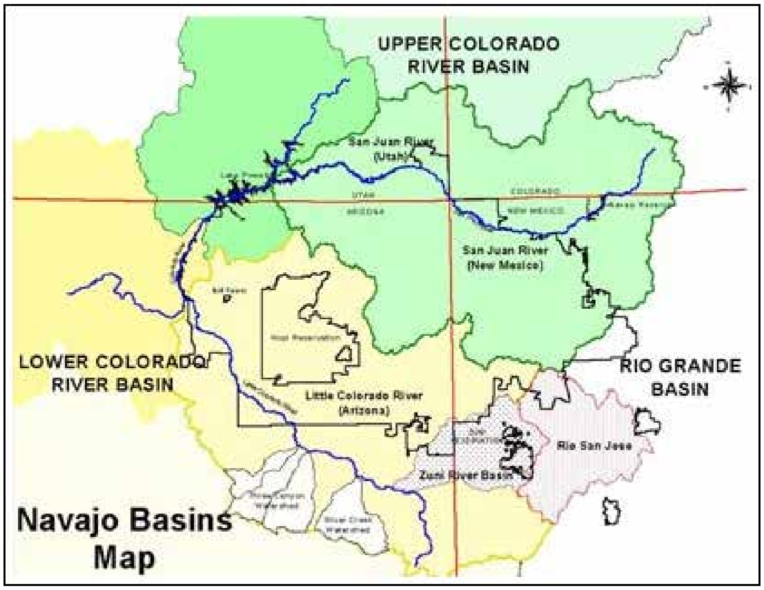

Figure 4.1. Navajo Basins Map. From a U.S. Geological Survey report on the Lower Colorado River (in press, fact sheet at: http://pubs.usgs.gov/fs/2011/3099/).

The Navajo Indian Irrigation Project

As authorized, the Navajo Indian Irrigation Project (NIIP) is a 508,000 af irrigation project, of which the Nation actually diverts roughly 353,000 af. In the authorizing agreement, the NN waived its right to 110,000 af of San Juan River (to be diverted to the Rio Grande basin). Importantly, the Act authorizing NIIP did not settle the Nation's claims to the San Juan River basin. NIIP entitlements were incorporated into the 2010 San Juan settlement agreement.

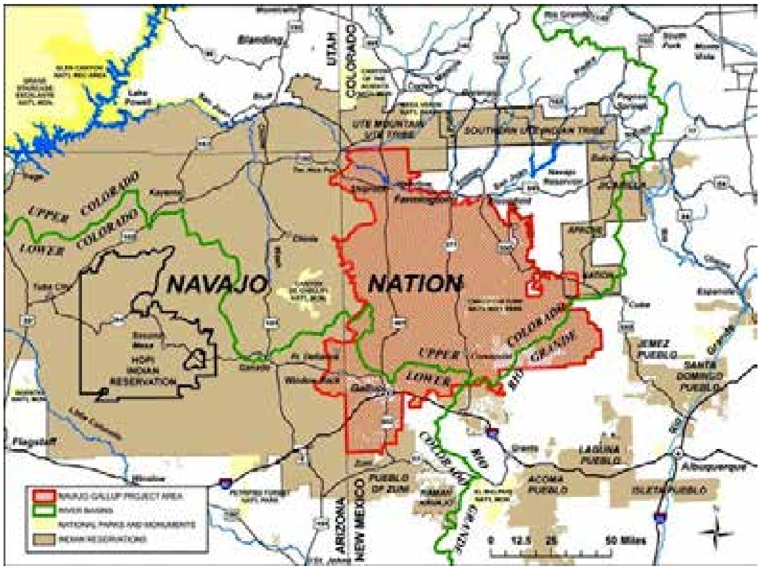

Figure 4.2. Navajo Nation boundaries map.

Settlements

Indian tribes must settle their federal reserved rights claims for each water basin with each state the basin touches. The NN has water rights claims in three states and several different river basins. Thus, the process of settling these claims involves numerous settlement efforts in different states. The NN is still seeking to quantify its water rights to the Colorado River, the Little Colorado River, and the San Juan River in Utah. Below is a brief summary of water rights claims in each state.

New Mexico

12 History, Navajo Nation, http://www.navajo-nsn.gov/history.htm.
13 Navajo Nation Dept. of Water Res., Draft Water Resource Development Strategy for the Navajo Nation 8 (July 2011).
14 Id.

In New Mexico, the NN has rights to the Little Colorado River, the Zuni River, the Rio Grande, the Rio San Jose and the San Juan River. The Tribe has been actively pursuing quantification of its claims to the San Juan River basin.[15]

Navajo Indian Irrigation Project

The history of water settlements for the Navajo Nation in New Mexico is complicated. In 1962, Congress approved the formation of the Navajo Indian Irrigation Project.[16] However, the settlement did not purport to resolve all of the Nation's claims to that water basin. The settlement authorizing NIIP was not a complete adjudication of the Nation's rights to the San Juan River. During settlement negotiations, federal officials had suggested that the Navajo could lay claim to 787,000 af of the San Juan River.[17] Instead, the settlement provided authority and funding for the Navajo Indian Irrigation Project, an 110,630 acre Navajo farm. In the enabling legislation it was anticipated that the farm would use up to 508,000 af of San Juan River water annually. In practice, the farm receives an average annual diversion amount of 353,000 af. The priority date of the water was to be not later than October 16, 1957.[18] This priority was based on the establishment of the irrigation project rather than the date that the reservation was established.

In exchange for development of NIIP, the Nation agreed to forgo 110,000 af of its San Juan River entitlement and to allow that water to be transferred through the San Juan Chama project to the Rio Grande River Basin. The NIIP was unique in several ways. First, the enacting legislation expressly condoned an inter-basin water transfer, supplying water from the Navajo Reservoir to the Rio Grande Basin. Even more remarkable is that this transfer delivers water from the Upper Colorado River Basin to the Lower Colorado River Basin in New Mexico.

The NN also agreed to reduce their consumptive use of NIIP water in times of shortage.[19] The settlement set forth that "[w]hen the physical supply of water in Navajo Reservoir is insufficient to meet the normal diversion requirement for delivery in Arizona, the Navajo Nation may temporarily forbear uses at the Navajo Indian Irrigation Project in New Mexico so that water may be delivered through NGWSP to Arizona."[20] The quantity of NIIP was recognized and incorporated into the San Juan River Settlement.

Water marketing is restricted In the NIIP agreement, and the included rights cannot be used outside of the state of New Mexico without the State's consent. This means that the Nation is required to act through its New Mexico Interstate Stream Commission subject to state law.[21]

The San Juan River Basin in New Mexico Navajo Nation Water Rights Settlement Agreement

As discussed above, NIIP failed to settle all of the Nation's claims to the San Juan River Basin in New Mexico. In 1975, the New Mexico state engineer filed a general stream adjudication which eventually led to the San Juan River Basin in New Mexico Navajo Nation Water Rights Settlement Agreement. The San Juan Navajo Water Rights Settlement recognizes roughly 600,000 af for agriculture, industrial, municipal, domestic and stock watering purposes. The San Juan River Basin Settlement is before the decree court in Aztec, New Mexico, which must rule on it by the end of 2013.

This settlement sought to settle all claims for all waters of the San Juan Basin once and for all. The Settlement also settled the Navajos claims to the other basins in New Mexico, including the Little Colorado River and the Rio Grande Basins. The cornerstone of the settlement was the Navajo-Gallup water supply project. The settlement permits the state of New Mexico to administer all rights in the

15 New Mexico, THE NAVAJO NATION WATER RIGHTS COMM'N, http://nnwrc.org/new-mexico.
16 Pub.L. 87-483, 76 Stat. 96, as amended, 43 USCS 615 et. Seq. (1976).
17 PHILIP L. FRADKIN, A RIVER NO MORE: THE COLORADO RIVER AND THE WEST 167 (1996).
18 Position Paper of the Ten Indian Tribes with Water Rights in the Colorado River Basin. Submitted to the Seven States in the Colorado River Basin. 1992.
19 San Juan River in New Mexico Settlement Agreement, U.S.-Navajo Nation, Apr. 19, 2005,, at paragraph 9.3.3.
20 Northwestern New Mexico Rural Water Projects Act, Pub. L. No. 111-11, § 10603(d), 123 Stat. 1368, (2009).
21 Consent Decree, New Mexico ex. rel State Engineer v. U.S., (No. CIV 75-184, 11 D. N.M., Aug. 9, 2010).

basin.[22] The New Mexico state engineer is permitted authority over water transfers, and "will consider evidence of historic use or non-use in determining whether [to grant] approval of an application filed under state law to change the purpose of place or use of irrigation water."[23] Furthermore, the Nation agreed to abide by the Upper Colorado River Basin Compact, limiting the its ability to use water in other states.[24]

Generally, the San Juan River Basin Settlement restricts uses in other states. Specifically, paragraph 9.11.2 (1)requires that Navajo Nation water rights in the Little Colorado River Basin and the Rio Grande River Basin cannot be "Exercised, transferred, leased or otherwise used to the extent that and only so long as, the rights are being supplied by the delivery of water diverted from the San Juan River Basin."

Zuni River Basin

The NN has claims to a small quantity of water in the Zuni River Basin in New Mexico, and recently filed a lawsuit to settle some of their claims.[25]

Arizona

In Arizona, the Navajo Nation has water rights to the main stem of the Colorado River, the Little Colorado River and the Gila River.[26]

Proposed Navajo-Hopi Little Colorado River Water Settlement Acts

Most recently the Nation has been attempting to settle all of its claims to the Gila and Little Colorado Rivers in Arizona. Several draft settlements have been proposed in recent years, including the Navajo-Hopi Little Colorado River Water Rights Settlement Act of 2012, introduced by Senators John McCain and Jon Kyl of Arizona.[27] The settlement, which would have settled claims to the Little Colorado River as well as claims to the C aquifer, required approval from both the Navajo Nation and the Hopi. The Navajo Nation voted to not approve the settlement.[28] Objections to the settlement included resistance to language that assured an ongoing water supply for the coal-fired Navajo Generating Station,[29] and a provision that was designed to limit the Nation's ability to sue for material damage from decades of water pumping by Peabody Coal.

The negotiation process and [ ] surrounding the failed LCR settlement has been highly controversial.

Utah

In Utah, the NN has claims to water from the upper basin of the Colorado River (most on the San Juan River).

San Juan Basin

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22 Paragraph 9.3: "The Navajo Nation and the United States agree that the State of New Mexico may administer in priority water rights in the San Juan River Basin in New Mexico, including rights of the Navajo Nation, as may be necessary for New Mexico to comply with its obligations under interstate compacts and other applicable law."

23 Paragraph 9.9 states in full that "Transfers of Water Rights. The New Mexico State Engineer will consider evidence of historic use or non-use in determining whether approval of an application filed under state law to change the purpose of place or use of an irrigation water right would be consistent with the provisions of section 72-5-23, NMSA 1978, as it may be amended."

24 Paragraph 9.12.1 "The San Juan River and its tributaries shall be administered consistent with the provisions of the Upper Colorado River Basin Compact (63 Stat. 31)."

25 See U.S. v. A&R Prod., No. 01cv00072 MV/LFG (D. N.M. filed Dec. 13,2012).

26 Arizona, NAVAJO NATION WATER RIGHTS COMM'N, http://nnwrc.org/arizona.

27 Leslie Macmillan, A Difficult Choice on Water, N.Y. TIMES, Apr. 6, 2012, http://green.blogs.nytimes.com/2012/04/06/a-difficult-choice-on-water/.

28 Sonja Horoshko, Navajo Council Rejects Proposed Water Settlement, FOUR CORNERS FREE PRESS, Sept. 27, 2012, http://fourcornersfreepress.com/?p=838.

29 Id.

The NN and the Utah government have a draft settlement agreement almost finalized. However, the federal government has to be a party to finalize the settlement. The proposed settlement would recognize an annual diversion of 314,851 af, of which 81,500 is depletion.[30]

Uses

Presently, the Navajo Nation's most pressing desired water use is for domestic development. However, the Nation is also engaged in and considering uses including for agriculture, water marketing, and for industrial and mining uses.

Domestic supply

Outmigration is a serious national concern for the NN. Thus, the development of basic infrastructure and a reliable domestic water supply is a national priority. John Leeper, former Director of the Navajo Nation Water Management Branch, emphasized the need for adequate domestic delivery systems to enable economic development. "[A]dequate water is a necessary, if not sufficient, condition for prosperity. And, if the proposed water projects can close these gaps by even a small percentage, the benefits that can be attributed to those projects are monumental."[31] The Navajo Department of Water Resources has developed a seven-part strategy to foster domestic development of water resources. The strategy includes developing regional water projects, improving small public water systems, rehabilitating small irrigation projects, completing NIIP,[32] and engaging in watershed restoration as well as drought mitigation and response.[33] Another important project is improving service to water haulers. Leeper estimates that in the Navajo Nation, hauling water costs about $18,000 per acre-foot.[34] Even with continuous development efforts, the Department of Water Management anticipates that Navajo families will continue to haul water into the foreseeable future. Leeper explains that:

> The Indian Health Service assumes that above a certain expense, homes become infeasible to serve from a public water system, and the Navajo Tribal Utility Authority will not accept operation of a system with fewer than three meters per mile. So, many families on the Navajo Nation will be hauling water for a long, long time.

In terms of regional water supply projects, the nation's long-term goals include several large regional water supply projects, including:

1. the Western Navajo Pipeline, (runs from Lake Powell to the Cameron Chapter)
2. developing an alternate water source for the Peabody Mine,
3. the Three Canyon Project,
4. the Ganado Regional Project,
5. the Central Navajo Utah Project,
6. the Farmington to Shiprock Pipeline (part of the ALP project to convey 4,600 of municipal water to Shiprock), and
7. the Navajo-Gallup Water Supply Project (will convey 37,000 acre-feet of water from Cutter Reservoir and the San Juan River and to 40 Navajo chapters in New Mexico and Arizona, the City of Gallup, and the southern part of the Jicarilla Apache Nation)

These projects are considered the fundamental structure of a domestic water development scheme.

30 UTAH CODE ANN. § 51-9-702 (2012).
31 Leeper, supra note 2, at 24.
32 NIIP was authorized in 1962 in tangent with the San Juan Chama Project to divert water from the San Juan River to irrigate approximately 110,000 acres (upon completion of the project).
33 Leeper, supra note 2, at .24-25.
34 Id. at 27.

Canyon De Chelly National Monument, Arizona. Photo: Julie Nania.

CHAPTER 5
FARMING

Agriculture is vital to the culture and economy of the Navajo people (NDWR, 2011). In this chapter we cover the farming of crops, while rangeland and livestock are covered in Chapter 6.

Agriculture on the Reservation generates some revenue and serves as an important subsistence resource. Farming on the Navajo Nation (NN) includes the Navajo Agricultural Products Industry (NAPI) as well as an abundance of small irrigation projects and family gardens.[1] According to the USDA's 2007 Census of Agriculture, there are over 10,000 Navajo and Hopi farmers and more than 500 native-operated farms (Yurth, 2009). The USDA acknowledges that these numbers are likely low; numerous small farms were excluded from the census because crops were used for subsistence instead of sale (Yurth, 2009). In general, agriculture on the NN is hindered by a lack of access to water resources for irrigation (Yurth, 2009).

In terms of large-scale farming, by far the largest operation on the Reservation is NAPI, near Farmington, New Mexico. NAPI is a tribal business enterprise with a mission "[t]o develop and manage a self-sustaining, profitable, and culturally and environmentally sensitive farming and agricultural processing business for the benefit of the Navajo Nation, the Navajo workforce, and regional and national economies." (NAPI, 2013) Nearly 70,000 irrigated acres of NAPI farmland produces mainly small grain, alfalfa, potatoes and corn, and specialty crops, including pumpkins and popcorn (Robertson, 2006). These crops are marketed both nationally and internationally under the Navajo Pride trademark. NAPI is profitable and contributes over $30 million annually to the economic base of the Four Corners region (NAPI, 2013).

NAPI is one of the few agricultural endeavors on the Nation not limited by available land or water (Robertson, 2006). NAPI oversees the operation of the Navajo Indian Irrigation Project (NIIP). The original agreement authorizing NIIP was completed in 1962 and the agreement provide ample water resources for the farming operation. NIIP entitlements were eventually incorporated into the 2010 San

1 In 1960, pursuant to Public Law 86-636, Navajo Tribe Transfer of Irrigation Project Works, Congress transferred title and operation and maintenance responsibilities for the Navajo irrigation systems from the BIA to the Navajo Nation.

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Juan settlement agreement which provided funding and diversions for 508,000 acre-feet annually (af) irrigation project (the actual annual diversion amounts to roughly 353,000 af) receiving water from the San Juan River from the nearby Navajo Dam and Navajo Reservoir (Robertson, 2006).[2] Presently, NIIP is incomplete; 40,000 acres of the original lands to be irrigated remain undeveloped. The Bureau of Reclamation (BOR) is responsible for development and maintenance of the project until it is completed in full. However, lack of sufficient funding is hindering NIIP completion (NDWR, 2011). When fully completed, NIIP will irrigate almost 111,000 acres of NAPI land.

In addition to NIIP, there are almost 90 smaller irrigation projects which have a combined potential to irrigate approximately 50,000 acres of land (NDWR, 2003). Some irrigation projects receive water from the San Juan River, some from alluvial wells and springs, some from surface water stored in reservoirs and others from rivers smaller than the San Juan River with no reservoir storage.

In addition to using irrigation water, many Navajo farmers rely on traditional techniques. Dryland farming, sometimes known as akchin farming, consists of more traditional techniques in which farmers take advantage of and plant in areas where water collects naturally instead of conveying water through irrigation ditches (additional discussion on akchin farming is provided below). Such techniques may include planting in alluvial flood plains along perennial and intermittent streams, planting on sand dunes watered by rainfall, or creating terraces to retain water near springs (NDWR, 2003; NDWR, 2011). These farmers typically plant for subsistence purposes.

The Navajo Department of Agriculture is the lead NN agency responsible for the planning, coordination, and management of all activities to protect Navajo agricultural resources (USDA, 2007). Although NAPI operates NIIP, the Bureau of Indian Affairs (BIA) is responsible for construction and maintenance of the system. The BIA has contracted with the Bureau of Reclamation (BOR) for some of these maintenance responsibilities but remains accountable for the oversight and compliance of the project.[3]

Local farming operations are overseen by NN farm boards.[4] These farm boards build capacity and promote the coordination of the NN with private entities and state and federal agencies. Farm boards play an important role in composing and reviewing plans for irrigation system and also provide information, education and training on all aspects of agricultural production, irrigation management, and even the economic side of farming (including marketing).

Farm boards are composed of a Chairperson and local representatives. Local chapter representatives to the farm board attend chapter meetings and report to the chapter on the activities of the farm board. Farm boards Thus, Farm Board representatives serve as the ties between the Board and local communities.[5]

5.1 Potential Climate Change and Variability Impacts on Farming

Climate change and variability impacts on crops may include both direct effects on plants as well as effects on what are sometimes called ecosystem services or ecosystem disservices to crops (Power, 2013; Zhang et al. 2007). Ecosystem services include water provision, soil structure and quality, and pollination. Ecosystem disservices include weeds, pests, and pathogens. Both direct impacts on plants

2 On the Navajo Reservation, the NIIP is one of the largest water development projects. NIIP and the San Juan Diversion were jointly authorized in 1962 through Public Law 87-483. The public law authorized the Secretary of Interior (SOI) to construct, operate, and maintain NIIP primarily to provide irrigation water to approximately 10,630 acres of land. NIIP was allotted 640,000 af in a 1956 State Water Use Permit and approval to divert 508,000 af of water in a 1974 contract with the SOI.

3 P.L. 87-483 authorized the act on June 13, 1962; the project was amended by P.L. 91-416 on September 25, 1970.

4 Farm boards are established within the Executive Branch of the NN under the recommendation of the Resources Committee. Each farm board must submit a proposed Plan of Operation and can be composed of several chapters or districts.

5 Reviewer Karletta Chief notes that the effectiveness of farm boards can vary greatly. Effective farm boards could serve as key components of the planning and implementation of climate change adaptation strategies on the NN.

Key Points: Potential Climate Change and Variability Impacts on Farming

- Increasing length of freeze-free growing season
- Rising temperatures may either lead plants to approach temperature optima or lead to heat stress
- Potential effects on nutritional quality in some cases
- Changes in water availability for crops
- Changes in soil quality and soil moisture content
- Disruptions or changes in pollination
- Possible introduction of new weed species
- Possible northward shifts in ranges for different insect pests

and impacts on ecosystem services and disservices to crops may result from climate changes and variability resulting in rising air temperatures, rising carbon dioxide (CO2) levels, and changes to precipitation regimes. Given anticipated increases in drought frequency, severity, and duration in the Southwest (SW), impacts related to water provision will likely be of particular concern to Navajo farmers.

Projecting climate change and variability impacts on crops can be challenging because responses can be species and location specific, contend with multiple changing variables, and require addressing ecosystem linkages at various scales. We note some potential climate change impacts below. However, for more in depth discussion of these and other potential impacts, we refer readers to a 2012 U.S. Department of Agriculture (USDA) report, *Climate Change and Agriculture in the United States: Effects and Adaptation*.

Direct impacts on plants

Plants have base temperatures at which growth starts, maximum temperatures at which growth stops (wilting point), and optimum temperatures at which growth is the fastest (Walthall et al. 2012). These cardinal temperatures differ among crops and among different growth stages within a single crop. Optimal temperatures for the reproductive stage, for example, are often lower than for the vegetative stage (Walthall et al. 2012). Barring other factors such as water availability, if temperatures start to approach optimum values, crop yields could increase. However, as air temperatures rise above optimum values, crop yields typically decrease at accelerating rates (Walthall et al. 2012).

Rising air temperatures can also increase the length of the growing season and could thus provide more time for increased biomass production if optimal temperatures are not exceeded (Walthall et al. 2012). At the same time, rising air temperatures will increase crop water demands. If these demands cannot be met, plant growth could be adversely affected. Because some crops need a minimum amount of "chill time" for growth (Frisvold et al. 2013), warming temperatures could potentially reduce yields.

Native corn and corn pollen being sold at the Window Rock flea market. Photo: Teresa Showa.

Apart from temperatures, plant photosynthesis involves the uptake of CO_2. More than 95% of plants use what is known as the C_3 photosynthetic pathway (Walthall, 2013). Most other plants, including corn, use what is known as the C_4 photosynthetic pathway. Again, barring other factors such as water availability, for C_3 plants, photosynthetic rates will increase with rising CO_2 levels, and thus higher CO_2 levels can increase photosynthesis and plant growth (Walthall et al. 2012). For C_4 plants, in contrast, photosynthetic rates are saturated at current CO_2 concentrations and so any response is likely to be less strong (Walthall et al. 2012).

Rising CO_2 levels could also affect crop nutritional quality. Some non-nitrogen fixing crops grown at elevated CO_2 concentrations have lower protein contents although the exact mechanism resulting in this is unknown (Walthall et al. 2012; Luber et al. submitted).

Ground level ozone can be produced both naturally and as a secondary pollutant. It is formed through photochemical reactions in which nitrogen oxides and carbon monoxide (generated by, for example, fossil fuel combustion) react with volatile organic compounds (VOCs) (Walthall et al. 2012). Ground level ozone is the primary component of urban smog (Walthall et al. 2012). Both ozone and its precursors can be transported hundreds of miles, impacting farmlands (Walthall et al. 2012).

Photo: Teresa Showa.

Ozone taken up through leaf stomata can interfere with photosynthesis and yield (Walthall et al. 2012). Some studies suggest that yields of crops such as alfalfa, potatoes, and wheat have already been adversely impacted by ozone (Walthall et al. 2012). Higher temperatures may result in increased generation of ground-level ozone because of the temperature dependence of ozone forming reactions and because biogenic emissions of VOCs, which are components of ozone forming reactions, may increase with rising temperatures (Bell et al. 2005). Large fires can also be a source of ozone precursors, and, in the SW, climate change and variability are anticipated to lead to longer fire seasons and increases in fire frequency and areal extent (see Chapter 3).

Impacts on ecosystem services to crops

Ecosystem services to agriculture enhance productivity or decrease production costs. One such service is water provision to crops. In the SW, it is anticipated that climate change and variability will result in more winter precipitation falling as rain rather than as snow, earlier snowmelt, and, possibly in some locations, lower precipitation (see Chapter 3). All of these could result in less runoff in the late spring to late summer. In areas that depend on snowmelt for irrigation, this could lead to irrigation water supply challenges. Additionally, lower soil moisture by early summer may result from a combination of decreased runoff as described above and increased evapotranspiration due to warmer temperatures and a reduced period of snow cover leading to a longer period of exposed vegetation and ground (Cayan et al. 2013; Painter et al. 2010). This would mean less available soil water for crops, particularly for crops grown in soils with limited water holding capacity (Walthall et al. 2012).

Anticipated increases in drought frequency, severity, and duration in the Colorado River basin would also affect water provision for crops. Direct climate change effects on groundwater are still not well understood (Taylor et al. 2013). However, depletion of groundwater supplies can occur as a result of non-climatic factors such as groundwater pumping.

Changes in precipitation regimes can also affect soil erosion and quality. If climate change and variability results in higher intensity precipitation events, this could lead to greater soil erosion and associated loss of soil organic carbon and nutrients, decreasing soil fertility (Walthall et al. 2012). If more winter precipitation falls as rain rather than as snow, this could potentially lead to more rain events overall with associated erosion impacts. Drought can also affect soil erosion. For instance, drought may cause reductions in plant cover due to limited water supplies leading to wind erosion of exposed soils.

Another ecosystem service that could be affected by climate change and variability is pollination. Approximately 75% of major food crops worldwide are pollinated by animals, in particular by insects (Power, 2010). If pollinators and flowering plants react differently to rising air temperatures, this could potentially create pollination mismatches with adverse consequences (Walthall et al. 2012).

Rising air temperatures may also affect pollinator activity patterns. One modeling study of pollination patterns under rising temperatures demonstrated differential responses among the pollinator species studied. Some species provided increased pollination services while others, including the honeybee (a major pollinator worldwide), provided fewer pollination services (Walthall et al. 2012). Increased diversity in native pollinator species could thus potentially provide a buffering effect for agricultural systems while agricultural systems in which the honey bee is the main crop pollinator could experience reduced pollination (Walthall et al. 2012). Even without considering climate change, the conservation of wild pollinator habitat adjacent to agricultural fields has been shown to improve pollination and increase crop yields (Zhang et al. 2007).

Impacts on ecosystem disservices to crops

Ecosystem disservices to agriculture decrease productivity or increase production costs (Zhang et al. 2007) and can include weeds, animal pests, and pathogens, which globally are responsible for 34%, 18%, and 16% of crop losses, respectively (Walthall et al. 2012; Oerke, 2006).

Climate change and variability impacts on weeds may be similar to those on crops. The few studies done on crop-weed competition showed that in a C_3 photosynthetic pathway crop vs. a C_4 weed situation, increased CO_2 levels favored the crop while in a C_4 crop vs. C_3 weed situation, higher CO_2 levels favored the weed (Walthall et al. 2012). Specific weed changes were not discussed in the USDA Climate Change and Agriculture report (Walthall et al. 2012). However, the report notes that the diversity and distribution of weed threats may change including the introduction of weed species not currently found in the United States (US) and that as a general rule of thumb, managers might want to look to southern locations to see what future weeds might be.

Climate change and variability may affect animal pests by creating favorable pest conditions (Walthall et al. 2012). In some cases, warmer winter temperatures can increase pests' winter survival rates (Walthall et al. 2012). Longer growing seasons may also allow insects to produce more generations per year, increasing insect abundances, and possibly promoting resistances to pesticides.

Like crops, insects have critical temperatures beyond which they do not thrive; therefore, rising temperatures may not be advantageous for all insect pests. In terms of geographic distribution, common models show expansion or northward shifts in ranges for different insect pests under rising temperatures (Walthall et al. 2012). Increased precipitation variability may also lead to more pest outbreaks and crashes, although extreme drought and extremely wet years may be unfavorable to insect pests (Walthall et al. 2012). Participants in ITEP's Southwest Climate Change Workshop reported that they are already observing new species of insects eating whole fields and destroying crops (Wotkyns, 2011).

Projecting crop pathogen responses to climate change is challenging because the plant host, pathogen, and disease vector (if a vector is involved) are all interacting separately with a changing environment and with one another. Outcomes depend on the specific species, location, as well as with what is happening in adjacent locations. For more discussion of climate change impacts on crop pathogens, we refer readers to the USDA Climate Change and Agriculture report (Walthall et al. 2012).

5.2 Vulnerability and Adaptive Capacity Factors

Climate, hydrologic, and ecosystem changes will interact with socioeconomic, infrastructural/ technological, political/institutional, socioeconomic and other vulnerability/adaptive capacity factors (Chapter 2) to create or help lessen impacts on the ability of Navajo farming both to provide nutritional security and to provide a source of revenue. We discuss some examples of these factors in more detail below; however, this is not meant to be a comprehensive discussion but rather a basis for identifying vulnerability and adaptive capacity factors as adaptation planning occurs.

Access to water for irrigation

Access to water is crucial for farming on the NN. In the future with climate change and variability, drought is anticipated to increase in frequency, severity, and duration. The vulnerability of Navajo farmers to drought depends in part on whether or not they have access to irrigation water and, if they do, the source and priority of the irrigation water. Thus, water rights issues that face the NN will have a major impact on the extent that water issues factor into agricultural needs (NDWR, 2011).

Certain existing provisions in water rights agreements will have implications for farming. For instance, under the terms of the NIIP P.L. 87-483 agreement, the NN must share in San Juan River shortages with other users. Thus, during shortages NIIP may face reduced water deliveries (see Case Study: NIIP Water Rights). However, overall, in terms of access irrigation water access, NAPI is considered to have low risk rights to San Juan River water (NDWR, 2003). Additionally, funding for the rehabilitation of Hogback and Fruitland irrigation projects was included as part of the San Juan Settlement Agreement, reducing water waste and enhancing delivery in those systems and enhancing local adaptive capacity (NDWR, 2011).

Irrigation infrastructure

The state of irrigation infrastructure will affect its usability. Insufficient funding is affecting not only the completion of NIIP as discussed above, but also NAPI's ability to maintain and repair NIIP's aging infrastructure. The backlog of deferred maintenance is growing, which could potentially lead to disruptions in water deliveries and decreases in crop yields (NDWR, 2011). A long-range plan for NIIP is being developed by the NN, the BOR and the BIA. It would be beneficial to consider funds for infrastructure repairs and potential climate change and variability impacts as part of this planning. Infrastructure repairs are discussed further below in the section 5.3 on farming adaptation strategies.

In terms of smaller irrigation projects, the NDWR has categorized irrigators and dry land farmers into four qualitative categories of drought vulnerability based on irrigation access and type of water source (USDA, 2007). The lowest drought risk category consists of irrigation projects, like NIIP, relying on San Juan River water (5 projects total/11,115 acres apart from NIIP) (USDA, 2007; NDWR, 2003). Irrigation projects in the low to medium drought risk category are fed by groundwater from alluvial wells or springs, which are generally stable sources of water even during short dry cycles (13 projects total)

Case Study:
NIIP Irrigation Water Rights

Article III of the NIIP Contract requires that whenever the SOI anticipates a shortage of the available water in storage at Navajo Reservoir, contractors mush share in the available water in proportion to the other contractors. In 2002, in the midst of an extreme drought, the NN requested that the Regional Director of the Upper Colorado Region declare a shortage at Navajo Reservoir. After the SOI declined to declare a shortage, the NN took action independently to reduce the likelihood that the NIIP water delivery would be reduced.

First, the NN requested and was granted a reduced San Juan River Recovery Implementation Program release. Next, NNDWR lobbied the BOR to obtain consent for reduced minimum flow releases to meet a court arrangement with local fly-fishing interests. The NN also persuaded the NM State Engineer to install additional metering devices for withdrawals from the San Juan River. Finally, the NN worked with the major users and administrative entities on the San Juan River (including the Jicarilla Apache Nation) to develop a shortage sharing criteria from the Navajo Reservoir which protects NIIP. This proactive approach is a great example of protecting against the potential implications of drought in the Four Corners. (NNIRC, 2003)

Photo: Julie Nania.

(USDA, 2007; NDWR, 2003). In a climate change context, however, such water sources may become less stable. The medium to high drought risk category consists of farmers that use storage reservoirs fed by surface water (the highest drought risk category consists of farmers using "run of river" irrigation projects without storage and dry land farmers, the majority of farmers on the Reservation) (USDA, 2007).

For many small irrigation systems, funding has become an issue. For about 100 years, the BIA oversaw construction and maintenance of the small irrigation systems on the Reservation (USDA, 2007). However, over the years, the BIA's budget has progressively decreased, which has negatively impacted the availability of funds for irrigation systems. As a result, many of the existing systems on reservations have deteriorated to such a degree that they are no longer in service (USDA, 2007). This in turn has led to the deterioration of associated institutions that oversee the operation and maintenance of the systems (NDWR, 2011).

The Natural Resources and Conservation Service (NRCS), BOR, BIA, NDWR and others have also identified a number of additional challenges for small irrigation projects (USDA, 2007). Many small irrigation systems were expanded beyond sustainable hydrologic limits, resulting in inadequate water supplies for irrigators. Some irrigation systems are trapped in a cycle of revenue loss; insufficient operation and maintenance results in inadequate water control, which results in more idle lands, which results in a further decline in revenue loss (NDWR, 2011). Local operating entities, such as water users' associations, may also be insufficient to administer the system.

To help address irrigation deficiencies, the NN Tribal Council approved a farm board plan for irrigators to collect assessments of irrigation project operation and maintenance (USDA, 2007). These assessments will evaluate irrigation systems to determine which have the best chance sustaining themselves hydrologically, institutionally, and agronomically (USDA, 2007). Substantively, irrigation assessments will include farming history; agricultural economics; water supply (i.e., surface water, groundwater, and reuse); capacity to pay water use assessments; system operation and overall efficiency; environmental compliance; budget requirements; implementation plans; education needs; and monitoring plans. The BOR has already conducted rehabilitation studies for the Fruitland, Cudei, and Hogback irrigation projects (NDWR, 2011). Finally, as the Nation works on rehabilitating irrigation projects, other considerations may include whether or not a particular type of irrigation system results in irrigation-induced erosion (Walthall et al. 2012).

In the planning process consideration of non-climatic factors on irrigation water supplies will also be important. For instance, direct climate change effects on groundwater are still not well understood. However, depletion of groundwater supplies can occur as a result of non-climatic factors such as groundwater pumping for irrigation (see Chapter 4 for additional discussion of groundwater drawdown). A USDA Farm and Irrigation Survey found that from 1994 to 2008, the average irrigation well depth to groundwater increased in all states except for Nevada (Frisvold et al. 2013). Increases in depth to groundwater can result in higher costs for irrigators to pump the water to the surface and may necessitate lowering pumps within wells, deepening wells, or eventually finding alternative water sources, all of which result in additional costs. For more information on Reservation water resources see Chapter 4, Water Resources.

Communication of climate change and variability information and agricultural education and outreach are also important in terms of building adaptive capacity, particularly in the Navajo language at the local community level where these are terms that are not translated.

The fourth annual Navajo Agricultural Conference held just this past April 2013 had two themes: drought management and climate change. The conference featured speakers from a variety of Navajo programs and from the US Geological Survey (USGS), SWCA, the Southwest Climate Science Center, and the University of Colorado to discuss up to date drought and climate information. The Navajo Nation Traditional Agricultural Outreach (NNTAO) project of the nonprofit organization Diné Inc. provides technical assistance and support for limited resource NN farmers and ranchers (NNTAO, 2013 a). NNTAO programs include the Western Navajo Nation Beginning Farmers and Ranchers Program which provides training in good farming and ranching practices, forums for sharing farming and ranching experiences and mentors for younger farmers and ranchers (NNTAO, 2013 a). NNTAO also provides training on how to use Finpack and Quicken financial planning and management software (NNTAO, 2013 b).

5.3 Potential Adaptation Strategies for Farming

Farming adaptation strategies can utilize and build on the adaptive capacity factors noted above. On the NN, strategies will likely center on water-related issues and protecting vulnerable lands (Wotkyns, 2011). Relief offered during severe drought will assist in agricultural viability (Wotkyns, 2011). Adaptation approaches can include water management and soil erosion management techniques. Other possible approaches include selection of crop species appropriate under potential climate scenarios, diversifying crop production and monitoring for shifts in the distribution of or emergence of new weeds, pests, and pathogens.

Adaptation strategies should be adapted only if suitable for the farm or region addressed. For instance, small-scale farms may not rely on irrigation at all, and thus irrigation reform and management adaptation strategies may be ill-suited to these areas. As illuminated by reviewer Karletta Chief, local farmers and dry land farmers typically do not depend on storage or reservoir operation. Thus, recommendations for reservoir maintenance may be unnecessary as well. Other communities may have opportunities to expand irrigation, particularly with the new Navajo-Gallup pipeline development. These and other considerations should be incorporated into the adaptation planning process, discussed in Chapter 2.

Water management and planning

As noted above, water provision to crops may become more challenging on the Nation under future climate change scenarios. Water management adaptation strategies can include: dryland farming techniques, the repair and improvement of irrigation systems, and limited irrigation techniques. Dryland farming involves farming in arid regions without the use of irrigation water. Dryland farming techniques focus on increasing water absorption and decreasing the loss of soil moisture. These techniques are also known as akchin techniques on the Reservation.[6]

Northern Arizona University provides a fact sheet on Hopi agriculture which describes akchin farming as a method where "Crops of corn, squash, and melons are planted in areas where floodwater spreads out at the mouth of an arroyo (gully)." (NAU, n.d.) The Ak-Chin tribe is descended from the Hohokam and has a long history of successful farming in very dry conditions. The modern Ak-Chin Tribe has a reservation south of Phoenix which runs the successful Ak-Chin Farms enterprise.

The Nation could make use of and build on Ak-Chin farming techniques and knowledge. Two dryland farming techniques noted in a 1998 primer by Creswell and Martin, *Dryland Farming: Crops and Techniques for Arid Regions* include clear fallowing and crop rotation.

Clear fallowing involves maintaining an area that is clear of any growing vegetation in a way that stores water from one year for use in the next. The land is worked to make the make the soil loose and permeable so that it can soak up rainfall while at the same time stubble (crop residue) and soil mulch is maintained to minimize evaporation. The worked area must be maintained free of weeds, which can use as much water or more water than crops. According to the Creswell and Martin primer, families in India that have clear fallowed 5 to 6 acres each year have been able to avoid drought-induced famine. Furthermore, crop loss during the fallow year had been offset to a large extent by increases in yields during the crop year.

Crop rotation in the context of dryland farming often refers to rotating between water conserving crops

6 Northern Arizona University provides a fact sheet on Hopi agriculture which describes akchin farming as a method where "Crops of corn, squash, and melons are planted in areas where floodwater spreads out at the mouth of an arroyo (gully)." (NAU, n.d.) The Ak-Chin tribe is descended from the Hohokam and has a long history of successful farming in very dry conditions. The modern Ak-Chin Tribe has a reservation south of Phoenix which runs the successful Ak-Chin Farms enterprise.

and water intensive crops. The decreased moisture use of a water-conserving crop can help maintain a moisture reserve in the soil that can contribute to the success of more water intensive crop planted in the subsequent year. For more in-depth information on these and other dryland farming techniques, we refer readers to the Creswell and Martin article (Creswell and Martin 1998).

In terms of irrigated agriculture, the Nation currently has a number of irrigation systems that are deteriorating or that are no longer in use. Rehabilitation and development of these systems could be significant adaptation strategies if climate change considerations with respect to, for example, impacts on potential source waters are taken into account (University of Colorado, 2009). In its 2000 Navajo Water Resource Development Strategy, the NDWR notes that institutional changes need to occur and that irrigators "must be willing to organize water users associations through their local farm boards and accept added responsibility for operation and maintenance [of the irrigation systems]". (NDWR, 2000) In the 2003 Navajo Drought Contingency Plan (DCP) (NDWR 2003) NDWR recommendations included improving reservoir operations and preparing Water Conservation and Management Plans for the various irrigation projects. These plans would address: "increasing irrigation efficiency, incorporating water users associations, improving operation and maintenance, establishing ditch riders, repairing and improving the hydraulic structures, pre-irrigating, increasing the water holding capacity of the soil, improving the prediction of the timing and duration of the peak runoff, drilling shallow alluvial wells, and other measures." (NDWR 2003)

Limited irrigation techniques are adaptation strategies that can be used when water is available for irrigation but the quantities are constrained. Such constraints may exist because of limited irrigation well capacities, restricted allocations, or reduced surface water supplies or storage (Schneekloth et al. 2009). We include some examples below and refer readers to a Colorado State University extension fact sheet on limited irrigation management for more detailed information and additional examples (Schneekloth et al. 2009).

One limited irrigation practice is to reduce irrigation during growth stages that are less sensitive to water stress, so as to save water for use during growth stages that are critical in terms of yield. For instance, for corn, water stress during the early stages has less effect on yield than water stress during the tassel to silk stages. Another technique is to irrigate fewer acres to the capacity needed by the crop rather than irrigate more acres at less than optimum capacity. In many cases, this leads to greater net returns (Schneekloth et al. 2009). Diversifying crops planted so that they have different timings of peak water needs is an additional strategy that spreads water requirements throughout the growing season (Schneekloth et al. 2009).

Photo: Teresa Showa.

In its 2003 DCP, the NNDWR provided for measures to adapt to and mitigate the effects of drought on Navajo farmers and ranchers. The recommendations included: improving reservoir operation and preparing water conservation and management plans; establishing an effective grazing policy and improving range management; providing additional assistance to ranchers in the form of information distribution, livestock sales, and USDA grain storage facilities, and improving the reliability of livestock supplies (NDWR, 2003). The DCP also included an assessment of the drought vulnerability of the Navajo Tribal Utility Authority (NTUA) municipal water systems. This vulnerability assessment can help to prioritize adaptation efforts.

Water rights issues the Navajo currently face will have a major impact on the extent that water issues factor into agricultural and rangeland needs. To date, NIIP has not reached its full potential due to lack of sufficient funding. As discussed above, the NN has made several specific recommendations that would enable NIIP to be fully functional including: increasing the annual construction funds to finish the distribution systems and on-farm components, increasing tribal employment by vertical integration, and increasing funding for on-going operation and maintenance. A long range plan for NIIP is being developed by the NN, BOR, and BIA.

On a larger scale, securing access to additional water sources will help ensure sufficient quantities of water are available for irrigation on the Reservation. When negotiating Navajo water rights settlements, the NN should carefully weigh any shortage sharing agreements or infrastructure components in the agreements. With an increased likelihood of drought in the future, shortage agreements may be more of a risk than they have been in the past. The source of the settlement water supplies could either be a risk or a positive adaptive capacity factor. Finally, like in the San Juan Settlement Agreement, the NN could potentially include irrigation and infrastructure monies to rehabilitate infrastructure or implement irrigation adaptation strategies.

Soil management

Soil degradation and erosion could potentially increase under climate change. Adaptation strategies thus include erosion control. Crop rotation was noted above in a water-conserving context. However, crop rotation can also involve the rotation of erosion resistant and susceptible crops to control erosion (see strip cropping below) and planting crops that are not related during successive seasons to decrease the build-up pests, virus, molds, etc. Crop rotation may also allow time for nutrients depleted during the growing of a certain crop to be replenished.

Strip cropping can also help to prevent erosion. Strip cropping involves planting alternating strips of crops that expose soil and permit erosion with crops that inhibit erosion (i.e. have dense foliage, dense grasses or legumes, hay crops nearing the end of their first growing season) (Creswell and Martin 1998; NRCS, 2008). This technique both increases water absorption and reduces erosion. Erosion resistant crops are rotated with those that are susceptible to erosion (Creswell and Martin 1998).

Crop residue management and cover crops are other erosion control techniques (Walthall et al. 2012). Precision conservation involves targeting erosion control techniques to portions of the landscape that are particularly vulnerable and takes into account factors such as slope gradient and length and soil properties (Walthall et al. 2012)

Farming techniques such as low-till and no-till farming can increase the amount of carbon stored in soil, reducing the amount of CO_2 released from tilling. State and USDA grants may be available to promote these conservation practices (University of Colorado, 2009).

Other measures

Another adaptation strategy is crop and variety selection. Some crop species or varieties within a single species may be more tolerant of higher air temperatures or limited water supplies or may be more resistant to particular diseases (Walthall et al. 2012). In addition, traditional food crops are often better adapted to the local environment and can be a source of climate change and variability resilience.

Certain crops, particularly corn, hold an important religious and cultural importance for many Navajo. Corn pollen is sacred to Navajos and is used in daily sunrise prayers, blessings, healings, and is used in various Navajo ceremonies. Corn is Navajo food staple and used in nearly every Navajo dish (i.e. blue corn mush, kneel-down bread, Navajo cake) and making of these dishes are central in Navajo ceremonies and rites of passages (i.e. Navajo wedding, coming of age, and first laugh). Any reduction of corn planting may result in substantial backlash. More appropriate adaptation efforts may focus on dryland farming, securing additional water supplies, or other adaptation strategies which do not require corn crop reductions.

Photo: Teresa Showa.

If new crops are introduced as the climate changes, farmers could potentially benefit from training related to growing the new crops. Crop diversification, as noted above, can also provide both water management and natural pest and pathogen control benefits and can help lessen the risk of severe economic loss in the case of drought or other climate-related disturbances (Walthall et al. 2012). Monitoring for shifts in the geographic distributions of or the emergence of new weed, pest, and pathogen species could help with response to potential threats to crops from these sources.

One potentially lucrative mitigation measure is the use of renewable "biomass" resources, including crops, agricultural, forestry, and animal wastes (University of Colorado, 2009). These sources of material can be used as a low-carbon energy source and could potentially provide an alternative for the agricultural sector to engage in climate change mitigation in a profitable way (University of Colorado, 2009). Many state renewable portfolio standards have biomass listed as a resource under several grant, tax, and other incentive programs (University of Colorado, 2009). On the NN, biofuels are really only potentially viable if produced as a byproduct for small-scale biofuels on location (see Chapter 12). However, there may be other potential uses for biomass, including for mulching to help prevent evaporation.

BOR's Water Management and Conservation Program funded a water management plan to describe water supply and demand, constraints on the systems, and alternatives. The result of the water management plan was a memorandum of understanding (MOU) between the NRCS, BIA, BOR, the NN, the farm board, the irrigators and other stakeholders (University of Colorado, 2009). Recommended next steps from the process include a water conservation plan and a technical assessment to provide guidance for BOR and the BIA to ensure NEPA compliance. In addition, NRCS in collaboration with water users can pursue EQIP opportunities for on-farm improvements (University of Colorado, 2009). It is also important to include rehabilitation and development of local irrigation and livestock water systems as part of adaptation and mitigation to drought (University of Colorado, 2009). Potential Adaptation Strategies for Farming.

The above discussion has focused on adaptation related to the ability of the Navajo farming sector to provide both nutritional security and revenue for NN residents in response to potential climate change impacts that include direct impacts on plants as well as impacts on ecosystem services and disservices to crops. However, in addition to receiving ecosystem services and disservices, agricultural ecosystems also provide ecosystem services (i.e. carbon sequestration) and disservices (i.e. nutrient runoff, pesticide poisoning of non-target species). As part of adaptation planning, it is important to consider how different adaptation strategies may affect the services or disservices provided by agriculture (see Chapter 2).

Communication also needs to be improved, including the distribution of climate and market information to Navajo ranchers (University of Colorado, 2009). Distribution of climate information has minimal cost and provides a large benefit to ranchers. For example, it is estimated that public announcements on the three major radio stations cost less than $14,000 per year (University of Colorado, 2009). Public announcements and the Navajo Monthly Drought Status Report can inform farmers and ranchers of drought alerts, warnings, and emergencies. It would also be useful to have access to agriculture market reports (University of Colorado, 2009).

It is crucial that communications and educational material be provided in the Navajo language. General educational materials in Navajo could help to further understanding about climate change and variability generally and could be used to disseminate information about adaptation strategies. Radio stations, including KTNN, could be used to reach isolated communities and to ensure that basic information is widely distributed.

Finally, it would be useful for the NN to develop an Agricultural Workgroup which would include representatives from livestock and farming associations, land management offices, agricultural water management agencies, and fish and game programs (New Mexico Drought Task Force, 2005). The purpose of the group would be to prepare mitigation and response plans for potential drought impacts directly to the agricultural sector (New Mexico Drought Task Force, 2005). One of the tasks from the Workgroup could be to utilize the water reuse investigation to assess opportunities to reuse water for recreation, athletic fields, agriculture, and wildlife proposed by NDWR and Reclamation.

Water Management Strategies
• Consider settlement terms which may have implications for access to water during shortages and drought. Focus on the source of water, shortage agreements, and intake infrastructure. Consider funding for climate adaptation strategies and infrastructure development as part of the settlement agreement.
• Continue with and complete localized assessments of irrigation project operation and maintenance
• Select and strategically repair viable irrigation systems
• Avoid irrigation systems which result in irrigation-induced erosion
• Consider non-climatic factors which may compound stress on irrigation water supplies (i.e., groundwater draw-down)
• Build adaptive capacity through communication and outreach
• Use akchin (dryland) farming techniques including clear fallowing and crop rotation (rotating between water conserving crops and water intensive crops)
• Use limited irrigation techniques (reduce irrigation during growth stages less sensitive to water stress; irrigate fewer acres to the capacity needed by the crop; diversify crops so that they have different timings of peak water needs
• Work on institutional changes through Water Conservation and Management Plans described in the DCP
Soil Management Strategies
• Crop rotation involving the rotation of erosion resistant and susceptible crops
• Strip cropping (planting alternating strips of crops that expose soil and permit erosion with crops that inhibit erosion)
• Use crop residue management and cover crops
Crop Services Strategies
• Use crop variety and selection techniques
• Select traditional food crops which do well in local conditions
• Monitor for shifts in pests and pathogens
Other Strategies
• Use biomass as mulch or to create fuel for farming
• Develop an Agricultural Workgroup with representatives from livestock and farming associations, land management offices, agricultural water management agencies, and fish and game programs

Table 5.1. Potential Adaptation Strategies for Farming.

5.4 Potential Funding and Other Support

The USDA provides several grant and loan programs for qualified domestic water purveyors in the agricultural sector (University of Colorado, 2009). Even so, due to the high demand, these programs are very competitive and are not able to meet the needs of everyone. In addition, many of the Navajo users do not qualify due to cost sharing requirements and other program requirements (University of Colorado, 2009).

The Resource Conservation and Development Program is an important authority and has a NRCS field office in St. Michaels, Arizona. This program supports priority projects across the five soil and water conservation district offices on the Navajo Reservation (University of Colorado, 2009). The USDA Environmental Quality Incentive Program (EQIP) is one of the main funding sources for on-farm water conservation projects (University of Colorado, 2009). Additionally, in the past, the NN has received assistance from the USDA's Enterprise Zone program. This program is available for areas that have special economic needs and it provides resources for infrastructure and institutional improvements. Participating in the Enterprise Zone program improves access to additional assistance from USDA rural development and other programs.

Funding Opportunity	Area of Focus	Source	Enablement and website
Agricultural Conservation Reserve Program	Cost-sharing of livestock and pasture water resources	USDA	Public Law 100-387 http://www.fsa.usda.gov/FSA/webapp?area=home&subject=copr&topic=crp
Rural Utilities Services	Provides grants for rural infrastructure development and increases job availability	USDA	http://www.rurdev.usda.gov/Utilities_LP.html
Disaster Assistance Programs	Provide support for crop loss, livestock loss, and damaged farm property	USDA	http://www.fsa.usda.gov/FSA/webapp?area=home&subject=diap&topic=landing
Federal Crop Insurance Act	Insurance assistance for commercial crops	USDA	http://www.rma.usda.gov
USDA Environmental Quality Incentive Program (EQIP)	Financial and technical assistance to agricultural producers to help plan and implement conservation practices	USDA	http://www.nrcs.usda.gov http://wps/portal/nrcs/main/?ss=16&navid=100120310000000&pnavid=100120000000000&position=SUBNAVIGATION&ttype=main&navtype=SUBNAVIGATION&pname=Environmental%20Quality%20-Incentives%20Program
Agriculture on Indian Lands	Protect and restore agricultural lands	DOI, BIA	https://www.cfda.gov/?s=program&mode=form&tab=step1&id=67dfbc87514d56e54f2ddd4318cf7831

Table 5.2. Federal assisted programs for domestic water purveyors in the agricultural sector.

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Photo: Julie Nania.

CHAPTER 6
RANGE RESOURCES

Livestock grazing is a fixture of the Navajo landscape and economy. Navajo ranchers have contended with droughts, harsh winters, wildfires, erosion, dust storms, disease, disappearing vegetation, desertification, range degradation, bad economies, and cultural change. Despite these challenges, they continue to raise horses, cattle, sheep, and goats in one of the driest regions of the United States (US).

6.1 Potential Climate Change and Variability Impacts on Range Resources

Changes to rangeland have deep implications for Navajo culture and traditional forms of livelihood. Climate changes including increasing CO_2 levels, rising temperatures, greater precipitation variability, and changing fire regimes may contribute to continuing changes in forage composition, productivity, and quality on Navajo rangelands. Sometimes one variable (CO_2, temperature, precipitation, and fire) may lead to changes in one direction, while a second variable will lead to changes in a different direction. Long-term changes will depend on how these different variables interact. For instance, if there is a loss of cool-season grasses, native warm-season grasses may increase, requiring a shift in seasons of grazing. The loss of cool-season grasses may be contributed to the increased dominance of non-native species, including cheatgrass.

Photo: Julie Nania.

Forage

Tribes in the Southwest (SW) have also have made their own observations about changes in the Four Corners rangeland forage due to drought. At the Institute for Tribal Environmental Professional's (ITEP) 2011 Southwest Tribes and Climate Change Workshop, participants from various SW tribes shared local knowledge about how their traditional areas were being impacted (Wotkyns, 2011). Participants noted

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that the nature of the rangeland is changing; cool season grasses are being lost, leading to a reduction in livestock's food supply (Wotkyns, 2011). Additionally, a general shift in the rangeland to those species better suited for drier conditions was noted (Wotkyns, 2011).[1]

Increased CO_2 concentrations in the atmosphere could potentially lead to increased plant growth (Frisvold et al. 2013). Although warmer temperatures could increase the amount of forage available during winter (Frisvold et al. 2013), drought is generally expected to increase in frequency, severity, and duration (see Chapter 3). Thus, winter droughts could offset increased winter pasture productivity (Walthall et al. 2012).

At the same time, higher CO_2 levels could adversely affect forage quality due to increases in the carbon to nitrogen ratios of plant materials and associated lower protein contents (Milchunas et al. 2005; NFWPCAP, 2012). Higher CO_2 levels may favor plants such as cheatgrass that use a type of photosynthesis known as C_3-photosynthesis (NFWPCAP, 2012). Warmer temperatures and fire-prone conditions may also favor invasive plants like cheatgrass. At the same time, hotter conditions and greater water stress could favor plants that use a type of photosynthesis known as C_4-photosynthesis (NFWPCAP, 2012). Plants which utilize C_4-photosynthesis (maize, millet, sorghum, etc.) are able to endure drought and high temperatures better than more common plants which utilize C_3-photosynthesis (wheat, potatoes, barley, oats, peaches, etc.).

Seasonal precipitation timing is critical to ecosystem stability in the SW. Whether climate change and variability will lead to an increase in total average seasonal precipitation or to a decrease, or whether the timing of the monsoon will be affected is not clear (Chapter 3). However, if reductions in winter precipitation occur, or if there is a delay in the onset of the summer monsoon, this would impact spring vegetation growth (Hiza-Redsteer, 2011). Periodic drought, heavy snowfall, or unseasonably late frost can suddenly decrease the availability of forage at any time (Richmond, 1989).[2]

Drought in the SW is expected to increase in frequency, severity and duration (see Chapter 3). Increased drought will likely bring a decline in native vegetation, increased erosion and desertification (including advancing sand dunes and dust storms), and lead to a further decline in the reliability of already-scarce water supplies (Institute for Tribal Environmental Professionals, 2009).

Warming tends to amplify the effects of drought by increasing plant mortality (Robles and Enquist 2011). Even if precipitation remains the same, the predicted increase in both average and extreme temperatures may decrease soil moisture content, stressing plants (Schwinning, 2008). Increased climate stress and overgrazing may combine to cause a permanent shift in plant composition from grasses to inedible shrubs and weeds (Auken, 2000). In some locations in the SW, changes in precipitation patterns have already resulted in some areas of arid grassland turning into desert shrubland (McCarty, 2001). Affected areas could produce less suitable forage for livestock grazing. Changes in ecology are discussed more in Chapter 9.

Rangelands may be composed of numerous vegetation types. Matt Williamson, Kane Two-Mile Ranches Program Director, notes that diverse types of vegetation will be affected differently by climate change and variability. Williamson provides the example that while changes in warm season grass components may make ponderosa pine forests more productive, the infilling of pinyon-juniper woodlands (potentially due to elevated CO_2 levels) could lead to less productivity.

Invasive species

Invasive species are a major concern on Navajo rangelands. Coconino County, located almost exclusively within the NN, has the highest number of documented invasive species in all of Arizona (EDDMapS, 2012). Many of these species thrive in the same ecosystems grazed by Navajo livestock. Some, such as tumbleweed (Russian thistle) and camelthorn (*Alhagi pseudalhagi*),are primarily spread by livestock

1 These observations are generalizations from tribal members living and working Reservation lands. Observations by tribal members may be used to supplement other scientific data.

2 Richmond noted the lack of apparent correlations between historic heavy winter snowfalls and drought, and "due to the friability of the soils, the permeability of the sandstone aquifers, and solar ablation, most of this moisture is not available to plant life on much of the Navajo Reservation except for the early period of germination."

grazing (Wotkyns, 2011). Other invasives may compete with forage for scarce water resources. For instance, tamarisk (also known as saltcedar) forces out native plants in riparian corridors and consumes large amounts of water (Wotkyns, 2011).[3]

Cheatgrass has invaded the native semi-arid grasslands and the open PJ woodlands of the Colorado Plateau (Grahame and Sisk 2002). Because cheatgrass is unpalatable to sheep and other livestock, animals tend to overgraze native plants when cheatgrass begins to prevail. In addition, unlike native bunchgrasses, cheatgrass dies by the end of July, avoiding the hottest and driest part of summer. Dead cheatgrass burns easily, causing early and abundant wildfires that further damage or kill native grasses. During a fire, early-maturing cheatgrass can take advantage of nutrients released by the fire to grow and produce seeds (each plant can produce over 1,000 seeds). Because cheatgrass quickly develops a large root system, by the time native grass seedlings start growing in April or May, cheatgrass has already stolen most of the water from the top foot of soil. Native seedlings are unable to get their roots deep enough into soil to access water before drought sets in and die of thirst. Without an ability to reproduce native grasses inevitably decline. Over time, cheatgrass comes to dominate. Cheatgrass also often opens the way for secondary invaders, including knapweed and thistle. For more discussion of climate change and invasive species on the NN, we refer readers to Chapter 9.

Water availability for livestock

Anticipated rises in temperature may lead to increased evaporation. With increases in drought frequency, severity, and duration, conditions leading to increased evaporation are likely to increase in frequency. Water for livestock on the Reservation comes from an estimated 7,500 stock ponds supplied by surface runoff and windmill-powered wells which tap into shallow, alluvial aquifers (NDWR, 2003). Stock ponds are already often dry during the summer and during droughts (NDWR, 2003). During droughts livestock water demands rise and groundwater levels drop; NDWR windmills often cannot supply enough water. Again, in the future with increases in drought, this will likely be the case more frequently. As noted in Chapter 3, springs and ephemeral streams and washes on the NN are also impacted by drought and changes in precipitation patterns. If ranchers rely on these resources to water their livestock, they may face similar shortage constraints.

A reduction in stock watering locations may also have additional indirect consequences for ranching. Matt Williamson notes that available water supplies play a crucial role in determining the distribution of livestock. Livestock will congregate around scarce water sources and deplete the forage surrounding the water resource. Thus, rangeland surrounding scarce water resources may be more rapidly degraded.

Livestock health

The health of range livestock may be impacted by changing climatic conditions. In the SW, heat waves are expected to increase in frequency, severity, and duration with nighttime heat waves increasing at a faster rate than daytime heat waves (Chapter 3). Livestock may be impacted by increases in the occurrence of extreme temperatures and nighttime conditions that do not allow for adequate livestock cooling (Walthall et al. 2012). Cattle, for example, are able to adapt their body temperatures to minor fluctuations of outside temperatures (Hahn, 1999). However, frequent changes and extreme temperatures can damage this ability (Hahn, 1999). Furthermore, persistent hot weather stresses cattle and can lead to a decrease in appetite, energy, milk production, reproduction rates and immune system strength (Hahn, 1999). Extreme heat, especially when coupled with drought, has been well documented to threaten the life of

3 Saltcedar was intentionally introduced in the US to help control stream bank erosion in riparian areas. Primarily as a function of its voracious reproductive capacity, saltcedar is outcompeting native cottonwoods and willows on the NN. Saltcedar seeds have no dormancy requirements and germinate in less than 24 hours, making the plant resilient and quick to spread. The seeds germinate best in moist silt, like that found in SW riparian habitats after floodwaters subside (Stevens, 1989a; Stevens, 1989b). Climate change is facilitating the spread of saltcedar because it is more tolerant than native species of harsh environmental extremes. Saltcedar's success in riparian environments in the SW appears to be a function of its phenomenal reproductive output and its greater drought and flood tolerance (Warren and Turner 1975).

livestock during past heat events and droughts (Walthall et al. 2012). Finally, during times of drought, another impact on livestock may be increased consumption of toxic vegetation when more desirable and palatable forage is no longer available (NDSU Extension, 2006).

Photo: Julie Nania.

Caring for animals under stressful conditions may require particular measures, including additional feed and water. The USDA reports that heat stressed animals require two to three times more water than the same animals under normal conditions (Walthall et al. 2012). Beyond direct threats from increased temperatures, an increased demand for animal feed (if vegetation decreases), water, and the spread of disease also endangers range livelihoods (EPA Backlund et al. 2008). Diseases are generally more prevalent and tend to spread more quickly in warmer and wetter climates (Gale et al. 2009). Although the SW tends to be arid, changes in the local precipitation and temperature patterns could affect disease prevalence. Nonetheless, climate change effects relating to diseases in the SW are more likely be more associated with localized pest increases and the increased vulnerability of the livestock themselves (Walthall et al. 2012).[4] Livestock under heat stressed conditions are more susceptible to disease as their immune systems are less able to fight off illness (Hahn, 1999). Potential disease impacts are under-researched yet have the potential to seriously harm herds. Understanding how disease may impact livestock will be important to understanding the best possible way to adapt to climate changes and variability.

6.2 Vulnerability and Adaptive Capacity Factors

Photo: Julie Nania.

A variety of vulnerability and adaptive capacity factors may interact with climate and ecological changes to create or to alleviate impacts on Navajo rangeland resources (see Chapter 2). Factors that contribute to negative impacts on rangelands and livestock may include: overgrazing, invasive species, feral animal overpopulation, livestock water infrastructure in disrepair, and poverty levels that make it difficult to purchase supplemental feed and water for livestock. Adaptive capacity factors include tribal sovereignty and authority to manage rangeland in response to climate changes and other conditions, a Navajo veterinary stockpile program to respond to potential animal disease outbreaks and a proposed Navajo Nation Integrated Weed Management Plan, among other things.

Grazing policies on Navajo lands has been implemented with extremely negative consequences; however, with the exercise of tribal sovereignty and passage of the Navajo Rangeland Improvement Act of 2013, grazing policy has a renewed potential to be a factor improving the adaptive capacity of the Nation. Some of these constraints/adaptive capacity factors are discussed in more detail below.

4 More frequent storm events and possible flooding could also impact disease spread and further weaken herd resistance to disease.

Overgrazing and invasive species

Livestock grazing has been called "the most widespread influence on the ecosystems of western North America." (Fleischner, 1994) Overgrazing creates habitat availability for inedible weeds to replace native plants (Fleischner, 1994). It can result in more surface runoff, flooding, soil erosion, and increased gullying (Fleischner, 1994). Increased gullying may in turn lower the water table below the reach of many grasses, causing the spread of inedible bushes and weeds with longer root systems. Moreover, overgrazing may contribute to increased frequency and severity of fire (due to cheatgrass), to the loss of local pollinators, and to decreases in water availability (i.e., from competition from tamarisk).

Soils may also be impacted by overgrazing. Biological crusts may be degraded from increased cattle foot traffic. Without the integrity of biological crusts to stabilize soils, wind erosion and dust storms may increase. We refer readers to Chapters 7 and 9 for additional discussion of climate change and cryptobiotic soils. Overgrazing has also been shown to increase soil compaction. Once rangelands have been overgrazed and compacted, studies have demonstrated that it may take from 100-200 years for native species to recover naturally (Bernstein et al. 2014; Prose and Metzger 1985). Compaction can decrease water infiltration, which can lead to severe desertification in arid and semi-arid areas like the NN (Fleischner, 1994).

Feral animals

In addition to overgrazing, feral animals are a huge contributing problem to Navajo grazing issues and a problem that ranchers quickly point to when anyone suggests a reduction of sheep or cattle (Yurth, 2009).[5] Under NN law, each government chapter has oversight for reducing the number of feral animals within its boundaries (NN Tribal Council, 2006). However, the effort to roundup feral animals has been thwarted because animals are often sold back into the community after the roundup and released back onto the range as "owned" animals, defeating the purpose of the roundup (NDWR, 2003).

There is a continued resistance to reductions of feral animals which roam the Navajo range, particularly to the reduction of horses. Many Navajo appreciate horses—wild or not—and want them left alone (NDWR, 2003). Horses are "considered one of the most valuable and sacred things among the Navajo people." (Gorman, 1974) Despite the cultural and economic changes experienced by the Navajo in the last eighty years, the Navajo connection to livestock and horses continues to run deep.

Navajo Nation National Veterinary Stockpile Tribal Plan

Photo: Julie Nania.

After years of collaboration and research, the NN has developed the *Navajo Nation National Veterinary Stockpile Tribal Plan* with detailed protocols to respond to animal disease outbreaks (Davis, 2010). In April 2011, the plan was tested via an exercise involving a mock 'breakout' of Rift Valley fever (USDA APHIS, 2011). The exercise involved a partnership with the US Department of Agriculture's Animal and Plant Health Inspection Service and twenty-eight other agencies and organizations and was deemed a great success. The exercise tested communication between tribal leaders, range managers, veterinarians and a host of other parties. Actual preparedness for an emergency was acted out in a step-by-step vaccine and medical response rehearsal, and included everything from organized communication to testing the temperature of the vaccines. The potential for increases in disease prevalence and transmission under a warmer climate are still not well understood, but the risk can be monitored by groups such as the NN Veterinary Livestock Program (Davis, 2010). The stockpile plan could be used to respond to such risks.

5 The BIA estimates that 60,000 feral horses roam the NN. An adult horse eats about twenty-six pounds of grass a day and it's estimated that horses strip about 1.6 million pounds of vegetation from the NN daily.

Grazing policy

Understanding the political and cultural aspects of grazing policy is essential to any realistic discussion about rangeland adaptation. The twin federal policies of stock reduction programs and the implementation of a grazing permitting system have reorganized the Navajo grazing regime. A common sentiment is that the current degraded state of the range can be blamed on federal government policies which restrict traditional grazing cycles and patterns (Goldtooth, 1974).[6]

During the first half of the twentieth century, the federal government engaged in several failed attempts at Navajo range management. In 1933, BIA Commissioner Collier presented the Navajo Tribal Council with a comprehensive program to reduce the number of livestock grazing the Navajo range and control erosion by expanding Reservation boundaries, developing new water sources, and reducing livestock holdings by federal livestock buy up programs. The goat reduction was advertised as a voluntary, temporary, and limited reduction to allow range recovery. However, Collier made acceptance of the stock reduction plan a prerequisite for two things the Tribal Council desperately needed from the federal government: water development and extension of the eastern reservation boundaries.

The goat reduction was a disaster. Because of inadequate processing capacity, canneries were overwhelmed; as much as 70 percent of the animals slated for removal were slaughtered on the spot. This combination of brutality, waste, and impoverishment created a lasting stigma that continues to surround the words "stock reduction" for many Navajo (Goldtooth, 1974).

Because of this history, the most pressing cause of the degraded Navajo range is one that few Navajo people and Navajo politicians are willing to openly discuss: too many animals grazing on the range (Weisiger, 2009). The Navajo people have adopted certain measures to address grazing issues in the past. Historically, the people responded to grazing pressure and drought by moving their livestock whenever and wherever throughout Navajo lands. As early as 1926, the Navajo Tribal Council recognized that the range faced problems, and adopted a resolution declaring that

> "[w]e realize that our people have thousands of horses which are of no use to them and which they should get rid of. These useless horses eat grass, which would support many thousands of heads of sheep and cattle which would bring in to us large revenue. We know now that we are greatly hurt in our dealings with Washington about extensions of our Reservations and money for the rental of outside land by having so many horses wasting the range. We propose to do our best and make our people see that this is true and to persuade them that they should get rid of a great many of these horses and secure better stallions so as to build up for freighting and for traveling around with." (Iverson, 2002)

Until recently, Navajo grazing policy remained primarily based on the BIA permit system from the 1930s and 1940s, as administered by the Navajo Nation's Tribal Council and local Grazing Committees. Although technically a Navajo code, the regulations were originally drafted and enforced by the federal government (Libecap, 1980).

In 1996, during the extended drought, the Navajo Nation Council asked its constituents for a "livestock adjustment," emphasizing that drought, and not overgrazing, was the reason and that the adjustment meant that the Navajo people should comply with their grazing permits by voluntarily reducing their stock to the number allowed by the limits of their permits (Weisiger, 2009). Stock owners did sell thousands of animals, but still sustained heavy losses to the remaining herds from dehydration and starvation (NDWR, 2003). One estimate of Navajo livestock population shows that between 1996 and 1997, sheep units (N.N. Code, 2009)[7] fell by 36,374 in one year (NDWR, 2003).

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6 Goldtooth explained that"[t]he people moved with their sheep whenever and wherever they wished with the seasons. A homesite is not good when a family lives in the same place too long. The vegetation . . . never gets a chance to grow again. Long ago, moving with the stock from one place to another was much better than what we do now. It gave the vegetation time to grow again." (Goldtooth, 1974)

7 One horse, mule, or burro equals five sheep units, one cow equals four sheep units, one sheep or goat equals one sheep unit.

In order to graze cattle, sheep, or horses on the range, a Navajo grazing permit is required. Permittees are restricted to the use of a specific grazing district, and the permittee may not graze more than ten head of horses or accumulate a total of over 350 sheep units (N.N. Code, 2009). Grazing permits can be bought and sold or exchanged; although ownership is limited to NN citizens, and they are subject to Navajo probate law, which allows division of permits among heirs (Bobroff, 2001).

The severe drought from 1994 through 2009 pushed this policy to its limits and created calls for reform from inside and outside the tribal government. In partial response, the Navajo Nation Livestock & Foreign Animal Disease Act of 2006 (NN Tribal Council, 2006) was passed to amend the regulations by providing penalties for grazing violations, setting procedures for initiating a "roundup" of feral and unsupervised animals, and making livestock owners legally responsible for keeping an eye on their animals (Smith, 2010).[8]

Photo: Julie Nania.

Overstocking is an ongoing problem, due in part to the structure of the permit system.[9] The most recent publically-available Navajo Nation Livestock Inventory is from 2001 (USDA, 2007).[10] For the grazing districts that were included in the Inventory, there were a total of 403,138 reported sheep units; only 285,346 sheep units had been permitted (NDWR, 2003). This Inventory indicated more than 117,000 excess livestock units, or forty percent overstocking. The 2003 Drought Plan observes that "the actual overstocking is much greater than the voluntary livestock count indicates" because a significant number of grazing districts did not report, and the Inventory failed to include penned and feral animals (NDWR, 2003).

More permanent efforts at grazing reform have met greater resistance. After the failed "livestock adjustment" in 1996 the NNDA drafted the Navajo Grazing Act to address some of the systemic flaws in Navajo range management (Paskus, 2002). A version of this act, the Navajo Rangeland Improvement Act of 2014, has recently been adopted by the NN. The noted purpose of the Act is to "Maximize, to the greatest extent practicable, the ecological health and productivity of Navajo rangelands, such that present and future generations of the Navajo People are able to enjoy the full potential of its material, traditional, cultural, spiritual, economic, environmental, and recreational benefits." (16 NNC. 101, 2014) Other purposes include maximizing the ecological health and productivity of Navajo rangelands, supporting Navajos who raise livestock for traditional, cultural, business, or home use, and harmonizing the varied and disparate legal regimes that regulate livestock grazing on Navajo rangelands. It has important substantive provisions, including regulations allowing for the withdrawal and reissuance of existing permits, dissolution of grazing boards and the requirement of conservation plans for the issuance of new permits.

Importantly, the Director is "empowered to establish and adjust range units based on the need to preserve the amount and quality of forage, land status, and customary use areas, land associated problems involved, or in furtherance of any mutually agreed upon or court-ordered resolution of a land

8 § 1363 (prohibiting failure to remove livestock trespassing on fenced areas and roadways); § 1364 (prohibiting failure to remove dead or injured animals); § 1370 (prohibiting failure to properly tag or brand animals with owner identification).

9 In 1941 BIA issued the initial 7,453 permits; in 1959 there were 8,390 permits, and by the 1990s, there were more than 12,000 permits (NDWR, 2003). Fractionation of permits through inheritance leads to an overall smaller herd size allowed for each permittee; for instance, if the original permit allowed 150 sheep units, when it is divided between two heirs, each heir will have a permit allowing 75 sheep units. Because small herd owners form the majority of Navajo stock owners (Libecap, 1980) (noting that by the late 1970s, over 80% of Navajo herds probably contained less than 100 sheep per herd)and are the most likely to exceed their permit allocations fractionation contributes to the problem of overstocking.

10 A 2007 USDA report shows an "inventory" of 319,224 horse, cattle, sheep, and goats on the NN, without indicating whether this number is in sheep units or an actual headcount.

dispute that envisions the establishment of range units." (16 NNC. 101, 2014) This new policy has the potential to greatly enhance the capacity of the NN to address climate change adaptation efforts on Navajo lands. Its evolving nature could also provide for future opportunities to address climate change concerns on the NN (16 NNC. 101, 2014).

6.3 Potential Adaptation Strategies for Range Resources

Above we discussed some of the potential climate change and variability impacts on rangelands, as well as some of the adaptive capacity and vulnerability factors which influence adaptation strategies and planning. It is important to note that rangelands are not uniform; rangelands may encompass a variety of different ecosystems and vegetation types. Thus, different rangeland ecosystems will respond to climate change differently, as will different livestock species. As discussed in Chapter 2, the strategies and considerations herein are a starting point for more in-depth adaptation planning. Ranchers will want to consider specific conditions and data as the engage in the adaptation planning process on the ground.

The NN today possesses the power as a sovereign nation to manage its rangelands how it sees fit. This presents a unique opportunity for the NN to exercise its right to environmental self-determination and decide for itself how to manage its range in response to climate change (Tsosie, 1996). Given the particularly complex socio-political considerations surrounding grazing, an approach that is actually likely to be adopted and enforced by the Navajo people themselves is crucial for adaptation success. Key categories to address for climate change adaptation including drought mitigation strategies mentioned in the Navajo Drought Contingency Plan (NDWR, 2003) and include improvements in range management and rangeland restoration, provision of additional assistance to ranchers, the marketing of a NN meat brand, improvements in the reliability of livestock water supplies, and disease monitoring and prevention.

Improvements in range management/rangeland restoration

Range management strategies proposed in the DCP include "conducting a comprehensive, accurate, and independent livestock tally" and using the tally as a tool to reduce the number of unauthorized livestock and to ensure that supplemental feed and water are only provided to permitted animals (NDWR, 2003). The DCP also suggests the removal of feral animals that may otherwise consume resources that could be used by livestock as a range management strategy. Other range management strategies that can help prevent further rangeland degradation include: preventing erosion through placing straw on hillsides, planting drought resistant species, or rotating grazing around parcels of range to allow the recovery of the range (Wotkyns, 2011).

Key Points: Potential Climate Change Impacts on Range

- Increasing CO_2 levels, rising temperatures, greater precipitation variability, and changing fire regimes may contribute to continuing changes in forage composition, productivity, and quality on rangelands
- Rangeland ecosystems may be changing variably
- Changes in temperature could potentially lead to increased winter pasture productivity (unless offset by increased drought)
- Increased drought occurrences could lead to a reduction in forage, livestock water supplies, and could increase stress on livestock
- CO_2 levels could adversely affect forage quality
- Higher CO_2 levels may favor plants that use C_3-photosynthesis
- Wildfire regimes could favor certain species, including invasive cheatgrass
- Plants which utilize C_4-photosynthesis may better endure drought
- Drought will likely bring a decline in native vegetation, increased erosion and desertification, leading to a further decline in the reliability of already-scarce water supplies
- Increased temperatures may stress plants and lead to increased plant mortality
- Diverse range ecosystems will respond differently to potential climate change impacts
- Invasive species may increase
- Livestock water demand may increase with drought and higher temperatures; at the same time, water scarcity may also increase
- Livestock may be more vulnerable to disease because of increased stresses

Key Points: Range Climate Change Adaptation and Variability Strategies

- Range restoration (re-vegetation, species selection, erosion control)
- Grazing rotation
- Select breeds for warmer and drier climate (adapted breeds, lighter coats, shearing coats)
- Disease prevention and monitoring (pest and vector control, vaccines, emergency plans)

Rotational grazing is a range management strategy highly recommended by the USDA and has been used by tribes in the past to help the rangeland sustain grazing for a longer period of time (Walthall et al. 2012). The Lasater Ranch in Colorado has excelled in their practice of rotational and deferred grazing regimes that involve not only rest periods but also alternating seasons during which a particular pasture is grazed.[11] As a result, they have witnessed a marked improvement in native range quality compared to the degraded condition in which they took over management of the ranch.

Managing which pastures are grazed during each season can allow further recovery periods for grasses prevalent during different times of the year (Giordanengo, 2013). Decisions on when to graze pastures may also be influenced by the dominant vegetation. For example, cheatgrass may only be palatable for a short period of time in the fall and early spring (Guerin, 2013). Some suggest that grazing cheatgrass during this season can help control the invasive plant once it has been established (Guerin, 2013; Giordanengo, 2013).

Effective range rotation regimes would require alterations to tribal range permits and cooperation with grazing officials. However, the benefits of a healthier pasture could outweigh the difficulties of altering current grazing patterns. If rangelands are unable to sustain the current number of grazing animals on them, smaller herd sizes may also be necessary to allow production to continue into the future (Walthall et al. 2012).

Restoration and reseeding degraded rangelands

While range restoration is widely recommended to improve the state of grazing, re-vegetation is challenging in arid and semi-arid areas (Fleischner, 1994). In one study, vegetation at an experimental site in southwestern Utah took fifty-nine years to recover "from a shrub-dominated, heavily overgrazed state in 1935 to a state where grass cover only slightly exceeded shrub cover in 1994."(Schwinning, 2008) Studies conducted in Arizona and New Mexico have indicated that "climate is the overriding factor determining the outcome of management actions" and that restoration programs "need to be flexible to account for climatic variation because in arid lands, vegetation response to management may be delayed, often several seasons, until adequate rainfall occurs." (Curtin, 2002)

Arid grasslands are some of the most difficult areas in which to restore native vegetation (Bernstein et al. 2014; Eckert et al. 1986; Palmer et al. 1997; Mosen et al. 2004). As discussed in Chapter 1, the vast majority of Navajo lands are considered arid lands. Conditions associated with climate change and variability may exacerbate difficulties with range restoration. Furthermore, conditions which make range restoration more difficult include "extreme temperatures, intense sun, high winds, limited moisture, and the low fertility of desert soils." (Bernstein et al. 2014) Restoration efforts may grow even more tenuous with continued climate change and variability "mak[ing] restoration to historic or "reference" conditions difficult, if not impossible." (Bernstein et al. 2014; Parmesean 2006)

Despite these difficulties, range restoration remains an integral range adaptation strategy. Reseeding arid rangelands may help to improve forage more rapidly than if permitted to recover naturally (Bernstein et al. 2014; Monsen et al. 2004). Certain restoration techniques have proven more effective in restoring arid grasslands. A study by Winkel and Roundy suggested that subsurface seeding improves germination in arid lands (Bernstein et al. 2014; Winkel and Roundy 1991).[12] A more recent study published by Bernstein et al.

11 For example, a pasture may be grazed during spring one year, then summer the following year, then fall the subsequent year, and then rested.

12 Imprinting may help facilitate seedling establishment (Bainbridge 2007). But even these more effective reseeding methods have their downsides; methods which involve soil disturbances can lead to increased colonization by invasive weeds (Bernstein et al. 2014; Sauer, 1988).

al. (2014) showed that the combination of drill-seeding and high winter-spring precipitation supported the germination of C_3 grasses (Bernstein et al. 2014). The Bernstein et al. (2014) study also demonstrated that cattle-trampling and broadcast seeding were far less effective methods of seeding (Bernstein et al. 2014).


Photo: Julie Nania.

Precipitation was also found to be a critical component of germination success in the Bernstein et al. (2014) study. Years with above average precipitation may present what Bernstein et al. refer to as "windows of opportunity" that "will be critical to restoration success." (Bernstein et al. 2014) However, high precipitation years may be hard to predict, particularly with the increased variability in precipitation patterns (see Chapter 3). Suggested seeding practices from the Bernstein et al. (2014) study are included in table 6.1, below. This combination may be suitable for Navajo grasslands, as the experimental site was "generally representative of rangelands across the Southwestern United States landscapes: extreme aridity, infertile soils, reduced native species richness, increasing dominance by exotic species, and a history of heavy grazing."(Bernstein et al. 2014)

Suggested seeding practices
• Seed only if there is a highly confident prediction of El Nino Southern Oscillation
• Use the drill seeding method for C_3 grasses within low-elevation, arid rangelands of the Colorado Plateau
• Focus on preventing or controlling non-native species
• Prioritize seeding methods which minimize soil disturbance to avoid increases in invasive species

Table 6.1. Suggested Seeding Practices from Bernstein et al. (2014).

Given the high costs and limited success of arid rangeland restoration efforts, the best adaptation approach will likely be to prevent further degradation of these lands or to start reseeding as early as possible. If lands are "early in the degradation process" seeding is far more effective than in those later along (Bernstein et al. 2014; Milton et al. 1994). For more in-depth information about appropriate local strategies for various range conditions, we refer readers to Restoring Western Rangelands and Wildlands (Monsen et al. 2004).

Organizations involved in researching rangeland restoration in the SW, including the Grand Canyon Trust, the Savory Institute, and the Nature Conservancy, can provide valuable information from their experiences in restoration. The New Mexico Chapter of the Nature Conservancy, for example, completed a rangeland ecosystem assessment for 14 million acres in the southern part of the state with the goal of identifying conservation and restoration opportunities (Yanoff et al. 2008). Landscapes that were currently in healthy condition were prioritized for conservation and landscapes that did not appear to require soil restoration or major investments to, for example, halt erosion were prioritized for restoration because of the lower costs involved in protecting/restoring such lands (Yanoff et al. 2008). Some landscapes requiring intensive restoration efforts were also considered restoration priorities because of their resource value (Yanoff et al. 2008).

The Grand Canyon Trust manages two ranches northwest of the NN and is currently creating a comprehensive Climate Change Adaptation Strategy for the 850,000 acres Kane and Two Mile Ranches. The Trust has been engaging in various restoration efforts to assess how arid and semi-arid rangelands will respond to restoration efforts. This effort calls on extensive on-the-ground monitoring information, cutting-edge models of landscape composition and ecosystem processes, and experimentation on the interaction of livestock with efforts to reduce cheatgrass. The Trust anticipates that a draft will

Key Points: Water Management Strategies

- Incorporating water development into range management planning using a "landscape" perspective
- Repairing windmills that supply stockwater
- Establishing circuit riders to keep track of chapter-level supply issues
- Creating distance between water sources to encourage rotational grazing to avoid range degradation

be available May, 2014.[13] These and other local resources can provide a more in-depth look at strategies best suited for particular vegetation, species and local conditions.

Adjust feed patterns for livestock

Although lands could potentially become incapable of supporting livestock, it is more likely that rangeland may continue to produce some forage. Reduced forage may require ranchers to supplement feed, change their operation (from cow/calf to steer for example), or work to alter their rotations.[14] Alternatively, ranchers may consider gradually shifting herd composition to livestock better adapted to the changing ecological conditions.

Additional assistance for ranchers

The NNDCP makes four suggestions for providing additional assistance to ranchers, including: 1) distributing climate and market information for ranchers more widely; 2) increasing the number of livestock sale barns and cattle auctions; 3) constructing storage for USDA grain; and 4) increasing the number of range managers who assist the Chapters with activities such as reseeding and restoring topsoil, introducing rotational grazing, and conducting workshops on decreasing livestock diseases (NDWR, 2003).

Better distribution of climate and market information through radio public service announcements is relatively inexpensive and could enable ranchers to make more informed and profitable choices about, for example, when to sell cattle. An increase in livestock barns and cattle auctions could facilitate such sales and voluntary reductions in herd sizes (NDWR, 2003).

Improvements in the reliability of livestock water supplies

The NNDCP makes three suggestions with respect to improving the reliability of livestock water supplies: 1) incorporating livestock water development into a comprehensive range management plan, 2) repairing and overhauling livestock well windmills and stockponds, and 3) establishing a local circuit riders program in which circuit riders will visit the Chapters and assist them with drought plans and the establishment of water user groups (NDWR, 2003).

Livestock water development could include actions such as installing supplies at new sites to create more distance between drinking locations and to encourage rotational grazing. Wind breaks could be installed around stock ponds to help decrease evaporation and loss of water. Aboveground storage tanks for water would also lose less water to evaporation than stock ponds. Repairing and overhauling windmills could decrease windmill downtime. However, as the NNDCP notes, any new livestock water development needs to be done with the bigger picture of sustainable range management in mind. New stock ponds could affect the water supply in stock ponds that are downstream. More importantly, if livestock water infrastructure is expanded beyond the capacity of the range to support the animals, the long-term effects could be ultimately very detrimental. Thus, one potential long-term solution would be to develop a landscape perspective on the distribution of water sources to identify critical "hotspots" for water supplies.[15]

Breed selection and management

There are many methods ranchers can use to help their range animals adapt to a warmer climate. The first option is to select range breeds which are already better adapted to warmer climates and drought conditions (Walthall et al. 2012). For example, cattle with lighter colored coats are less susceptible

13 Hoglander et al. Climate Change Adaptation Strategy for the Kane and Two Mile Ranches. Grand Canyon Trust. Work in progress.

14 This adaptation strategy was suggested by Matt Williamson, manager of the Kane and Two Miles Ranch at the Grand Canyon Trust.

15 Suggestion from Matt Williamson, Program Manager of Kane and Two Mile Ranches, Grand Canyon Trust.

Integrated Range Management and Monitoring on the Wind River Reservation

In Wyoming, the 595,000-acre Northern Arapaho Ranch, is owned and run by the Northern Arapaho Tribe, and is the largest cattle ranch in Wyoming and the largest certified organic cattle operation in the US (Northern Arapaho Ranch website). The ranch incorporates careful monitoring of range conditions and wildlife into its range management and actively protects a diversity of predators (i.e., wolves, mountain, lions, grizzly bears, coyotes), wild ungulate populations (i.e., moose, elk, and mule deer), and small mammal, bird, and plant species on its lands. Maintaining these broader ecosystem relationships provides benefits in terms of cattle populations. Predators, for example, ensure that the cattle as well as the wild ungulates do not linger in any location too long (such as riparian areas) and may help prevent the spread of diseases.

Photo: Robert Durell, wyofile.com.

to overheating (Walthall et al. 2012). Along with this option, the USDA also recommends choosing breeds whose habitat can be more easily modified to meet its particular needs through nearby facilities (Walthall et al. 2012). Selecting species better suited to changing vegetative conditions could also be a practical adaptation strategy.

Heat relief

Providing heat relief to animals in the form of shade or sprinkling with water[16] can be effective methods to help control heat stress (Walthall et al. 2012). Shade could be from built structures, especially built in areas which also provide wind cooling, or from plants (Nienabar and Hahn 2007). Studies have shown that application of water to the skin, with or without air flow, can very effectively cool animals (Nienabar and Hahn 2007). Livestock that can be sheared, such as sheep, can be sheared to promote cooling (Nienabar and Hahn 2007).

Another simple way to adapt to hotter weather is to change grazing and movement times. Avoiding manipulation during the hottest times of the day allows animals to rest and can reduce metabolic heating (Walthall et at. 2012). It is also recommended that ranchers avoid moving or feeding during dusk when wind is generally at a minimum and the natural cooling effects are less (Nienabar and Hahn 2007). Feeding practices can be altered to match the behaviors of animals under heat stress. As temperatures increase, animals tend to reduce eating to avoid metabolic heat generation. Therefore, avoiding feeding during the hottest time of day can encourage animals to eat during cooler periods and avoid food waste (Walthall et al. 2012).

Disease monitoring and prevention

Disease prevention is also an important aspect to consider when planning for climate change. Controlling vectors of disease through insect and pest control or through preparation of emergency plans and vaccinations can all help avoid disease breakouts (Hahn, 1999).

"Boutique" Markets for Navajo Agricultural Products

One interesting adaptation strategy may be the development of market niches for Navajo wools, hides and meat products. Using Navajo casinos and resorts could provide a ready outlet for marketing these goods to tourists.[17] This could reduce the amount lost to "middle men" and could improve the market

16 As discussed above, access to water is a serious issue on the NN. Sprinkling with water should only be resorted to under extreme conditions.

17 Suggestion from Matt Williamson, Program Manager of Kane and Two Mile Ranches, Grand Canyon Trust.

price of these items above the cost if they were sold at feedlots. As discussed in Chapter 7, the NN is seeking to increase tourism on the Reservation. Serving NN marketed meat could provide larger margins for livestock producers as well as a niche market for NN resorts. By increasing margins per animal, the economic strain on ranchers could be reduced, incentivizing conservation and stock reduction. A pilot project could be used to test if a niche market could be created for NN meat.

Certain adaptations will be more effective and feasible in different locations. Ranchers will need to be selective and aware that some changes may intensify issues if not executed well. For instance, providing only a small amount of shade for cattle will encourage them to cluster together and may reduce wind cooling (Nienabar and Hahn 2007). Therefore, if cost prohibits large scale operational changes, behavioral changes, such as timing grazing to the cooler part of the days, could be more effective. Adapting ranching and range management to a warming climate in the long run has the potential to benefit livelihoods, grazing animals and the rangeland itself.

6.4 Potential Funding and Other Support

There are several federal programs that the Reservation could utilize to fund range restoration projects, supplemental forage costs, and losses of livestock due to drought. Select programs are noted in the table below. Additional resources may exist at the federal and state levels.

Funding Opportunity	Area of Focus	Source	Enablement and website
Agricultural Conservation Reserve Program	Cost-sharing of livestock and pasture water resources	USDA	Public Law 100-387 http://www.fsa.usda.gov/FSA/webapp?area=home&subject=copr&topic=crp
Grassland Reserve Program	Help prevent grazing and pasture land from being developed, while still allowing current grazing activities	USDA	http://www.fsa.usda.gov/FSA/webapp?area=home&subject=copr&topic=grp
Rural Utilities Services	Provides grants for rural infrastructure development and increases job availability	USDA	http://www.rurdev.usda.gov/Utilities_LP.html
Disaster Assistance Programs	Provide support for crop loss, livestock loss, and damaged farm property	USDA	http://www.fsa.usda.gov/FSA/webapp?area=home&subject=diap&topic=landing
Livestock Forage Program	Financial assistance to producers who suffered grazing losses due to drought or fire	USDA	http://www.fsa.usda.gov/FSA/webapp?area=home&subject=diap&topic=lfp
Livestock Indemnity Program	Assistance to producers for livestock deaths that result from disaster	USDA	http://www.fsa.usda.gov/FSA/webapp?area=home&subject=diap&topic=lip
Emergency Assistance for Livestock, Honey Bees, & Farm-raised Fish	Assistance for losses not adequately covered by other programs	USDA	http://www.fsa.usda.gov/FSA/webapp?area=home&subject=diap&topic=elap
Rangeland Research Program	Restoration of rangelands	USDA	http://www.nifa.usda.gov/fo/fundview.cfm?fonum=1780

Table 6.2. Federal assisted programs for range restoration projects, supplemental forage costs, and losses of livestock due to drought.

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Photo: Julie Nania.

CHAPTER 7
HUMAN HEALTH

Climate change has the potential to affect human health, including morbidity (illness) and mortality (death), in a variety of ways. Certain changes may cause direct impacts; for example, higher temperatures may lead to increased occurrence of heat strokes. Other changes may impact human health indirectly, by exacerbating already existing medical conditions or changing the geographic ranges of disease vectors (Brown et al. 2013).

This chapter summarizes the direct and indirect effects climate change may have on human health within the Navajo Nation (NN). Potential impacts from temperature and precipitation extremes, increases in the frequency and size of wildfires, increases in dust storms, and changes in ecology will all be considered. We first describe potential climate change and variability implications for: heat and cold stress; air quality; infectious diseases; medicinal plants, nutrition and food security; access to food, water, and health care; and stress and mental health. Next we discuss some health-related vulnerability and adaptive capacity factors. We finish the chapter with suggestions of potential adaptation strategies and the identification of programs that might be able to help finance public health adaptation and implementation.

7.1 Potential Climate Change and Variability Impacts on Human Health

Key Points: Heat and Cold Stress

- Anticipated rises in air temperatures will likely contribute to heat stress
- Although the frequency of cold waves may decrease, they may remain severe and contribute to cold stress

Heat and cold stress

Heat waves, as defined according to current climate conditions, are expected to increase in frequency, severity, duration and spatial extent in the future. Summertime temperatures are likely to rise more than those of other seasons, potentially by 5.5 °F to 9 °F by mid- to late- 21st century. Rising temperatures are expected to increase the incidence of heat stress.

Heat stress is already the leading cause of weather-related

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deaths in the US (Brown et al. 2013). Furthermore, heat-related morbidity and mortality are likely substantially underreported (Brown et al. 2013). Arizona experiences the greatest number of annual heat-related deaths in the U.S. (Brown et al. 2013). In addition to direct impacts, high temperatures can also indirectly affect human health by exacerbating pre-existing medical conditions or reducing the efficacy of medications (Brown et al. 2013). Cold waves are expected to decrease in frequency (see Chapter 3) but may still occur and contribute to cold stress and hypothermia.

Air quality

Climate and associated ecological changes can affect air quality by influencing overall concentrations of allergens, particulate matter and ground-level ozone. In both 2011 and 2013, NN administrative offices in Window Rock were closed because mold contamination increased the potential for respiratory problems (ICTMN, 2013a; Smith, 2011). In these cases, declining roof conditions and/or closed air vents may have combined with moisture seepage to exacerbate the problem (ICTMN, 2013a; Smith, 2011). In the future, extreme precipitation events and rising temperatures (Chapter 3) could contribute to conditions that support the growth of mold (Luber et al. submitted).

Key Points: Air Quality

- Longer growing seasons may lead to increased pollen generation
- Allergen potency may increase
- Anticipated increases in wildfire prevalence and dust emissions could increase air particle pollution
- Rising air temperatures and wildfires could contribute to increased concentrations of ground-level ozone

A warming climate is also likely to mean a lengthening of the growing season (see Chapter 3) leading to earlier and longer spring blooms and increased pollen generation for many plant species (Brown et al. 2013; Luber et al. submitted). In addition, as the geographic ranges of plants change, some pollen producing species may disappear from a region while new ones move in (Brown et al. 2013). It is also possible that the allergen content and potency of some species' pollen may increase. Finally, climate variability could potentially affect the long-range, intercontinental transport of dust and any associated pollen and mold (Brown et al. 2013). Further research is needed on potential allergen impacts (USEPA, 2008).

Another anticipated climate-related change in the SW is an increase in the severity and extent of wildfires, which can lead to poor air quality both locally and downwind (see Chapter 3; Luber et al. submitted). Wildfire smoke contains particulate matter, including fine particle pollution less than 2.5 micrometers in diameter ($PM_{2.5}$) (Brown et al. 2013). Wildfires can cause conditions in which $PM_{2.5}$ levels greatly exceed national standards (USEPA, 2013a). In children, $PM_{2.5}$ exposure has been shown to exacerbate asthma and increase respiratory symptoms (Brown et al. 2013). $PM_{2.5}$ exposure can also exacerbate medical conditions in the elderly, and others with cardiopulmonary disease, and has been associated with increased emergency room visits and hospitalizations (Brown et al. 2013). An increase in dust emissions due to increased aridity and land use changes (Brahney et al. 2013) as well as increased wildfire frequency (Houser et al. 2001) may exacerbate respiratory problems.

Ground-level ozone is a pulmonary irritant that can damage lung tissue and cause respiratory symptoms, such as shortness of breath and pain from coughing or deep breathing, thereby aggravating asthma and other respiratory conditions (USEPA, 2013b; Brown et al. 2013). Ground-level ozone forms when air pollutants such as carbon monoxide, nitrous oxides, and volatile organic compounds (VOCs) interact in the presence of sunlight (USEPA, 2013b). It is a key component of smog. Rising air temperatures may result in greater ozone formation because of the temperature-dependence of ozone-forming reactions (Bell et al. 2007). Wildfire smoke can also contain VOCs, which, as noted above, are ozone precursors (Luber et al. submitted). Additionally, as temperatures increase, the generation of biogenic (i.e., produced by living organisms) VOCs also increases (Bell et al. 2007). Climate change could thus potentially contribute to increase ground-level ozone concentrations in already polluted areas (USEPA, 2013b). It then may be transported long distances by wind to affect more rural areas (USEPA, 2012).

Infectious diseases

Climate change and variability can also affect the occurrence of infectious diseases, including valley fever, vector-transmitted diseases, and diseases caused by consumption of contaminated food or water. Changes could influence the diseases' geographic distribution, their transmission frequency, and the timing of outbreaks (Luber et al. submitted). Projecting whether disease incidence will increase or decrease can be complex, and may also be location and disease specific (Brown et al. 2013). Demographic and sociologic factors are also important in determining whether diseases occur (Gubler et al. 2001).

Valley fever is an infection caused by the coccidioides fungus, found in soils. After a dry spell, farming, construction, wind, and other soil-disrupting processes may release spores of the desiccated fungus into the air. People who inhale the spores can become infected. Between 1998 and 2011, nearly all cases of valley fever in the US occurred in Arizona (66%) and California (31%). The number of cases is on the rise in both states and elsewhere in the SW. In Arizona, the number of reported cases increased from 1,474 in 1998 to 16,467 in 2011, and in New Mexico, Utah, and Nevada combined, the number of cases increased from 72 in 1998 to 237 in 2011 (CDC, 2013). Some health officials are calling the increase in the number of valley fever cases an epidemic (CDC, 2012). It is hypothesized that soil moisture promotes fungal growth while subsequent dry spells contribute to the release of spores. Climate changes and variability are expected to affect the growth and release of the fungus (Brown et al. 2013). However, while some studies have found correlations between weather and valley fever occurrence, others have not found any significant correlation. This complicates predictions of future valley fever occurrences (Brown et al. 2013).

Key Point: Infectious Diseases

- Climate and ecological changes will affect the occurrence of infectious diseases, however, the direction of the changes (increased or decreased incidence) is often site and disease specific.

Vector-transmitted diseases include diseases borne by insects and rodents. Vector-transmitted diseases currently found in North America include Lyme disease, dengue fever, West Nile virus, Rocky-Mountain spotted fever, Chagas disease, the plague, and hantavirus pulmonary syndrome (CDC, 2012; Luber et al. submitted). Of these, the plague and hantavirus occur almost exclusively in the SW (AZ, NM, UT, CA, CO, NV). The plague is a serious bacterial infection transmitted by fleas and maintained in rodents (Gubler et al. 2001; Mayo Clinic Staff 2013). Between 2005 and 2009, forty-three cases occurred in the US; 93% of those were in the SW region (Brown et al. 2013). Plague outbreaks occur most often when temperatures are between 75 °F and 80 °F (Brown et al. 2013). Climate events, such as above-average precipitation and drought, could affect rodent food availability, and thus rodent populations and plague occurrences (Gubler et al. 2001). One study conducted in New Mexico found that higher than normal winter-spring precipitation was positively associated with incidences of plague (Parmenter et al. 1999).

Several types of rodents can carry hantaviruses. The deer mouse is a particularly notorious source (Gubler et al. 2001; Mayo Clinic Staff 2011). Hantavirus exposure most frequently takes place indoors when field rodents infest buildings (Gubler et al. 2001; Mayo Clinic Staff 2011). Dried rodent urine, droppings, and saliva can be disturbed and released into the air, infecting people who breath that air (Gubler et al. 2001; Mayo Clinic Staff 2011). In 1993, a hantavirus outbreak in the Four Corners region seemed to be associated with a dramatic increase in rainfall during the 1992-93 El Niño event. As rodent food sources increased, the rodent population grew twenty-fold (Gubler et al. 2001). By 1995, rodent populations and hantavirus occurrences had declined. Between 2005 and 2009, there were 136 cases of hantavirus pulmonary syndrome, of which 61% occurred in the SW (Brown et al. 2013).

West Nile virus is an infection transmitted by mosquitoes (Mayo Clinic Staff. 2012). The first occurrences of the virus on the NN took place in 2003 (Joe, 2003). Climate change can affect mosquito-borne illnesses in a variety of ways. Mosquitoes require stagnant water to breed, and extreme precipitation may create or wash away breeding sites. Conversely, drought can cause water stagnation, leading to expansions in breeding locations. Overall increases in temperature can also reduce vector breeding time, increase biting behavior and decrease pathogen incubation periods. This decrease in incubation time means that vectors will become infectious more quickly. However, once threshold temperatures are reached, mosquito mortality may rise (Hales et al. 2003; Luber et al. submitted). Estimates of changes in West Nile virus, based on projections of future temperature increases, show increased risk of transmission in currently cooler areas, such as the foothills of the Sierra Nevada and Rocky Mountains and along the California coast (Brown et al. 2013).

Exposure to water-borne pathogens may increase with extreme weather events. Diarrheal illnesses, such as salmonella and campylobacteriosis, can occur from exposure to food and water-borne pathogens. Increased temperatures and the combination of unusually low and high precipitation may increase the frequency of occurrences (Luber et al. submitted).

Medicinal plants, nutrition, and food security

Climate change and variability may have a variety of impacts related to nutrition and food security. For example, concentrations of nutrients, including calcium, iron, and zinc, may decline in some crops (Luber et al. submitted). Protein levels in crops such as sorghum, barley, and soy may also be negatively impacted, as elevated CO_2 levels are associated with decreased nitrogen concentrations (Luber et al. submitted). If climate change results in rising food prices, this could contribute to food insecurity (Luber et al. submitted).

Ecological changes, which may accompany a changing climate, can affect the ranges, quality, and quantities of natural resources (Lynn et al. 2013). Traditional healers rely on certain native plants, and some Navajo residents rely on or supplement their diet with subsistence gathering (e.g., pine nuts), fishing, hunting, ranching (e.g., sheep, cows, goats) or farming (e.g., corn), including the use of dryland or "akchin" methods that make use of water harvesting techniques (NDWR, 2003; Novak, 2007). Some Navajo are advocating a return to traditional foods and the promotion of community and home gardens as a means of diabetes intervention (Lombard et al. 2006). However, traditional resources may become less readily available with a changing climate.

In interviews, Navajo elders have noted the loss of medicinal plants from the Reservation, (Redsteer et al. 2011) a phenomenon also observed by tribal members participating in a 2011 Southwest Tribal Climate Change Workshop (SWTCCW) (Wotkyns, 2011). Interviews with eighteen Navajo community members involved in ranching, mainly from the Tsaile-Wheatfields and Crystal Chapters, indicated that all had experienced ranching losses (Novak, 2007). Interviewees attributed the losses to reasons directly or indirectly linked to climate, including voluntary reductions due to drought, lack of water, greater grazing competition from deer, coyote predation, excessive snowfall, and conflicts with other ranchers (Novak, 2007). Similarly, interviews with Navajo community members from the Tsaile-Wheatfields and Crystal Chapters who are involved in farming indicated that eleven of the fourteen members had experienced losses. All losses were attributed to drought, or a combination of drought and dam-diversion wear-down, wildlife and freezing. With respect to losses incurred by wildlife, some farmers linked the losses to the decreased forage available due to the drought (Novak, 2007). Due to the cumulative effect of these impacts, climate change and variability could have implications for food quality and security.

Key Points: Medicinal Plants, Nutrition, and Food Security

- Climate changes and associated ecological changes can affect the geographic distributions, quality, and quantities of traditional medicinal plants and foods and the ability to ranch and farm
- Impacts that are already being observed on the NN include the loss of native medicinal plants and ranching and farming losses

Disruptions in access to food, water, sanitation, and health care

Climate events can affect water supply, stormwater, wastewater, transportation, power, communication, shelter, and other infrastructure in ways that disrupt access to water, food, and healthcare and exacerbate associated health impacts (Houser et al. 2001).

Key Point: Disruption in Access to Health-Related Infrastructure

- Anticipated increases in drought, heat waves, intense precipitation events and changes in ecology can all affect infrastructure in ways that disrupt access to food, water, sanitation, and healthcare

In the future, droughts are expected to increase in frequency, severity, and duration in the SW (Chapter 3), potentially leading to the excessive drying of soils. This, in turn, can damage pipes and contribute to breaks in water mains (Riley et al. 2012). Droughts may affect groundwater levels and quality affecting the efficacy of groundwater pumping equipment. In addition, droughts may impact surface water quantity and quality and the effectiveness of surface water supply infrastructure.[1] Thus, access to potable water may be impeded.

Lower streamflows associated with droughts can increase concentrations of pollutants, affecting the ability of treatment plants to meet safe drinking water standards (CDC et al. 2010). If a drought spurs an outbreak of wildfires, subsequent runoff may contain increased sediment levels that can clog water supply treatment plants. For example, runoff entering the Strontia Springs Reservoir in Colorado after the 1996 Buffalo Creek fire caused Denver to shut down one of its treatment plants and required extensive reservoir cleaning (Denver Water, 2013).

While cold waves may become less frequent, their severity may remain the same (Chapter 3). Thus, the possible impacts from extreme cold temperatures remain a health threat. From December 2012 through January 2013, parts of the Reservation experienced weeks of temperatures ranging from the teens to -25 °F (ICTMN, 2013 a). Frozen and broken water lines drained millions of gallons from water tanks and contributed to severe water shortages affecting at least 2,000 homes. The lack of water resources threatened the closure of essential facilities, including a Fort Defiance hospital (Congresswoman Kirkpatrick, 2013). These conditions prompted President Obama to issue a major disaster declaration for the NN (Congresswoman Kirkpatrick, 2013).

Climate change could increase the frequency of extreme precipitation events (Chapter 3), leading to blizzards or floods that could cut off access to food, water and health care.[2] In 2010, a severe blizzard on the NN caused a variety of health and other impacts, many of which are discussed in a case study in Chapter 11. One of the key vulnerabilities was the difficulty in communications, which hampered emergency response efforts.

Flooding can also result in a variety of health consequences. A surge of water can block roads, inundate towns, drown citizens, damage buildings to the point of being unsafe and contribute to mold infestations. Vital infrastructure, such as sewage treatment plants, may also be affected. On the Crow Reservation in Montana, a 1978 flood clogged sewers, backing sewage up into homes (Doyle et al. 2013). A 2011 flood caused water from a wastewater lagoon to overflow into the Little Bighorn River, and inundated downstream homes and businesses (Doyle et al. 2013). The Crow Reservation's Environmental Protection Department attempted to shock chlorinate domestic wells which had been flooded, but were unable to treat all of them. The flooding also caused water damage and mold infestations in homes (Doyle et al. 2013). The increased intensity of precipitation may adversely affect health by increasing nonpoint source pollution, and elevating levels of turbidity, organic matter, pathogens, and pesticides in surface waters. Groundwater quality may also be affected in cases of increased infiltration (Kundzewicz et al. 2008).[3]

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1 For instance, the Standing Rock Sioux Tribe in North Dakota depends on a single intake pipe from the Missouri River for its water supply. During a 2003 drought, river levels dropped so low that silt and sludge clogged the pipe, cutting the tribe off from its water supply for several days and temporarily closing an IHS hospital (Albrecht, 2003).

2 Other reservations have experienced similar events. On the Cheyenne River Sioux Reservation in South Dakota, severe winds associated with a January 2010 winter storm downed thousands of power poles and caused massive power outages throughout the reservation. When backup generators at a water supply treatment plant malfunctioned, the plant had to go offline for several days (Elcock, 2010). Power outages also prevent hospitals from refrigerating medicines or operating life support systems. If heating or cooling systems are affected by power outages during periods of extreme temperatures, the number of cases of heat or cold stress may increase (Maynard, 1998).

3 Changes in ecology also have the potential to disrupt community health infrastructure. For example, some Native communities in Alaska have found that warmer temperatures are contributing to algal blooms in the lakes

Stress and mental health

Climate change and variability could also lead to increased stress and mental health challenges (Luber et al. submitted). Native American participants in a US Global Change Research Program Circles of Wisdom workshop identified historical grief as a current health stress affecting tribes (Maynard, 1998). This grief may stem from loss of homelands, disruption of traditional ways of life and many other factors. SWTCCW participants noted that climate change could further impact the mental health of tribal peoples (Maynard, 1998). Many Native Americans harbor close spiritual, cultural, and economic connections with their homelands. As ecosystems change, they may experience an additional sense of loss along with the loss of traditional plants and wildlife on those lands.

For example, regardless of the degree of engagement in gathering, hunting, fishing or subsistence farming and ranching, these activities form a key part of Navajo cultural identity (Novak, 2007). The wool from sheep is used in traditional Navajo rug weaving (Novak, 2007). Corn pollen is central to a wide variety of Navajo ceremonies and blessings (Lynn et al. 2013) and families supply animals for a variety of cultural and social activities (Novak, 2007). The impact of climate change on these food and medicinal resources can therefore also have a substantial impact on mental stress. Emotional stress from climate change threats to their livelihoods and health may also increase.

Climate-related disasters also frequently cause mental health effects. The implications of Hurricane Katrina, wildfires, heat waves and floods on mental health are well documented (Luber et al. submitted). Research in Australia has examined the mental health effects of drought (Hart et al. 2011; Sartore et al. 2007). At least one study has found that people with mental illness may be more susceptible to health impacts associated with heat (Luber et al. submitted).

7.2 Vulnerability and Adaptive Capacity Factors

Climate, hydrologic, and ecosystem changes interact with land use, political, socioeconomic and other vulnerability/adaptive capacity factors (Chapter 2) to intensify or reduce impacts on community heath. We discuss a number of these factors here.

Healthcare providers serving the NN include the Navajo area Indian Health Service (IHS), 638 IHS self-determination contract providers, private clinics, private hospitals and traditional healers. In 1977, the Navajo Nation Council established the Navajo Division of Health (NDOH), which has taken the lead to address many public health concerns, including diabetes prevention and elder care (Joe, 2004).

Public health on the Reservation is already far below the national standard in many respects. Post-neonatal (< 1 year of age) death rates, and death rates from diabetes, pneumonia/influenza and tuberculosis, are all two to eight times higher than in the US as a whole (Joe, 2004). Poverty levels on the Reservation exacerbate health problems because financial resources for health care are limited. Residents must often travel long distances to obtain medical care (Butler, 2009), constraining access to preventive health services.

It can be difficult to recruit and retain Reservation health care providers, which also affects the health services provided. In 2004,

Key Points: Vulnerability and Adaptive Capacity

- Vulnerability factors include: high poverty levels, long distances to reach health care facilities and difficulties retaining health care providers
- Vulnerable subpopulations include: children, the elderly, pregnant women, water haulers, those with pre-existing medical conditions (e.g., asthma, diabetes), the economically disadvantaged, those who live in poor housing conditions, people with mental illness
- Adaptive capacity on the NN includes Community Health Representatives, the Navajo Nation Special Diabetes Project, and senior citizen centers run by the Navajo Area Agency on Aging

that supply their drinking water (Brubaker et al. 2010). The blooms clog water filters, disrupt water treatment, and substantially increase the amount of labor and consumables needed to treat water. During the summer of 2008, treatment plant operators had to change filters nearly fifty times per day, compared to the typical four times per day (Brubaker et al. 2010).

nursing vacancy rates on the NN exceeded 25% (USCCR, 2004). Regulations can also impede health care facility improvements or lead to inefficient spending of government funds. At the Gallup Indian Medical Center, for instance, even minor facility modifications must be authorized by Congress (USCCR, 2004). Another example of these restrictions is the regulation requiring that IHS funds targeted for substance abuse services on the NN only be spent on temporary and not permanent structures (USCCR, 2004).

Additional factors may influence the NN's susceptibility to the climate impacts described above. For example, housing conditions can affect whether heat or cold stresses occur. An estimated 16,000 families on the Reservation do not have access to electricity, which may constrain access to air conditioning and refrigeration for medications (NTUA, 2013). The siting of residences in close proximity to areas with high wildfire risk, or in locations downwind of urban areas, influences the potential impacts on air quality from fires or ground-level ozone. Wood-burning stoves present another threat to air quality. According to the Census Bureau's 2006-10 American Community Survey, 61% of occupied housing units on the reservation rely primarily on wood for heating. Although the impacts vary with operating practices and the type of equipment used, wood burning can contribute to particle pollution, emit hazardous air pollutants (USEPA, 2013 c) and interact with air pollution from other, climate-related sources to amplify poor air quality.

Approximately 44,000 homes on the Reservation have inadequate water supply, sewage disposal and/or solid waste disposal (IHS, 2010), all of which can also contribute to exposure to infectious diseases. Some Navajo residents must travel long distances to reach grocery stores and an estimated 25%-40% of the population on the Reservation hauls water (see Chapter 4) (NDWR, 2003). These residents may be more likely to experience disruptions in their access to food and potable water during extreme climate events. During climate-related disasters, many units on the Reservation may be cut off from emergency responders. According to the 2006-10 American Community Survey, 39% of occupied housing units on the Reservation had no phone service.

Certain subpopulations may be particularly vulnerable to climate-related public health impacts and vulnerability, adaptive capacity, and risk assessments should be done to identify such groups. Potentially vulnerable subpopulations include: children, the elderly, pregnant women, people who haul water, people who work outside, the economically disadvantaged, those who live in poor housing conditions, people with mental illness or post-traumatic stress disorder, those who live in floodplains and those with pre-existing medical conditions (Houser et al. 2001).

Asthma sufferers, for instance, may be particularly vulnerable to climate change-related effects on air quality. According to a National Center for Health Statistics data brief, for the US population as a whole, between 2001 and 2010 asthma prevalence increased from 7.3% to 8.4% (Akinbami et al. 2012). From 2008-2010, asthma prevalence among American Indians and Alaska Natives averaged 9.4% (Akinbami et al. 2012).

People with diabetes, as another example, can be more susceptible to heat stress even at temperatures of 80 °F or 90 °F (Kovats and Hajat 2007; Nassar et al. 2010). High temperatures can also affect diabetes medications and damage equipment, like glucose meters and test strips, used for self-management making it necessary to protect them from heat (Nassar et al. 2010). Among Native American communities, the adult-onset of diabetes has become pandemic (Houser et al. 2001). Rates of diagnosed diabetes among American Indian and Alaska Native youth between fifteen and nineteen years of age increased by 110% between 1990 and 2009 (DHHS, 2012). According to data from the 1997 Navajo Health and Nutrition Survey, the age-standardized prevalence of diabetes mellitus among Navajo aged twenty years and older was 23% and among Navajo forty-five years and older was over 40% (Will et al. 1997). Roughly one third of those with diabetes were unaware that they had the condition (Will et al. 1997).

Water haulers, as noted above, are another potentially vulnerable subpopulation. According to one study, the average hauling trip is fourteen miles one way (ITFAS, 2008) and some families may have to travel as far as forty miles one way (NDWR, 2003). During droughts, the distances that must be traveled to find public water systems with available supplies increase, as do the costs of hauling the water. To avoid traveling long distances, some residents start to use non-potable sources instead. If temperatures rise and the prevalence of droughts increase, such challenges will become more common.

The NN has established a number of programs that may be able to help vulnerable subpopulations adapt to climate change. In 1968, the Navajo Council established a Community Health Representative (CHR) Program. CHRs live in communities throughout the Reservation to provide care for a variety of diseases (Begay et al. 2011). They are certified nursing assistants and typically have first responder training and cardiopulmonary resuscitation, public health, and food handler certifications (Begay et al. 2011). CHRs could potentially be a resource for providing climate-related health and wellness information (Houser et al. 2001).

To combat diabetes, the Nation has established a Navajo Nation Special Diabetes Project (NNSDP). For about fifteen years the NNSDP has worked to educate people about diabetes and to promote prevention and management through exercise, nutrition and diet. The NNSDP attends fairs throughout the Nation to provide health screenings and to sponsor games and healthy snacks for Navajo youth. In addition, the project has established wellness centers that are open to the public free of charge and that have a variety of workout classes. The NNSDP also hosts fun runs and bike rides.[4]

Within the NDOH, the Navajo Area Agency on Aging (NAAA) runs over 90 senior citizen centers throughout the Reservation that provide health, educational, and social opportunities for Navajo elders. Like the NNSDP and CHRs, the NAAA is a forum that could be used to convey climate-related health risk information. Senior centers may also serve as locations that provide relief from climate-related events, including heat and cold extremes. The introduction of broadband internet services to a greater part of the Navajo Reservation could also expand the possibilities of telemedicine and telemental health.

7.3 Potential Adaptation Strategies for Human Health

Here we present possible adaptation strategies with respect to potential climate change impacts on health. Because prevention can save lives and be less expensive than treating communities once health impacts occur (Luber et al. submitted), monitoring and early warning system strategies can be key and could be developed for heat waves, allergens, air pollution, diseases, droughts, fires and floods.

Public health education, training of professionals and paraprofessionals, and outreach to community members with regard to protective behaviors are also important strategies (Houser et al. 2001). Health education and outreach can take place in a variety of forms, including face-to-face discussions with CHRs (Houser et al. 2001), radio campaigns, text message alerts, and the use of bulletin board messages. The best form of communication may differ for each subpopulation and according to the type of health information being conveyed. Therefore, the efficacy of information dispersal should be evaluated and outreach activities planned accordingly. As noted above, children, the elderly, and those with diabetes are among the subpopulations that may be particularly vulnerable to various climate change impacts. As a result, schools, senior citizen centers, and diabetes wellness centers may be good locations at which to conduct climate change outreach.

One example of public health education conducted in the past that could provide climate change adaptation benefits was the U.S. Environmental Protection Agency's Native American Asthma Radio campaign. The campaign, launched in 2001, educated listeners about environmental triggers of asthma in children in Native American languages, including Navajo. These ads advised family members who

4 The NNSDP has been involved with hosting a range of community events. In September 2011, the NNSDP, in cooperation with the American Diabetes Association and Conoco-Phillips, sponsored the Four Corners Tour de Cure with 10, 25, 60, and 100-mile courses on the farm roads of the Navajo Agricultural Products Industry (NNSDP, 2011). In 2012, the project coordinated, the Second Annual Running for a Stronger and Healthier Navajo Nation event held from October 21-27 (NNSDP, 2012). Over 1,200 runners participated in the 400-mile run from Pine Hill, NM to Aneth, UT. In March 2013, the NSDP held a two-day nutrition conference in Tuba City (NNSDP, 2013).

are smokers to smoke outside, suggested placing teddy bears in the freezer to kill off dust mites and recommended thoroughly drying bath toys to get rid of mold. Further health-related education could include topics such as: pest protection (e.g., repellent, window screens), disease awareness, and disaster response procedures (Gubler et al. 2001).

Community Health Adaptation Strategies
• Monitoring and early warning systems for heat waves, allergens, air pollution, diseases, droughts, fires and floods (Overpeck et al., 2013)
• Public health education about climate change impacts and protective behaviors
• Establishment of cooling centers for heat waves (Overpeck et al., 2013)
• Review and strengthening of occupational safety standards for outdoor workers (Brown et al., 2013)
• Integration of veterinary case surveillance and public health disease surveillance (Gubler et al., 2001)
• Landscape management to reduce disease vectors / vector-control programs (Brown et al., 2013)
• Restoration of ecosystems that support traditional medicinal plants and foods (Lynn et al., 2013)
• Protection of medicinal plants and relocation (Maynard, 1998)
• Work with non-tribal governments to establish off-reservation access to traditional medicinal plants and foods (Lynn et al., 2013)
• Improvement / development of sustainable food systems to support nutritional diets (Maynard, 1998)
• Development of food cooperatives (Breshears et al., 2011)
• Improvements in storm drainage, water supply, sanitation, communication and other infrastructure
• Development of disaster preparedness, response and mitigation plans that incorporate climate change considerations and lessons learned
• Provision of mental health services through the use of videoconferencing technology (Morland et al., 2013)
• Adequate insulation and ventilation for homes
• Stronger building codes that include climate considerations
• Restricted development in floodplains (Greenough et al., 2001)
• Microfinance or tool-sharing / training programs to enable residents to repair homes

Table 7.1. Community health adaptation strategies.

Improved emergency and health services could further help address health impacts from climate change and variability. Allowing vulnerable subpopulations to access locations with air conditioning (such as schools, senior centers, and diabetes wellness centers) during heat waves could provide relief and reduce morbidity and mortality related to heat stress. Expanding access to mental health services could also alleviate some of the stress brought on by climate change impacts. Telemental health services, which use information technology such as internet video teleconferencing to deliver mental health care, could be a way to expand support services without requiring patients to make difficult commutes. Broadband telemental health services can include: clinical assessment, individual and group psychotherapy, educational interventions, and more. (Morland et al. 2013).

Ensuring high quality housing and safe infrastructure will also be important to protect residents from extreme temperatures, poor air quality, flooding, and severe storms. Establishing and enforcing building codes with regular checks and upgrades can help prevent future infrastructure damage. Training on how to design, build, and remodel homes in a way that increases resilience to changing climatic conditions could also be provided to agencies such as the Navajo Housing Authority and others involved in home construction (Houser et al. 2001).

Tribal response to climate change can also involve the protection and promotion of traditional plants, medicines and food sources. On the Hopi Reservation, for example, the goal of the Natwani Coalition is to promote healthy food systems for the Hopi and Tewa people by supporting the growth of traditional foods, the continuation of traditional Hopi farming practices, and the development of innovative new ones. To achieve those goals, Natwani initiatives include a monthly radio program, a bi-annual Agriculture and Food symposium, and a farming curriculum for youth (Hopi Foundation, 2013). Food cooperatives provide an additional means to avoid food shortages. Individuals who rely on food harvested from just one location–pinyon nuts grown on their property, for example–may be more vulnerable to ecosystem crashes. Joining a cooperative that allows individuals to harvest in other locations, however, can increase resilience to isolated ecosystem disturbances (Breshears et al. 2011).

Disaster risk management and comprehensive emergency plans can help to further reduce the risk of disruptions in access to food, potable water, sanitation, and health care while lessening the public health consequences of climate-related hazards such as heat or cold waves, droughts, wildfires, severe storms, floods, and landslides (Greenough et al. 2001; Keim, 2008). Disaster risk management may be broken down into four phases: 1) preparedness, 2) mitigation, 3) response and 4), recovery (see table 7.2 below) (Greenough et al. 2001).

The Four Stages of Disaster Management	
1) Preparedness	Pre-disaster planning and activities that help facilitate effective emergency response once a disaster has taken place (Greenough et al. 2001; Keim, 2008). Examples: purchasing or strategically locating backup power generators and water pumps for use during flood emergencies (Keim, 2008).
2) Mitigation	Actions that minimize the adverse effects of climate hazards. Examples: early warning systems, the retrofitting of buildings, and changes to building/zoning codes to promote climate resilience (Greenough et al. 2001).
3) Response	Planning and activities that provide for quick, short-term relief efforts after a disaster has occurred, or, in the case of drought, for longer more sustained operations (Greenough et al. 2001; Kleim, 2008). Examples: evacuation plans and the provision of safe food, water, sanitation, and shelter (Kleim, 2008).
4) Recovery	Short and long-term efforts undertaken after a disaster has occurred to rebuild communities (Greenough et al. 2001).

Table 7.2. The four stages of disaster management.

The four phases of disaster management are not mutually exclusive. Mitigation activities, for instance, can take place during the recovery phase (Greenough et al. 2001). Disaster management can be improved by developing preparedness, response, and mitigation plans either for a particular hazard or multiple hazards. The Nation already has multi-hazard mitigation plan and a drought contingency plan into which it could potentially incorporate climate change considerations. Once plans are developed, it is critical that they be periodically updated….land use changes, new technologies, and the like. Finding resources. Finding resources to undertake updates can be challenging, and educating both federal and tribal staff on their importance may be needed (Redsteer et al. 2013). In addition to such plans, conducting in-depth evaluations of what has and has not been effective in handling past disasters is also key to improving disaster management. Evaluations should be incorporated as a continual part of the disaster risk management process, and changes should be implemented according to their findings. Finally, effective communication and outreach about the plans are crucial.

The adaptation strategies introduced above are a few potential options for the NN to consider when engaging in adaptation planning for human health on the Reservation. These strategies can be tailored to best fit the needs of Navajo communities. When engaging in the adaptation planning process (see Chapter 2), the NN may develop additional strategies to meet its human health needs.

7.4 Potential Funding and Other Support

There are several federal programs that the Reservation could utilize to fund adaptation strategies, health education projects, and health services. Select programs are noted in the table below. Additional resources may exist at the federal and state levels.

Funding Opportunity	Area of Focus	Source	Website
Building Resilience Against Climate Effects in State, Territorial and Tribal Health Departments	Public health consequences of climate change	CDC	http://www.grants.gov/search/search.do?mode=VIEW&oppId=171355
Clean Water Indian Set-Aside Grant Program	Wastewater infrastructure that protects human health	USEPA	http://water.epa.gov/type/watersheds/wastewater/Clean-Water-Indian-Set-Aside-Grant-Program.cfm
Community Facility Grants	The development of essential community facilities in rural areas and towns of up to 20,000 people	USDA	http://www.rurdev.usda.gov/HAD-CF_Grants.html
Distance Learning and Telemedicine Loan and Grant Program	To use advanced telecommunications technologies to enhance learning and health care opportunities for rural residents	USDA	http://www.rurdev.usda.gov/UTP_DLT.html
Drinking Water State Revolving Fund Tribal Set-Aside Program	Improve public health by improving drinking water system infrastructure	USEPA	http://water.epa.gov/grants_funding/dwsrf/allotments/tribes.cfm
Low Income Home Energy Assistance Program	To keep families safe and healthy through assistance with energy costs	HHS	http://www.acf.hhs.gov/programs/ocs/esource/the-liheap-tribal-manual http://www.acf.hhs.gov/programs/ocs/liheap-tribal-contact-listing
Native Agriculture and Food Systems Initiative	Increase access to fresh and healthy foods in Native communities	NGO	http://www.firstnations.org/NAFSI
Native American Research Centers for Health Grants	Academic-level biomedical, behavioral and health services research	NIH	http://www.nigms.nih.gov/Training/NARCH/
Pre-Disaster Mitigation Grant Program	Hazard mitigation planning and the implementation of mitigation projects, prior to disaster events	FEMA	http://www.fema.gov/pre-disaster-mitigation-grant-program
Rockefeller Family Fund	Protection of health as affected by the environment	NGO	http://www.rffund.org/grants/environment

Rural Housing Repair and Rehabilitation Grants	Loans and grants for very low-income homeowners to repair, improve, or modernize their dwellings, or to remove health and safety hazards	USDA	http://www.rurdev.usda.gov/HAD-RR_Loans_Grants.html
Science for Sustainable and Healthy Tribes	Health impacts of climate change and indoor air pollution	USEPA	http://www.epa.gov/ncer/rfa/2013/2013_star_tribal.html
Section 306C Water and Waste Disposal Grants to Alleviate Health Risks	Provide water and waste disposal facilities and services to low income rural communities facing significant health risks	USDA	http://www.rurdev.usda.gov/UWP-Colonias.html
Seventh Generation Fund for Indian Development	Health, education, energy, environmental justice	NGO	http://7genfund.org/grant-application
Rural Development Utilities Grants	Grants for projects related to well refurbishment, water, wastewater, solid waste, and broadband	USDA	http://www.rurdev.usda.gov/UWP-individualwellsystems.htm
Weatherization Formula Grants	Grants for low-income individuals to increase the energy efficiency of their dwellings, reduce their expenditures, and improve their health	DOE	http://www1.eere.energy.gov/financing/solicitations_detail.html?sol_id=481

Table 7.3. Federal assisted programs for adaptation strategies, health education projects, and health services.

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Chaco Culture National Historical Park, Nageezi, New Mexico. Photo: Julie Nania.

CHAPTER 8
TOURISM, RECREATION AND CULTURAL RESOURCES

Tourism accounts for a significant portion of the Navajo Nation's (NN) economy (Tiller, 2005). The Navajo Reservation contains some of the most majestic natural and cultural settings in the United States (US). The Reservation contains several major national and tribal recreation areas, parks, and historic monuments, including Chaco Culture National Historic Park, Canyon de Chelly National Monument, Four Corners Navajo Tribal Park, Navajo National Monument, Window Rock Tribal Park, and Monument Valley Navajo Tribal Park. Approximately 2.5 million people visit the NN's tribal parks and recreation areas annually (Tiller, 2005). In 2008, Canyon de Chelly National Monument alone received over 860,000 visitors (National Park Service, 2008).

These sites are not only important for tourism and recreation—many are also of cultural and historical significance to the Navajo. Accordingly, preserving these sites for their cultural significance is one of the primary goals of Navajo tourism (Discover Navajo, 2008). Tourism brings in around 17% of total tribal revenue annually (NN Division of Economic Development, 2014). In 2011, total revenue from tourism related activities was over $112 million, with the lucrative summer season generating about $38 million (Northern Arizona University, 2012). A portion of tourism revenue is reinvested in protecting and discovering Navajo historical sites (NN Division of Economic Development, 2014).

In addition to providing funds for culturally important preservation and discovery, tourism is also important from an economic development perspective. Increasing tourism to help increase and diversify the NN's economic base is one of the economic development goals emphasized in the Nation's development planning (Choudhary, 2004). Sustainable tourism development should incorporate potential climate impacts as well as vulnerability considerations. The remainder of this chapter discusses potential climate change and impacts on the Navajo Reservation, adaptive capacity factors, and potential tourism adaptation strategies.

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8.1 Potential Climate Change and Variability Impacts on Tourism, Recreation and Cultural Resources

The Navajo tourism industry could be impacted by climate change because popular tourist and recreational activities are dependent on resources vulnerable to a changing climate (Smith et al. 2000). Climate change impacts on forests, for example, are directly linked to impacts on tourism and recreation. An illustration of this is the fact that increased numbers of wildfires will likely shorten the time periods during which campsites and trails are open (Houser et al. 2001). Changing ecosystems may disrupt wildlife and plant communities, impacting tourism inspired by these resources (Houser et al. 2001). The desert landscape of the Nation is already being impacted by severe drought, which has been affecting plant growth, wildlife prevalence, and the availability of other resources needed for recreation.

Key Points: Summary of Climate Change Impacts on Tourism, Recreation and Cultural Resources

- Changes in availability of game species
- Loss of water-based recreational resources (lakes)
- Damage to monuments and cultural resources from increases in erosion factors
- Negative eco-system impacts
- Potential increase in days suitable for Navajo recreation

Hunting is one recreational activity that may be impacted by climate change. Several NN trophy species, including the desert bighorn sheep (N.N. Heritage Program), and mule deer (N.N. Department of Fish and Wildlife, 2010), are vulnerable to the impacts of climate change. With increasing temperatures, forage for these species could become scare, water holes could dry up, and further habitat degradation through soil erosion, storms, and human impacts could limit the species' range (deVos and McKinney 2007).

Water-based recreational activities could also be threatened by climate change. In particular, drought could limit the opportunities for lake-based recreation on the Nation. Some Reservation lakes have already partially or completely dried up. To'ahidiilíinii, or Many Farms Lake, was once a source of fish and a gathering place for local residents and wildlife. The lake is now described as "an abandoned murky pond with no fish, useful only to dragonflies" (Jimmy, 2013). The disappearance of Many Farms Lake is an example of the type of resource loss that could become more common with climate change.

Another way that climate change may impact tourism is by causing increased risk to the physical integrity of natural and cultural monuments (Smith et al. 2000). The USFS and non-profit organizations have warned that climate change is a major threat to the viability of many historic and natural sites and monuments (Saunders and Easley 2006). The NPS has already identified Chaco Culture National Historic Park and Canyon de Chelly National Monument as being "in immediate, imminent danger from natural erosive factors."(Saunders and Easley 2006) Climate change may result in increased flooding and erosion that could increase potential harm to monuments (Saunders and Easley 2006).

Reaching beyond particular impacts on hunting, water-based recreation, and the integrity of monuments, climate change has the potential to affect tourism by negatively impacting the SW desert ecosystem as a whole. Such ecosystem-wide effects could damage the biodiversity and beauty that are major attractions for the tourist population. Additional information on fish, wildlife, plants and biodiversity can be found in Chapter 9.

The disparate effects and variability of climate change mean that climate change's effects on tourism and recreation are uncertain. In some instances, climate change's effects on the environment may actually benefit tourism. For example, recreation may increase in response to longer summer seasons and warmer weather (Smith et al. 2000). However, potential benefits are uncertain at best and must be understood within the context of the overall effects of climate change.

8.2 Vulnerability and Adaptive Capacity Factors

Climate, hydrologic, and ecosystem changes interact with land use, political, socioeconomic and other vulnerability/adaptive capacity factors (Chapter 2) to intensify or reduce impacts on tourism and recreation on the NN. We discuss a number of these factors here.

The potential positive and negative economic, cultural, and environmental impacts of tourism may lessen or exacerbate climate impacts on tourism planning. Tourism can provide revenue to support local jobs and cultural activities, as well as to protect cultural and natural resources (Eagles et al. 2002). Through developing tourist opportunities, local communities can increase leverage for conservation and increase leverage and funding for local development projects (Eagles et al. 2002). In addition, further development of the tourist industry, especially cultural tourism, has the potential to strengthen local economies, empower residents, and protect cultural history (Steele-Prohaska, 1996).

Tourism's potential benefits are accompanied by potential drawbacks. First, increased tourism may contribute to GHG emissions. Current CO_2 emissions from tourism represent 4.95% of total annual global CO_2 emissions (Gössling, 2010). Most CO_2 emissions attributed to the tourist industry result from travel (air and other travel modes), accommodations, and destination activities. For regions aiming to increase tourist opportunities, energy use, transportation costs, water consumption, and other impacts from human traffic can all contribute to increases in emissions (Gössling, 2010).

In addition to a potential increase in GHG emissions, tourist activities may result in direct environmental damage from increased land use. Development of roads and transportation to tourist sites can cause erosion, habitat fragmentation and can diminish the natural beauty of the landscape (Eagles et al. 2002). Increased human traffic can lead to erosion of soils and historical sites, waste problems, habitat disruption, the spreading of invasive species, air and water pollution, and visual and noise pollution (Eagles et al. 2002).

Many potential Navajo tourist locations are protected sites with sensitive ecosystems. For example, living, cryptobiotic soils populate much of the SW desert ecosystem. These soils are currently endangered by human activity at the Grand Canyon, Navajo National Monument, and other tourist sites on the Nation (Cole, 1991). Life in the SW desert is uniquely linked to the bacteria, water, and life processes on the living soils, and disruption of these soils is highly detrimental to the desert ecosystem (Brotherson and Rushforth 1983). Small or even minimal changes in water availability and soil stability can lead to large biotic changes in cryptobiotic soils (Walla and Virginia, 1999), making them vulnerable to the more frequent droughts and extreme weather events that may result from climate change. Because potential Navajo tourist sites are ecologically sensitive, they are particularly vulnerable to both climate change and the potential impacts of tourism-driven increases in human traffic.

In addition to negative environmental impacts, tourism can also create negative cultural impacts ranging from cultural insensitivities to removing local residents from historical lands. Residents on the NN have already expressed concerns over tourism projects and their potential impacts on communities. Sociocultural issues are important to evaluate because the NN may want to limit tourist access to sensitive areas of particular cultural, religious, or social importance, or otherwise protect the privacy of Navajo communities. Thus, careful planning and communication with local residents are important factors for cultural tourism planning (Steele-Prohaska, 1996).

Other constraints may factor into tourism planning. One current constraint with regard to tourism and development planning is the lack of comprehensive tourism data. Until basic information is collected about tourism and recreation on the Reservation, it may be difficult to obtain political support to alter any tourism and recreation activities. Another significant barrier to tourism on the NN is the initial cost of developing tourist facilities. Access is a key component to increasing tourism to Navajo sites. As discussed below in Chapter 11, the state of roads and transportation on the Reservation is generally considered to be unsatisfactory (Lew, 1996). With climate change, the cost of maintaining infrastructure could potentially increase. Additional infrastructure will be needed to increase services to tourists, in the form of hotels, shops, food options, and fuel stations (Eagles et al. 2002). Improving communication from broadband, wireless, and internet access can also help attract tourists and create a more coordinated tourism system (Eagles et al. 2002).

Photo: Julie Nania.

Under Executive Orders 13423 (Bush, 2007) and 13514 (Obama, 2009), every federal agency is required to consider climate change risks in future planning and to set energy and resource consumption reduction goals. In response to this federal mandate, the NPS developed a Climate Change Action Plan (Plan) (National Park Service, 2012). The Plan develops monitoring goals and high priority areas for future programs (National Park Service, 2012). The NPS also created the Green Parks Program, which focuses on reducing the environmental impact of National Parks (National Park Service, 2012). Neither Chaco Culture National Historical Park nor Canyon de Chelly National Monument are members of the Program. However, both parks have environmental stewardship goals to complete for the 100th anniversary of the NPS in 2016. Chaco National Park's goals include: controlling invasive species, reducing the environmental impact of the park's operations, establishing environmental education programs, and using alternative energy. Through these initiatives, the federal government has begun to demonstrate its commitment to adapting and mitigating climate change. These federal goals could facilitate climate change adaptation planning and have implications for local management of parks on the NN.

8.3 Potential Adaptation Strategies for Tourism, Recreation and Cultural Resources

Existing tourism may be impacted by climate change. The potential impact of new tourism development will need to be considered in future scenarios which consider potential negative environmental and cultural effects. Planning and mitigation have the potential to help the NN tourism sector adapt to climate change while reaping the benefits of tourism while avoiding its negative drawbacks.

Global adaptation to climate change for the tourism and recreation sectors includes strategies aimed at improving carbon policies and mitigating the impact of tourism on GHG emissions (Gössling, 2010). The NN can help to mitigate climate change by minimizing GHG emissions. Using local resources will reduce CO_2 emissions from the travel and production sectors (Eagles et al. 2002). Encouraging ecotourism values such as low energy use and minimal interruption of natural processes could help NN visitors to minimize their contributions to climate change.

Developing and adapting tourism to a possible warmer climate will mean taking into account all possible climate impacts on recreational activities and tourist sites. While some impacts may be negative, others may prolong and improve the tourist season (EPA, 2013). At this point, coastal, island, and ski industry tourism have been the primary targets of adaptation research. Other tourist destinations, including the SW region, lack adequate information to develop site-specific adaptation strategies. As potential climate scenarios become more specific to locales within the region, changes in recreational activities may be better anticipated. More research into recent climate trends from average temperature to precipitation

Key Points: Adaptation Strategies for Tourism and Recreation

- Research local climate trends (temperature, precipitation, soil quality, wildlife, etc.) to better plan for possible future conditions
- Compile comprehensive tourism data (demographics, comments and recommendations, cost and revenue)
- Balance shrinking winter recreation opportunities with increased spring and summer activities
- Develop local-focused and low environmental impact tourism plans
- Include local residents in tourism decisions
- Set clear boundaries for tourism to better protect cultural and ecological concerns at sites

could help form a clearer idea of what the NN can expect for the coming years.

Higher temperatures may mean a longer season for summer activities, such as hiking and backpacking. Conversely, recreation days may be limited by heat or reduced water in reservoirs and streams. Adaptation strategies may include balancing out a shorter season for winter activities with a longer spring and summer recreation season. For this reason, adaptation for tourism and recreation should emphasize diversification of tourism income sources.

One method for targeting opportunities to diversify options for tourists will be to develop comprehensive tourism databases and research what tourists are looking for in a trip to the NN (Lew, 1996). The 2011 *Navajo Nation Visitor Survey* is a great start to this process (Northern Arizona University, 2012). Research and databases of resource use, including hunting and fishing records, will also be important to ensure sustainable uses of local resources (Lew, 1996). How the Nation decides to frame tourism opportunities will also impact who decides to visit the Nation and how tourism will impact the local environment and communities.

By encouraging locally-focused tourism and ecotourism, the NN may be able to mitigate the potential negative cultural and ecological impacts of tourism. Ensuring that tourism is locally-focused will help to ensure that more revenue and benefits remain in local communities and that the Nation's culture and history are respected. Focusing on ecotourism can encourage visitors to respect local ecosystems and stay within designated tourist zones.

The following are excerpts from a set of guidelines for developing tourism in culturally and environmentally sensitive areas that may be adopted if appropriate (Eagles et al. 2002):

Guidelines for Developing Tourism in Culturally and Environmentally Sensitive Areas
• Develop a site plan, focusing on detailed design. The plan should minimize site disturbance, physical intrusion, and intervention.
• Ensure that linkages, or features connecting one tourist area to another, are considered (for land use, nearby trails, camps, etc.).
• Design guidelines should recognize Navajo cultural characteristics and design features, colors, etc.
• Design and operate services so as to minimize use and production of water, energy, waste, sewage, effluent, noise, light, and any other emissions.
• Materials should be indigenous, appropriate to the area, and low maintenance.
• Include the local community by hiring local workers, buying local products and food, and returning portions of profits to local projects.

Table 8.1. Guidelines for developing tourism in culturally and environmentally sensitive areas (Eagles et al. 2002).

While tourism can improve local economies and increase protection for local historic sites and resources, it also comes with possible ecological and cultural downsides. The more the NN can encourage minimal impacts from tourism while still providing a quality tourist experience, the better the Nation and the tourism industry will be able to adapt to climate change.

8.4 Potential Funding and Other Support

There are several federal programs that the Reservation could utilize to fund preservation projects and to develop access to tourist sites. Select programs are noted in the table below. Additional resources may exist at the federal and state levels.

Funding Opportunity	Area of Focus	Source	Enablement
Tribal Heritage Grants	Assistance for tribes cultural preservation	DOI, NPS	http://www.nps.gov/history/hps/HPG/Tribal/index.htm
Community Connect	Provision of broadband services	USDA	http://www.grants.gov/search/search.do;jsessionid=td0RRymMGYpwRnHkxgWrvvszn64ny1ZfkpMsMhvvDP12zJh36n3K!856986300?oppId=236253&mode=VIEW
Rural Business Opportunity Grant (RBOG)	Technical and training services for rural businesses	USDA	http://www.grants.gov/search/search.do;jsessionid=td0RRymMGYpwRnHkxgWrvvszn64ny1ZfkpMsMhvvDP12zJh36n3K!856986300?oppId=235219&mode=VIEW
Public Transportation on Indian Reservations	Increase access to transportation on reservations	DOT	http://www.grants.gov/search/search.do;jsessionid=td0RRymMGYpwRnHkxgWrvvszn64ny1ZfkpMsMhvvDP12zJh36n3K!856986300?oppId=233674&mode=VIEW
Rural Community Development Initiative (RCDI)	Aid for rural development projects	USDA	https://www.cfda.gov/?s=program&mode=form&tab=step1&id=77d7add2d3e374b260f063e114a0d04d
Outdoor Recreation Acquisition, Development and Planning	Assistance to plan and develop outdoor recreation sites	DOI	https://www.cfda.gov/?s=program&mode=form&tab=step1&id=d22c137cdbc03ccd6bdd5d0bb6abdbd7
Native American Graves Protection and Repatriation Act	Funding to consult and document Native remains and cultural items	DOI, NPS	https://www.cfda.gov/?s=program&mode=form&tab=step1&id=629aff983def2ce876d49a2815dadc33
National Park Service Conservation, Protection, Outreach, and Education	Program to assist and encourage conservation, historic preservation and sustainability	DOI, NPS	https://www.cfda.gov/?s=program&mode=form&tab=step1&id=866cc0fec5ee8b68b598780c5c4e3f74

Table 8.2. Federal assisted programs for preservation projects and to develop access to tourist sites.

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Photo: Julie Nania.

CHAPTER 9
FISH, WILDLIFE, PLANTS, AND BIODIVERSITY

The Navajo Nation (NN) encompasses a diverse group of ecosystems ranging from sub-alpine conifer forests to desert scrub (Nystedt, 2005), at elevations that vary from roughly 2,600 to 10,400 feet. It is home to thirteen federally endangered or threatened species, as well as six species or subspecies of plants and animals that are endemic to the area (Nystedt, 2005). The Navajo Nation Code (NNC) protects many additional plant and animal species that are considered threatened by the NN, including the bald eagle, bighorn sheep, and razorback sucker (Department of Fish and Wildlife, 2008).

The biodiversity of the NN plays an integral role in Navajo life. As important plant and animal species are becoming scarcer, many Native American communities are finding it increasingly difficult to practice traditional cultural activities. Although the Navajo economy is not based on subsistence activities, many Navajo still engage in traditional hunting, fishing, and gathering to supplement their diets with plants and animals. Traditional medicines, derived from wild plants, remain an integral part of life (Houser et al. 2001). In addition, some Navajo strongly associate with particular species as part of their clan identities. Many also respect and hold sacred the individual roles of all life on Mother Earth and consider all species to be relatives. Impacts on species and natural ecosystems are thus of inherent concern.

9.1 Potential Climate Change and Variability Impacts on Fish, Wildlife, Plants, and Biodiversity

Key Point

- Ecological changes may increase or decrease species population numbers, and alter distributions and the timing of life cycle events

Climate and hydrologic changes (see Chapter 3) may lead to a variety of ecological changes on the Reservation. Ecological changes may include increases or decreases in the overall abundance of plants and animals, changes in population distributions as species shift towards the poles or along elevational gradients to keep within certain temperature ranges, and alterations in the timing of life

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cycle events such as animal migrations (Manley, 2008). Examples of changes already occurring in the SW, or potential future changes, are discussed below. We refer readers to Chapter 10 of this report for more impacts specifically related to forests. In addition, the National Fish, Wildlife, and Plants Climate Adaptation Strategy (NFWPCAS, 2012) provides an extensive table of observed and projected ecological changes according to broad ecosystem categories. Cultural dependence on the availability of certain plants and animals will likely be affected by these changes (Manley, 2008).

Photo: Julie Nania.

At a 2011 Institute for Tribal Environmental Professionals (ITEP) workshop, tribes in the Four Corners region noted a variety of changes taking place in wildlife species' geographic ranges and population sizes. Some of these changes are likely related to the ongoing drought, and could be indicative of similar changes that might occur in the future if droughts increase in frequency, intensity and duration. Elk are wintering in different places, while predators such as bobcats and bears are heading to lower elevations (Wotkyns, 2011). Skunks, bobcats, bears, mountain lions and elk are changing their locations according to changes in vegetation and prey behavior, prairie dogs are moving into populated and irrigated areas, and sandhill cranes and white winged doves are moving north (Wotkyns, 2011).

In recent years the tribes have also observed that there are fewer songbirds on their lands, populations of mule deer and prairie dogs are shrinking, quail are producing fewer clutches per year, eagles have abandoned their eggs, and populations of bark beetles, grasshoppers and mosquitoes have increased (Wotkyns, 2011). In a number of areas losses of medicinal plants, native tobacco, pinyon and cottonwood trees have also been reported (Wotkyns, 2011).

Changes in phenology are already occurring in the Southwest (SW), although they are more evident in moister, higher elevation regions than in more arid, lower elevation regions (Fleishman et al. 2013). Observed changes include: earlier arrival of migratory birds at their breeding sites, earlier emergence of butterflies, earlier egg-laying by Mexican Jays, and earlier emergence of marmots from hibernation (Fleishman et al. 2013). Some forbs are blooming earlier, increasing the probability that they may be killed by subsequent frosts (Fleishman et al. 2013). Observed decreases in the abundance of flowers mid-growing season could have negative impacts on pollinators that depend on them (Fleishman et al. 2013). In stream ecosystems, warming water temperatures can trigger fish fry to emerge from their eggs earlier than normal. In turn, this may lead to a mismatch between fry and their food supplies if the timing of their life cycle does not change at the same rate (Crozier et al. 2008).

Key Points

- Climate changes may change interspecies relationships by reducing available prey and increasing competition
- Increased incidence of extreme weather events, such as wildfires or droughts, may affect important lifecycle triggers for some plants and animals

Changes in climate could affect interactions among species, such as predator-prey relationships, herbivory, competition, parasitism, disease and mutually beneficial relationships (Fleischman et al. 2013). For example, some tribes have reported that decreases in prairie dog populations reduce the prey available to eagles (Wotkyns, 2011). This, in turn, could affect eagle populations. The Bureau of Land Management's

Photo: Julie Nania.

(BLM) Rapid Ecological Assessment for the Colorado Plateau notes that more widespread fires affecting shrubland could lead to declines in the populations of small mammals that serve as prey for Golden Eagles, negatively affecting Golden Eagle populations in areas subject to fire (BLM, 2012). Since Golden Eagles have a broad range extending from Mexico to the Arctic, reductions in their prey base could lead them to relocate to other areas within their range.

Mule deer may also be vulnerable to disruptions in their food supply due to climate change. Mule deer feed on high quality forage that is more likely than other fodder to die off in warmer temperatures (deVos and McKinney 2007). In addition, the quality and quantity of certain brushes that mule deer feed on are dependent on winter precipitation. The quality of winter foraging conditions has been linked to mule deer population sizes (deVos & McKinney 2007). Changing fire regimes may also impact mule deer forage by favoring cheatgrass and displacing important native shrub communities that provide food for mule deer (NFWPCAS, 2012).

Similarly, drought is likely to influence the quality of food available to coldwater fish. Mayflies, for example, are an important source of prey for coldwater fish. Their emergence is triggered by warmer water temperatures, which indicate that peak streamflows have subsided. One study found that the mayflies that emerged during years with lower streamflows were generally smaller than those emerging during higher flow years, when emergence was delayed and larval feeding times were longer (Fleishman et al. 2013). Smaller mayflies provide fewer nutrients for coldwater fish.

Key Points

- Invasive species may be better adapted than native plants to take advantage of increasingly limited resources as the climate changes
- It may be difficult to distinguish nonnative, migrating species from invasive species

Members of SW tribes have expressed concern over recently observed increases in invasive species (Wotkyns, 2011). At 280 recorded species, Coconino County, located almost exclusively within the NN, has the highest number of documented invasive species in all of Arizona (EDDMapS, 2012).[1] SW tribal members have observed that native plants are progressively being replaced with non-native invasive species, such as tumbleweed (Russian thistle) and camelthorn (*Alhagi pseudalhagi*), a highly successful plant primarily spread by livestock grazing and wind (Wotkyns, 2011). Tamarisk, also known as saltcedar, is a plant that was initially introduced to prevent erosion. Instead, it forces out native plants in riparian corridors, including those on the Navajo Reservation (Wotkyns, 2011).[2] Cheatgrass, another invasive of serious

1 This number does not include invasive species found exclusively in the non-contiguous sections of the NN in New Mexico, including: Ramah Navajo Indian Reservation in western Cibola County, Alamo Bend Navajo Indian Reservation in northwestern Socorro County and Canoncito Indian Reservation in western Bernalillo County.

2 Saltcedar was intentionally introduced in the US to help control streambank erosion in riparian areas. Primarily as a function of its voracious reproductive capacity, saltcedar is outcompeting native cottonwoods and willows on the NN. Saltcedar seeds have no dormancy requirements and germinate in less than 24 hours, making the plant resilient and quick to spread. The seeds germinate best in moist silt, like that found in SW riparian habitats after floodwaters subside (Stevens, 1989a; Stevens, 1989b). Climate change is facilitating the spread of saltcedar because it is more tolerant than native species of harsh environmental extremes. Saltcedar's success in riparian

concern, has invaded native semi-arid grasslands and the open PJ woodlands of the Colorado Plateau (Grahame and Sisk 2002). Additional introduced species that have harmed plant communities on the Colorado Plateau include Dalmation toadflax (*Linaria dalmatica*) and leafy spurge (*Euphorbia esula*). Invasive plants consume scarce water resources (Grahame and Sisk 2002) and may even threaten the very survival of native species if they take over an ecosystem before natives are able to transition to new more suitable habitats (Tausch, 2008).

Photo: Julie Nania.

Invasive plants often have higher dispersal, reproduction and growth rates. In turn, these characteristics result in a greater ability to adapt to changing conditions,[3] and contribute to the establishment and persistence of invasive species (Fleischman et al. 2013). Climate change and variability could create triggers, such as severe storms, that induce non-native plants to become invasive, shift the ranges of invasive plants or play a role in their introduction or spread (NFWPCAS, 2012). To complicate matters further, it may be difficult to distinguish between a new species that is a threat to the native ecosystem, and a new arrival whose presence is justified by the changing climate.

9.2 Vulnerability and Adaptive Capacity Factors

Climate, hydrologic, and ecosystem changes interact with land use, political, socioeconomic and other vulnerability/adaptive capacity factors (Chapter 2) to intensify or reduce impacts on fish, wildlife, plants, and biodiversity. We discuss a number of these factors here.

Certain species may be more vulnerable to the impacts of climate change. Species that are likely to be particularly vulnerable include those with small geographic ranges, narrow physiological tolerance, limited dispersal abilities or a limited ability to colonize new areas, specialized habitat requirements, low reproductive rates, long generation spans, strong co-evolved dependencies, low genetic diversity, small populations, and dependencies on environmental cues that trigger, for example, breeding, migration, or hibernation (NFWPCAS, 2012). In addition, species that are already threatened by non-climatic factors may also be more vulnerable (NFWPCAS, 2012).

As discussed in Chapter 2, it is important to consider non-climatic factors in conjunction with potential climatic impacts when assessing adaptation strategies. Non-climatic stressors can negatively affect fish, wildlife and plants and can originate both on and off the Reservation. Potential stressors include: pollution; habitat loss and fragmentation from urban expansion, energy and other development, and road-building; increased human demands on water sources that lower instream flows; overgrazing, which contributes to land degradation and the spread of invasive species; and the disruption of historic fire regimes (NFWPCAS, 2012; Rose, 2010). However, the ability to respond to non-climatic stressors may be constrained by the availability of resources to monitor and plan for species transitions in response to climate change.

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environments in the SW appears to be a function of its phenomenal reproductive output and its greater drought and flood tolerance (Warren and Turner 1975).

3 Like native plants, certain invasive species could be adversely impacted by climate changes.

Key Points

- Species with small geographic ranges or populations, narrow physiological tolerance, limited dispersal abilities, specialized habitat requirements, low reproductive rates and genetic diversity, long generation spans and dependencies on environmental cues or other species may be more vulnerable to climate change impacts
- Stressors related to climate change include pollution, habitat loss and fragmentation, increased human demand for water, overgrazing, and the disruption of historic fire regimes
- Risk assessments can help identify climatic and non-climatic stressors that will affect a species or ecosystem

Vulnerability and risk assessments can help identify more specific climatic and non-climatic factors that are affecting, or have the potential to affect, a particular species or ecosystem. For example, the BLM is currently conducting Rapid Ecological Assessments (REA) to evaluate vulnerability factors for specific species (BLM, 2012). The REA for the Colorado Plateau found that declining Golden Eagle populations were caused by the combined impacts of conversion of open shrubland habitat to agricultural uses or by wildfires (affecting eagle prey populations); eagle mortality related to collisions with power lines, wind turbines, and vehicles; mortality related to secondary poisoning, when prey already-sickened by pesticides, rodenticides, or herbicides is consumed; and poaching, despite the protections of the Bald and Golden Eagle Protection Act. Thus, Golden Eagle populations are affected by stressors related to land use, infrastructure and law enforcement, in addition to climate change (BLM, 2012).

Non-climatic stressors may similarly impact other species. Livestock overgrazing and invasive species may reduce the vegetation available to mule deer (BLM, 2012). Desert bighorn sheep may be affected by diseases associated with proximity to domestic livestock (BLM, 2012). Identifying these and other non-climatic factors that influence species and ecosystems can provide a foundation for strategies to reduce the influence of these non-climatic stressors.

Photo: Julie Nania.

For more in-depth information on vulnerability assessments in a fish and wildlife context, we refer readers to a National Wildlife Federation (NWF) publication, *Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment* (Glick et al. 2011).

The NN already has several programs and plans in place that can provide additional adaptive capacity for responding to climate change. On the Navajo Reservation, the Navajo Nation Department of Fish and Wildlife (NNDFW) already stocks fishing areas to ensure that opportunities exist for fishermen. The Navajo Nation Invasive Plant Committee is developing a comprehensive *Navajo Nation Integrated Weed Management Plan* to address the control and management of non-native invasive species throughout the Reservation and surrounding communities. The plan calls for coordination with tribal, federal, and local partners and stakeholders, and could incorporate climate change considerations.

The NNDFW identified six types of wildlife areas, each of which merits different restrictions on development. A significant portion of the Reservation has been designated as area types 1 and 2, containing the best habitat for endangered and rare plants, animals and game species. Development is not permitted or is restricted within these areas. In addition, the NNDFW established the Navajo Endangered Species List and the Navajo Natural Heritage Program to catalog and monitor rare and at-risk plant and animal species to protect the Reservation's biological diversity.

Case Study: Desert Bighorn Sheep

Known as tsétah dibé to the Navajo, the desert bighorn sheep is not a federally listed species but is nonetheless protected on the NN under Navajo law (Mikesic and Roth 2008). The bighorn is a trophy species and an important feature of the rugged deserts on the Reservation. It subsists on the relatively low-quality forage and short grasses which populate desert slopes. Desert bighorn tend to avoid habitats with taller plants in order to maintain their ability to see potential predators (McKinney and Smith 2006). Because of this behavior, desert bighorns in Arizona struggle with highway and urban construction, degraded forage quality and quantity, and other human impacts which lead to shrinking habitat and populations (McKinney and Smith 2006). Climate change has the potential to impact desert bighorn habitat by reducing the quality of forage as rainfall decreases and average temperatures increase, both of which have already been noted in the SW (McKinney et al. 2006).

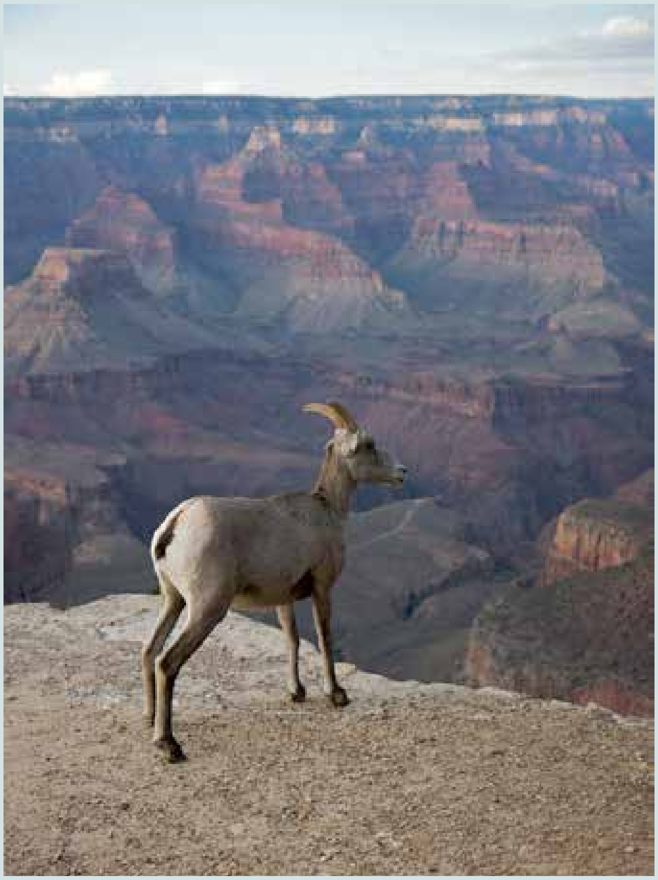

Photo: Wikimedia Commons, Marcin Wichary.

Protecting and restoring the Reservation's desert bighorn population has become a priority of both the NN and the Arizona Game and Fish Department. A partnership between these entities has succeeded in increasing the Reservation population from ten bighorn in the 1970s to over 300 today (Navajo Nation Zoo, 2011). The project also transplanted twenty sheep across highway 93 to Peoples Canyon, Arizona, to expand the range of the species and combat habitat reduction problems (AZGFD, 2011). The Navajo Zoo now houses several rescued desert bighorn sheep to remind people of the importance of the species to the Reservation (Davis, 2012). The success of the desert bighorn project is a significant example of what is possible when a concentrated effort is made to protect biodiversity.

The NNDFW is already studying certain species of concern. Recognizing the ecological and cultural importance of mule deer to the NN, the NNDFW and High Desert Adventures (a local hunting group) have instituted a 3-5 year *Navajo Nation Mule Deer Management Plan* (NNDRW, 2010). The plan includes research to understand herd composition and the effects of hunting on male, female and young populations. The plan also calls for multi-stakeholder input on the importance of the species to the NN. The partnership's goals are to restore the herd population to ideal population ratios, to possibly reconfigure game maps and target species, and to raise awareness of the importance of the species (NNDRW, 2010).

The mule deer is not the only species the Nation is working to conserve. After extensive research, the NN created its own lists of endangered and threatened species on the Reservation (Mikesic and Roth 2008) and developed specific conservation plans, including the Navajo Nation Management Plan for the Mexican Spotted Owl (Mikesic, 2000), the Bald and Golden Eagle Nest Protection Plan (NNHP, 2008) and the Mesa Verde cactus transplant program (Hazelton, 2011).

Key Points: Biodiversity Adaptation Strategies

- Identify wildlife zones and species
- Develop monitoring plans
- Implement specific protection strategies
- Protect habitat or create refugia
- Habitat restoration
- Use innovative agricultural, ranching, forestry and agroforestry techniques to create new habitat
- Reduce non-climatic stressors such as pollution and overgrazing
- Where appropriate, modify harvest limits/ seasons
- Improve wildlife disease surveillance and response
- Reduce non-climatic stressors
- Document local knowledge about species and ecosystem changes taking place
- Identify knowledge gaps, research priorities and potential partnerships for conducting research
- Engage the public in citizen monitoring and stewardship efforts
- Avoid deforestation and promote afforestation
- Continue researching at-risk species/ environments

9.3 Potential Adaptation Strategies for Fish, Wildlife, Plants and Biodiversity

To conserve fish and wildlife, the NN could build upon the strong adaptive capacity base it already has in place to locate, monitor and protect important habitats. For example, the Navajo Natural Heritage Program can provide the foundational information that is necessary for habitat management. The NNDFW could work with other governmental agencies, such as the United States Forest Service, the National Park Service and state wildlife agencies, to develop appropriate adaptation strategies. These agencies can provide guidance on region-specific adaptation strategies, which the NNDFW may consider and implement. For example, in September 2009 the Association of Fish and Wildlife Agencies helped state wildlife agencies assess climate change strategies and create adaptation plans (FWA, 2009). That same year, Jonathan Mawdsley and co-authors published a paper in *Conservation Biology* that reviewed "climate-change adaptation strategies for wildlife management and biodiversity conservation." (Mawdsely et al. 2009) In 2010, the USFW published *Rising to the Urgent Challenge: Strategic Plan for Responding to Accelerating Climate Change* (Fish and Wildlife Service, 2010). In 2012 the National Fish, Wildlife, and Plants Climate Adaptation Partnership issue0d the *National Fish, Wildlife, & Plants Climate Adaptation Strategy* (NFWPCAS, 2012). We identify relevant examples of fish and wildlife climate change adaptation strategies from these and other reports below. Strategy categories and approaches may overlap with one another. For additional strategies and more in-depth discussion, we refer readers to the original documents.

Protecting biodiversity involves many areas of focus. One option for habitat conservation strategies is to identify refugia as sites for long-term species retention. Refugia are areas that are naturally buffered against ecological disturbances and climate changes, enabling them to act as refuges for species.

Direct species management strategies could focus on the species' specific range and risks, particularly along major ecological transition zones between eco-regions. Mapping at-risk species to determine potential conservation zones or alternative habitat areas may help insure against the potential loss of habitat due to climate change. Relocation of vulnerable species (i.e. human-facilitated translocation to bypass a barrier) to sites where conditions are more favorable could also be considered (Mawdsely et al. 2009; NFWPCAS, 2012).

For long-term species conservation it may be helpful to form partnerships with zoos, botanic gardens, arboreta and aquaria. These facilities can help to establish captive populations of species (Mawdsley et al. 2009). Seed banks can also help to preserve the genetic diversity of plants (NFWPCAS, 2012).

Strategic restoration activities constitute another important component to the protection of biodiversity. Strategies may include restoration of existing protected areas or targeted restoration efforts to maximize ecosystem resilience or maintain ecosystem function. "Resilience" refers to an ecosystem's capacity to resist change, the degree of change it can experience while retaining control over its structure, and its ability to reorganize itself after disturbance (Bunnell and Kremsater 2012). An example of a restoration project that maximizes ecosystem resilience is the restoration of wetlands and natural floodplains, which dissipate wave energy, minimize erosion to upland ecosystems, and improve water quality by filtering out pollutants and sediments (Interagency Workgroup on Wetland Restoration, 2003; Rose, 2010). A variety of restoration methods can be employed, including the installation of fencing to prevent cattle from overgrazing wetland vegetation, and the re-contouring of a site to achieve a topography that allows wetland vegetation to thrive (Interagency Workgroup on Wetland Restoration, 2003). One example of a restoration project that maintains ecosystem function is the creation of a forest riparian buffer to slow water flow, which may have elevated nutrient levels from agricultural runoff, to facilitate nutrient uptake by plants before the water reaches a stream (Mawdsley et al. 2009).

Key Points

- Restoration strategies may seek to restore existing protected areas, maximize ecosystem resilience and/or maintain ecosystem function
- Habitat representation, replication and connectivity are factors that can help protect species against uncertain climate changes

Realignment is a process by which ecosystems are restored to current or anticipated future conditions, rather than to historical ones, and is a promising method for ecosystem conservation (Millar et al. 2007). For example, fire-adapted vegetation may be seeded or planted in forests that are susceptible to increased wildfire frequency and severity (Rose, 2010). Even if restoration projects are not sustainable in the long-term, they may provide shorter-term benefits for species in transition (Mawdsley et al. 2009). In addition, some SW tribal members have noted that restoration work could potentially provide additional reservation jobs (Wotkyns, 2011).

Another approach to adaptation is to increase the extent of protected habitats and promote habitat connectivity. In choosing which areas to protect, habitat representation is an important factor to consider. Protecting areas with a variety of physical environments (e.g., topography, geology, soil) and biological communities can help conserve a broad range of genetic diversity (Mawdsley et al. 2009). Another factor to consider is replication. Multiple examples of a single ecosystem type should be protected to help guard against the uncertain impacts of climate change and other stresses (Rose, 2010). Finally, the ability of species to move within various habitat areas can be enhanced by promoting habitat connectivity with movement corridors (both along elevational and latitudinal gradients), stepping stones (i.e. habitat islands between larger reserves), or stopovers for migratory waterfowl.

Research, monitoring of species and adaptive planning will all be crucial for the success of conservation activities in the long-term. Strategies could include improvements in the coordination and efficiencies of wildlife and ecosystem monitoring across NN agencies and among tribal, state, and federal entities. Climate change considerations could also be incorporated into species, land/water management, and economic and development plans (Mawdsley et al. 2009). Monitoring data can be used to quantify changes to wildlife and ecosystems, to develop management strategies, and to evaluate the effectiveness of strategies that are implemented. Improving coordination in monitoring among NN agencies and among tribal, state, and federal entities could help improve efficiencies and decrease costs. Citizen monitoring efforts such as the National Phenology Network, based out of the University of Arizona (http://www.usanpn.org), or public efforts to identify invasive species could provide additional monitoring resources.

Key Points

- Climate change should be considered as part of the long-term focus of any species, land/water management, and economic and development plans
- Public outreach and education are important components of climate change planning

To be successful, climate change planning and conservation will need to involve outreach and education of the general public. Strategies must focus on increasing public awareness and understanding of potential climate change impacts on fish and wildlife.

Mitigation efforts designed to reduce overall GHG emissions should be a long-term focus of any conservation plan. Habitat improvements, afforestation and restoration of degraded lands will help to sequester carbon and improve the overall state of the larger ecosystem. Beyond direct conservation measures, promoting 'green' activities and energy efficiency measures may help reduce certain climate change impacts.

9.4 Potential Funding and Other Support

A number of federal programs, most notably from the United States Department of Interior (DOI), provide assistance to address wildlife management, habitat conservation, and restoration activities. Some of these programs deal with species protections, while others offer assistance for long-term habitat planning.

Funding Opportunity	Area of Focus	Source	Enablement and Website
Tribal Wildlife Grant and Tribal Landowner Incentive Program	Wildlife preservation grants	DOI, USFWS	http://wsfrprograms.fws.gov/subpages/GrantPrograms/TLIP/TLIP.htm
Cooperative Landscape Conservation and Adaptive Science	Adaptive management program for habitat conservation	DOI, USFWS	http://www07.grants.gov/search/search.do;jsessionid=1zq2RhrVLlHt2DMD11f11JbntjhsqKtWJhqh6G7W2f088GhzJypJ!1585022828?oppId=173973&mode=VIEW
Fish and Wildlife Management Assistance	Help protect wildlife species and minimizing invasive species	DOI	https://www.cfda.gov/?s=program&mode=form&tab=step1&id=918ff6b127f35f4769bf19782629bcb3
Partners for Fish and Wildlife	Technical and financial support for restoring native habitat	DOI, USFWS	https://www.cfda.gov/?s=program&mode=form&tab=step1&id=8dafc52e565501e22fc041c9153f7305
Endangered Species on Indian Lands	Help implement endangered species protection	DOI, BIA	https://www.cfda.gov/?s=program&mode=form&tab=step1&id=b3df86f0f59751311ea5649350e62adc
Lower Colorado River Multi-Species Conservation Program	Aid in protection of habitat and water quality and quantity	DOI, BOR	https://www.cfda.gov/?s=program&mode=form&tab=step1&id=f970a7cea51ead2c89f9aa6f23b2970b
Upper Colorado River Basin Fish and Wildlife Mitigation Program	Aid in wetland and other ecosystems conservation	DOI, BOR	https://www.cfda.gov/?s=program&mode=form&tab=step1&id=709bf4513b394ba98c89803b7e2021f6
Voluntary Public Access and Habitat Incentive Program	Public access grants to increase wildlife area and conservation programs	USDA, FSA	https://www.cfda.gov/?s=program&mode=form&tab=step1&id=49390c337683ee218680750655e89c1e
Community Forest and Open Space Conservation Program	Support to establish protected forest land	USDA, USFS	https://www.cfda.gov/?s=program&mode=form&tab=step1&id=1c9139179a87c6b4edf68cd423e3b5b0
Wildlife Habitat Incentive Program	Aid to protect wildlife species and habitat	USDA	https://www.cfda.gov/?s=program&mode=form&tab=step1&id=1df0cf74b009ece09a4aa2e60d6899e1
Conservation Stewardship Program	Assistance to protect natural resources and landscapes, including rangeland	USDA, NRCS	https://www.cfda.gov/?s=program&mode=form&tab=step1&id=779dad5af70cf80df15191c1d65428e3

Table 7.2. Federal assisted programs for adaptation strategies, health education projects, and health services.

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Photo: Julie Nania.

CHAPTER 10
FOREST RESOURCES

The Navajo Forest has significant economic, social and cultural importance and is a key resource on the Navajo Nation (NN) (Pynes, 2013). The Reservation contains approximately 1 million acres of ponderosa pine and mixed conifer forest and an additional 4.8 million acres of pinyon-juniper (PJ) woodlands, with woodlands typically being drier than forests (Tiller, 2005; NFDe, 2013). The bulk of the pine-fir forest, which includes ponderosa pine, Engelmann spruce, Colorado blue spruce, Douglas fir, and corkbark fir, is located on the Defiance Plateau and in the Chuska mountain range in eastern Arizona and western New Mexico (Yazzie, 1987).

The Navajo Forestry Department (NFD) manages all tribal forests except those located in national parks and historic sites (Public Lands Interpretive Association, 2012). Timber harvesting has been going on in Navajo forests since the early 1880s (Einbender-VelezLeGrand, 1993). Historically, forests were managed by the Bureau of Indian Affairs (BIA). In the early 1970s the NFD began taking over Navajo forest operations. Today, the NFD manages about 600,000 acres of the Reservation's pine-fir forest and all of the Reservation's PJ woodlands with only a limited staff (Patrick, 2011). The NFD has evolved from a contractor for thinning operations to the entity in charge of almost all aspects of Navajo forest management. Currently the NFD issues forest/woodland product permits, develops regulations and management plans for specific forest areas, enforces regulations, and prepares and administers timber sales. (Einbender-VelezLeGrand,1993; NFDa, 2013; NFDb, 2013; NFDd, 2013). In addition, the NFD is responsible for fire prevention, thinning, reforestation, disease control, and conducting forest inventories (Einbender-VelezLeGrand, 1993; NFDb, 2013; NFDc, 2013; NFDd, 2013). Approximately 230,000 acres of Navajo pine/mixed conifer forests and 1.1 million acres of PJ woodlands are open to commercial use (NFDe, 2013; Becenti, 2010).

NN Forests are utilized for a variety of purposes, including firewood gathering, supplying wood products for home building, and livestock grazing (Einbender-VelezLeGrand, 1993). The NFD sells timber to local residents from a woodlot business, and sold 363 cords (454 tons) of firewood to 2,474 customers in 2012 (NFDe, 2013). Woodlot supplies are limited, and in past years the NFD has encouraged local residents to gather their own wood before winter limits supplies (NFDe, 2013).

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Photo: Julie Nania.

The Navajo do not just utilize forests for wood products and grazing. Many Navajo also have significant cultural ties to their forests. The presence of a healthy forest is important for the life bond between the Navajo and their environment (Einbender-VelezLeGrand, 1993). Many cultural traditions rely on forest resources as a source of medicine, herbs, and food (Einbender-VelezLeGrand, 1993; FTT, 2012).

In addition to fulfilling traditional needs and common uses, NN forests provide important ecosystem services. Winter snowpack in the forest region is an important source of water for the area. Forests help regulate the timing and amount of surface and groundwater discharge through slowing runoff and increasing filtration and also improve water and air quality (Einbender-VelezLeGrand, 1993; FTT, 2012). Forests provide wildlife habitat and recreational opportunities (NFD f, 2013) and play an important role in storing and sequestering carbon (FTT, 2012).

10.1 Potential Climate Change and Variability Impacts on Forest Resources

Climate change could have a significant impact on NN forests. One study has noted that on the Colorado Plateau "[t]hose habitats with the highest temperature change and the most species of conservation concerns include subalpine forests, PJ woodlands, sage shrublands, and Colorado Plateau canyonlands and grasslands" (Robles and Enquist 2011). NN forests are largely composed of a combination of these ecosystems (with the exception of subalpine forests). Climate change may affect forest and woodland ecosystems by causing shifts in the distribution and viability of plant and animal species, altering forest processes such as tree demographics and carbon and nutrient cycling, and altering forest disturbance regimes (such as fire cycles) (Dale et al. 2001).

Key Points: Potential Climate Change and Variability Impacts on Forest Resources

- Shifts in the distribution of species
- Altering forest processes such as tree demographics and nutrient cycling
- Changes in forest disturbance regimes including fire cycles

Climate change and variability impacts on forest ecosystems can, in turn, have socioeconomic effects on the people who use forest resources (Dale et al. 2001). This section focuses on potential changes in forest disturbances that may result from climate change. These include changes in fire frequency and intensity, drought frequency, intensity, and duration, insect and pathogen epidemics, and the ways in which these disturbances interact.

Fire

Fire is a natural and recurrent feature of the SW landscape. Climate can influence fire frequency, intensity, and size by affecting fuel availability and flammability (Fleishman et al. 2013). Fires, in turn, affect forest ecosystems by contributing to habitat conversion and causing tree mortality, shifts in successional directions and erosion (Dale et al. 2001). These fire impacts can affect forests as a resource

Key Points: Potential Climate Change Impacts on Wildfire Regimes

- Changes in the frequency, intensity and size of fires
- Increased fires may result in tree mortality and habitat conversion

for wildlife habitat, timber, and recreation. In addition, fires can negatively impact human health (Dale et al. 2001).

The frequency and size of fires has increased throughout the West since about the mid-1980s (Fleishman et al. 2013; Robles and Enquist 2011). Record-setting fires have occurred in Arizona and New Mexico within the past decade, resulting in changes to the landscape (Steenburgh et al. 2013). Members from tribes in the SW also have reported an increase in fire intensity and frequency. As a result, fires have endangered historical sites and affected water quality, fisheries, traditional and exotic species, salamanders, mudslides, and flooding (Wotkyns, 2011). In the future, warmer temperatures, increased drought frequency, severity, and duration, and longer forest fire seasons associated with earlier snowmelt and ground exposure are anticipated to lead to increased fire frequency, severity, and size (Westerling et al. 2006).

Historically, large fires were common in the forests of Arizona, New Mexico and southern Utah (Keane et al. 2008). However, these fires were low intensity and low severity fires, causing very little tree mortality. In modern times, fire regimes have been disrupted by logging, livestock grazing, and fire suppression. This disruption has allowed the development of dense forest canopies and high fuel loads. As a result, in contrast to historic fires, large, modern fires are primarily crown-type fires, such as the 2002 Rodeo-Chediski fire in Arizona, which affected forests and grazing lands belonging to the White Mountain Apache Tribe (Redsteer et al. 2013).

Large crown fires can lead to long-term changes in forest habitat (Keane et al. 2008). A survey of ponderosa pine forests severely burned by crown fires found that only roughly one third had recovered to historic ecosystem forest structure. Another third became "hyper-dense" forests, vulnerable to further crown fires. The final third converted to grasslands or oak woodlands (Keane et al. 2008). In mixed pine-oak forests, severe fires resulted in landscapes with more oak and less pine. Invasive species have also been quick to colonize some burned areas (Keane et al. 2008).

In PJ woodlands, although total fuel loads can be high, surface fuel loads are typically low and the tree canopy is often discontinuous (Keane et al. 2008). Thus, historically, widespread, low-intensity fires in PJ woodlands have been infrequent, with large, stand-replacing fires occurring mainly during very dry conditions with high winds. Drier conditions and increased winds make PJ woodlands more likely to burn (Fitzgerald, 2013). Accordingly, climate change may lead to increased risk of fire in PJ woodlands. In addition, higher temperatures and CO_2 levels may be contributing to increased foliage and canopy extent in PJ woodlands, and to the growth of introduced annuals (Keane et al. 2008). These increases in foliage, canopy extent, and growth of annuals could affect both PJ fire regimes and post-fire ecosystem trajectories. As an ecosystem, PJ woodlands are not adapted to frequent fire. Recent drought has caused large crown fires in some PJ woodlands, resulting in their conversion to desert grasslands (Fitzgerald, 2013). This burn/conversion pattern may become more commonplace with anticipated climate changes.

Drought and warmer temperatures

Like fire, drought is also a natural and recurrent feature in the SW. Direct effects of drought on forests include water stress, reduced reproduction, reduced biomass in the understory, and, if conditions become intense enough, tree mortality (Dale et al. 2001; Redmond, 2013). Small plants, such as seedlings or saplings, are more susceptible to drought-related die-off (Dale et al. 2001). Large trees, having deeper root systems and greater reserves of carbohydrates and nutrients, are less susceptible to die-off, but may nonetheless die if conditions become severe enough (Dale et al. 2001). One indirect effect of drought on forests is to make trees more susceptible to insect or disease outbreaks. Another indirect affect is to increase the flammability of the forest by decreasing decomposition rates and allowing organic material to build up on the forest floor (Dale et al. 2001).

In addition to the effects noted above, drought, in combination with warmer temperatures, could impact the production of pine nuts throughout the SW region. During normal years, pine nuts create a substantial opportunity for income generation. However, due to warming temperatures, pine nut production at higher elevations has fallen by approximately forty percent in the past four decades (Redmond, 2013). Increasing temperatures likely impact seasonal triggers for cone production and may further reduce the pine nut crop. Pine trees at lower elevations are also restricted by water availability. Thus, drought conditions may lead to fewer pine cones being produced (Redmond, 2013).

Beyond causing the production of fewer pine cones, drought may impact the pine nut crop by decreasing the number of cone-producing trees. The rapid and nearly complete pinyon pine mortality at a number of locations in the SW between 2000 and 2003 was attributed to bark beetle outbreaks in trees made more susceptible to die-off by drought-created stress exacerbated by warmer temperatures (Fleishman et al. 2013). Because of pinyon nut reproduction cycles, it may be several decades after a large die off before pre-drought production levels can be attained again (Breshears et al. 2011). In addition, observations indicate that drought can alter PJ woodland structures at regional scales (Robles and Enquist 2011). In some locations, widespread pinyon mortality has shifted PJ woodlands from predominately pinyon to predominantly juniper stands (Robles and Enquist 2011).

Key Points: Climate Change, Drought and Potential Impacts on Forests

- Direct effects may include water stress, reduced reproduction, increased tree mortality
- Indirect effects of drought may include increased forest flammability, susceptibility to insect and disease outbreaks, increasing fire risk
- Pine nut production may drop

Beyond affecting trees, drought can also impact other aspects of forest ecosystems. Severe drought can cause a reduction in understory vegetation that may pave the way for invasive species such as cheatgrass and thistle. Changes in understory vegetation may, in turn, alter the fire regime and reduce forage production and habitat quality for wildlife. For example, during droughts, oaks have reduced or ceased production of masts, which are an important source of food for wild turkeys and bears.

Insect and disease outbreaks

Climate change can directly affect the survival, reproduction, dispersal, and distribution of insects and pathogens (Dale et al. 2001). It can also indirectly impact insects and pathogens by affecting organisms that compete with or consume them. Because of the complexity of interactions, climate change and variability may cause increased disturbance from a particular insect or disease in some cases, and result in decreased disturbance in others (Dale et al. 2001). Although wildfires are a serious potential threat from climate change, in many cases forests are influenced more by insects and disease than by fire. For example, as of 2010, the forested area in Arizona and New Mexico affected by bark beetles was twice that affected by fires in recent decades (Fleishman et al. 2013).

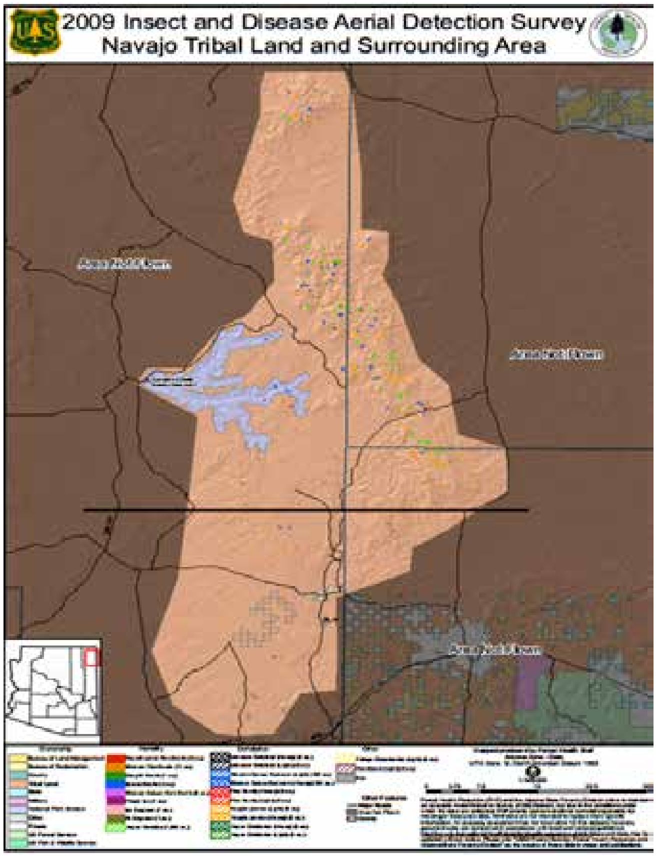

Figure 10.1. Map of bark beetle impacts on tree stands. Colored dots indicated mortality and defoliation.

Bark beetles are one example of an insect that is affected by climate. Bark beetles have impacted approximately 300,000 acres of PJ woodlands on the Reservation and could potentially threaten more acreage with severe tree die-off (Becenti, 2010). Although bark beetles are a natural component of the region's ecosystem, warming temperatures have allowed them to move northward and to higher elevations, and to survive the winter in greater numbers (NFWPCAP, 2012). Warmer temperatures have also sped up the beetle's life cycle, allowing more generations to be produced each year (NFWPCAP, 2012). In the early 2000s, prolonged drought stressed trees and rendered them more susceptible to mortality from bark beetle outbreaks. The combination of more bark beetles and increased tree vulnerability has led to severe tree die-off in some locations. During 2002 and 2003, approximately 20 million ponderosa pines died in Arizona and New Mexico. On the NN, higher elevation forests were the hardest hit by the bark beetle epidemic (McKinnon, 2005).

The impact of bark beetle outbreaks reaches beyond tree mortality. Both snowpack and runoff are affected as beetle-kill trees die off. Winter snow accumulation in the forests of the SW is an important source of runoff that feeds groundwater and stream sources (Guido, 2008). The presence of trees regulates snowmelt and the accumulation of snow. Research has demonstrated faster snowmelt and greater snow accumulation in pine beetle impacted areas (Pugh and Small 2002). Dropped needles may act to decrease snow albedo causing snow to melt faster. In addition, as trees die and lose their needles more sunlight reaches the ground causing faster melting than would occur if the ground were shaded by a more intact canopy (Pugh and Small 2002). The decrease in tree canopy also allows more snow to accumulate on the ground, leading to increased runoff from snowmelt (Pugh and Small 2002). The resulting increase in the amount and intensity of runoff could potentially lead to flooding and erosion. Although forest comprises less than five percent of the Reservation, the winter snow pack in this relatively small area is an important source of water in a dry land (Einbender-VelezLeGrand, 1993). Earlier snowmelt in pine beetle affected areas may have large ramifications for lakes, streams, forest ecosystem recovery, and fires.

10.2 Vulnerability and Adaptive Capacity Factors

Climate, hydrologic, and ecosystem changes interacting with land use, political, socioeconomic, and other vulnerability/adaptive capacity factors can either create or help lessen impacts on forest ecosystems. Vulnerability factors that may stress forest ecosystems include: overgrazing, certain timber harvesting practices, air pollution, and conversion to agricultural uses (FTT, 2012). Another vulnerability factor is constraints on economic and personnel resources that can affect on-the-ground management efforts. Regulatory barriers can make it difficult to obtain federal funding for forest management on the Reservation. For example, because most NN commercial forests are not located adjacent to federal lands, they are not eligible for funding under the Tribal Forest Protection Act (Becenti, 2010).

Adaptive capacity factors include collaboration between NFD and Kaibab National Forest employees, the Native Plant Garden and greenhouses maintained by the NFD, and hazard fuel reduction practices. Additionally, although the Navajo Forest Management Plan and timber operations on the Reservation have met with some controversy in the past, both include aspects that could contribute to the adaptive capacity of the Nation in the future. The following material discusses each of these adaptive capacity factors in more detail.

Collaboration with Kaibab National Forest

The NFD has recently begun collaborating with employees of the Kaibab National Forest near Flagstaff, Arizona, to discuss possible resource sharing options (Patrick, 2011). Increased coordination between the NFD, other tribal governmental entities, and non-tribal government agencies involved in forest management could facilitate the creation of effective mid- and long-term climate change adaptation strategies.

Navajo Native Garden and NFD Greenhouses

The Navajo Native Garden in Fort Defiance was started nearly thirty years ago by the NFD. The garden contains over 110 plants important to the Navajo for medicinal, culinary, basketry, or ceremonial uses (Hongeva, 2013). Future plans include adding sculptures and a play-area for children as well as hosting gardening workshops (Hongeva, 2013). The NFD greenhouses have grown over 4 million seedlings for use in restoring forests around the Reservation and for reclaiming coal mines (Hongeva, 2013). Maintaining the Navajo Native Garden preserves native plant species need they be reintroduced to particular areas in the future.

Hazard fuel reduction practices

The NFD currently conducts hazard fuel reduction practices such as thinning. Various studies have examined areas burned in the massive 2002 Rodeo-Chediski fire in Arizona and reported that trees in areas that had not undergone fuel reduction experienced high mortality (Keane et al. 2008). In contrast, in areas that had received fuel reduction treatments in the preceding eleven years (such as prescribed fire or cutting and burning) exhibited primarily surface fire behavior and most trees survived. Moreover, the treated areas protected adjacent, untreated areas on the downwind side, suggesting that hazard fuel reduction practices and ecological restoration can reduce the impacts of fires (Keane et al. 2008).

Forest management plans

In the early 1990s, the NFD developed a 10-year Navajo Forest Management Plan (NFMP) that made use of a "Legacy Forest" approach with the goal of meeting current needs while preserving the forest for future generations (Einbender-VelezLeGrand, 1993). The plan included provisions protecting some sensitive areas from harvest. Plan provisions addressed riparian zones, sacred sites, buffers around home sites, Mexican spotted owl habitats and blue spruce stands vulnerable to management concerns. However, implementing the original NFMP proved complicated, and there was controversy surrounding both the NFMP and timber operations taking place at the time (Einbender-VelezLeGrand, 1993). Examining the problems surrounding the original NFMP may provide insight into how future plans could be altered to potentially improve forest management and thus increase adaptive capacity.

Under the NFMP, many residents approved of timber operations because of the revenue, employment, and wood collecting opportunities the operations provided. However, residents also had serious concerns about the protection of wildlife and about the slash left behind, which was unaesthetic and frequently hindered grazing. Some also felt that the amount of harvesting taking place was unsustainable and that sacred sites were not being protected to a sufficient degree. In addition, the logging of old growth, or grandfather trees, was a grave concern for some because of the loss of both wildlife habitat and the Navajo culture that the trees represented (Einbender-VelezLeGrand, 1993). The NFD felt that its restrictions on harvesting were adequate to protect the biodiversity supplied by the old trees (Einbender-VelezLeGrand, 1993). Suggestions for improvements in timber harvesting based on one research project that took place during the late-1980s/early-1990s included better protection of sacred sites, improved post-harvest restoration, improved communication between residents and the NFD, and management that showed more respect for the forests and forest residents (Einbender-VelezLeGrand, 1993).

At present, the NFD has a comprehensive Forest Management Plan (FMP) (Becenti, 2010). Because the NFD is funded through the BIA, this plan must follow the federal forest management plan requirements (25 USC. 3010). Federal forest management plans require addressing fire and insect management, conducting regular forest inventory assessments, and establishing forest goals (BIA, 2009). Every alteration to the management plan and any forest actions must be in compliance with the National Environmental Policy Act, the Endangered Species Act, and the National Historic Preservation Act (BIA, 2009). The current FMP also includes guidelines for future timber operations.

Climate change considerations could potentially be included in future updates of the FMP. However, currently, because of financial and resource constraints, the department has not been able to implement the plan in full. This lack of implimentation is contributing to minimal fire management in forests on the Reservation. Lack of fire management is of concern given the current occurrence of large, catastrophic fires in the SW and the fact that wildfires are likely to increase in frequency and extent in the future (see Chapter 3).

Timber industry

From 1962 to 1994, the Navajo Forest Products Industry (NFPI), a tribal corporation, ran most of the tribal timber business, producing annual harvests of approximately 40 million board feet and employing around 400 people (Einbender-VelezLeGrand, 1993). However, because of local controversy surrounding forest management, forest degradation, and huge company debt, NFPI closed down in 1994 and the NN was forced to bail out the company (Manning, 1995). Since then, Navajo forests have largely been left to recover and be used for local purposes (Dine CARE, 2010).

There are no longer any large-scale sawmills on the NN. In 2012, NFD purchased a portable sawmill, which they hope will encourage the timber industry to restart (NFDa, 2013). A timber management program will operate under the NFD with the goal of increasing timber production on the Nation in a way that will use tree harvesting to improve the health of forests. By guiding the harvesting of certain forest areas, the management plan aims to limit forest fires, prevent the spread of insect pests, improve wildlife habitat, and improve range and water quality (NFDa, 2013). All of these goals are relevant both today and as adaption strategies for future climate change.

Some local residents are voicing concerns regarding the regrowth of the timber industry, pointing to past degradation of forest resources and the importance of the limited forestland on the Nation (Dine CARE, 2010). The timber industry on the Nation has a complicated past and an unclear future. Future management will require consideration of job creation, traditional cultural, wildlife, and water resource needs, and potential climate change impacts on forest ecosystems.

10.3 Potential Adaptation Strategies for Forest Resources

Incorporating climate change considerations into forest management on the NN will require addressing the shortcomings of past management strategies, addressing current forestry issues such as degraded ecosystems, and adapting for warmer temperatures, increased droughts, increased wildfire frequency and extent, and more severe weather.

Forests have been adversely impacted through past management decisions, natural disasters, insect infestation, and invasive species. Forest restoration, realignment, and management will necessarily incorporate various treatments to address wildfire mitigation, forage improvement, wildlife habitat improvement, and ecological restoration (Romme et al. 2009).

One often-cited conceptual framework for thinking about adaptation strategies and treatments for managing forests under changing future climate conditions was presented in a paper by Millar et al. and involves considering resistance, resilience, and response options (2007).

Resistance strategies try to minimize or prevent changes to forests (Millar et al. 2007). One example of a resistance strategy is installing a complete fire fuel break around a location containing a threatened or endangered species. Additional examples include intensive removal of invasive plants or taking defensive actions at key migration points to block incursions of pests or diseases into new areas (Millar et al. 2007). There have been many advances in insecticide treatments of tree stands to withstand beetle attacks (Fettig et al. 2013). Because resistance strategies often have high costs, and because conditions may eventually change, resistance strategies are often considered best used as short-term measures for protecting highly valued resources such as grandfather trees.

General Forest Resource Adaptation Strategies
• Implement fuel reduction
• Implement forest thinning as a source of firewood or for commercial use
• Implement uneven-aged forest management
• Use prescribed burning
• Develop an aggressive fire management program to improve forest health
• Incorporate fire management into planning
• Partner with the USFS; consider sharing traditional knowledge with foresters
• Establish a greenhouse with native seedlings
• Consider cultural traditions(e.g., wildfires part of the natural cycle)
• Maintain biological diversity by developing plans for species sensitive to fire
• Plan for post-disturbance management. Treat forest fires as a natural ecological disturbance
• Implement early detection and rapid response- Monitor post-fire and remove/control exotic species
• Determine native species tolerant of fire
• Incorporate climate change and variability considerations into planning

Table 10.1. General forest resource adaptation strategies.

Resilience strategies increase the ability of ecosystems to return to prior conditions after a disturbance such as a fire or insect infestation (Millar et al. 2007). Examples of resilience strategies include reducing non-climatic stressors on forest ecosystems, thinning dense forest stands, removing ladder fuels under fire resistant trees, and using prescribed fire to burn fine fuels, kill fire susceptible trees, and decrease forest susceptibility to high intensity fires (Millar et al. 2007).

Two additional resilience strategies are protecting refugia and intensively managing vegetation restoration to help promote the establishment of native, “historic” vegetation. Refugia are locations that are naturally resilient to many climate changes such as microclimates in mountainous regions or locations with certain soil types (Millar et al. 2007). Again, resilience strategies are often considered best used as a short-term measure for highly valued resources because conditions may eventually change to such a degree that resilience strategies may no longer be effective.

Restoration is a complex process that should be approached with care. Given the variety of physical environments, biological communities, and current and past management interventions, a single model of prescribed restoration treatments may be inadequate, and could result in well-meaning restoration efforts actually moving a forest farther from its historical or desired condition (Romme et al. 2009). However, understanding the factors and patterns influencing how a particular landscape came to be could provide insights regarding how restoration or realignment (see below) could be implemented most successfully (Romme et al. 2009).

Response strategies increase the ability of ecosystems to transition to a new state. Examples of response strategies include: assisting transitions, promoting connected landscapes, promoting diversity in age classes, species mixes, and genetic stock, implementing realignment activities (see below), anticipating and planning for unusual events, and increasing management decision flexibility (Millar et al. 2007). Response strategies are typically considered to be longer-term approaches. Assisting transitions, realignment, promoting diversity and planning for unusual events are discussed further in the following paragraphs.

Assisting transitions could involve seeding/planting species outside of their historic ranges along expected climatic gradients or modifying harvest schedules or thinning activities with climate change considerations in mind (Millar et al. 2007). One example of assisting a transition is thinning a forest to a lower basal area than historic conditions dictate so that the remaining trees are less vulnerable to drought. Another example is favoring drought tolerant tree species near the margins of forest zones. For instance, in an area where ponderosa pine forest transitions to PJ woodlands, planting pinyon or juniper could be favored over planting ponderosa pine. On-the-ground monitoring can help determine how species are shifting so that management strategies can mimic what is happening naturally.

Realignment involves restoring ecosystems to current or anticipated future conditions rather than historic conditions after a disturbance has occurred. Examples of realignment include seeding/planting native fire-adapted vegetation in forests that may experience increases in wildfire frequency and severity (Rose, 2010), or planting native species/genetic varieties that tolerate higher temperatures.

Promoting diversity in terms of age classes of native tree species, native species mixes, and genetic stock can aid in climate change adaptation by increasing the likelihood that some individuals/species/varieties will be suited to emerging conditions or able to withstand disturbances (Millar et al. 2007; Rose, 2010). Promoting diversity can thus be either a resilience or a response strategy. Forests in early successional stages after a disturbance has occurred are practical places where ecosystems can be reset (Millar et al. 2007). One example of the benefits of diversity is that enhancing the diversity of species and ages of trees may reduce the likelihood of a large-scale bark beetle outbreak (Bentz, 2008).

Resistance, Resilience and Response Strategy Examples
Examples of resistance strategies *(Typically shorter-term strategies for highly-valued resources)* • Installation of a complete fuel break around an area containing an endangered species • Intensive removal of invasive plants • Defensive actions at key migration points to block incursions of pests or diseases into new areas • Insecticide treatments of trees to withstand beetle attacks
Examples of resilience strategies *(Typically shorter-term strategies for highly-valued resources)* • Thinning forest stands • Making use of prescribed fire • Restoration projects • Identifying and protecting refugia
Examples of response strategies *(Typically longer-term strategies)* • Promoting connected landscapes to allow species to move to areas that may be better suited to meet their habitat needs under a changing climate • Promoting diversity in native forest age classes, species mixes, and genetic stock • Realignment projects • Anticipating and planning for unusual events such as winter flooding and large fires • Increasing management decision flexibility and response

Table 10.2. Resistance, resilience and response strategy examples.

Planning for climate change and variability involves anticipating and preparing for the unusual or threshold events that may become more common due to climate changes and variability (Millar et al. 2007). For example, more winter precipitation falling as rain rather than snow could lead to unseasonal flooding. Earlier snowmelt could lead to longer fire seasons and fires occurring at abnormal times of year. Fires may occur in unusual locations, such as subalpine environments. Warming temperatures may lead to insect and disease outbreaks at new, higher elevations. More frequent, severe, or longer droughts could lead to widespread tree mortality. Attempting to anticipate and prepare for such occurrences is another adaptation strategy that can help to lessen the impact of climate change (Millar et al. 2007).

Examples of resistance, resilience, and response climate change adaptation strategies for forests are summarized in table 10.2. For additional strategies, we refer readers to the Millar et al. (2007), Dale et al. (2001), and Hansen et al. (2001) papers and to the Forest Service's Climate Change Resource Center website (http://www.fs.fed.us/ccrc/topics/wildland-fire.shtml).

In addition, because of anticipated increases in wildfire frequency and extent, we present specific measures centered on fire management in table 10.3. Some of these measures were identified by tribal members attending a 2011 Southwest Tribal Climate Change Workshop (Wotkyns, 2011). Others are from the Forest Service Climate Change Resource Center website, noted above. We also refer readers to the Tribal Wildfire Resource Guide produced by the Intertribal Timber Council and the University of Oregon (Resource Innovations, 2006) as well as to the Joint Fire Science Program website (http://www.firescience.gov/index.cfm).

Due to the uncertainties in future climate conditions, it is important to incorporate research, monitoring, and evaluation into management (Romme et al. 2009). Examples of research areas of interest raised at a 2011 Southwest Tribal Climate Change Workshop (Wotkyns, 2011) include research on how PJ ecosystems might respond to climate change (for example, would thinning PJ provide any hydrologic benefits) and research on how fire behavior might change based on different temperature and precipitation scenarios. Establishing partnerships with the Forest Service, state agencies, academic institutions, nonprofit organizations, and other tribes to address research, monitoring, evaluation, and management needs may be an adaptation strategy.

Wildfire Adaptation Strategies
• Develop early fire detection programs
• Develop fire management programs to promote ecosystem health as well as manage fire
• Implement fuel reduction and forest thinning
• Use prescribed burning
• Fuel reduction in a checkerboard/mosaic pattern
• Identify species, populations, and communities that are sensitive to increased fire and develop conservation plans for them
• Establish seedbanks and/or a greenhouse for seedlings so that if a fire occurs, lost trees can be replaced
• Restore for realistic outcomes – determine thresholds for species and functions and identify those species and vegetation structures tolerant of increased fire
• Monitor post-fire conditions and eliminate or control exotic species

Table 10.3. Wildfire adaptation strategies.

10.4 Potential Funding and Other Support

A number of federal programs, most notably from the United States Department of Interior (DOI), provide assistance to address wildfire management, forest restoration and forest planning. Some of these programs deal with species protections, while others offer assistance for long-term planning.

Funding Opportunity	Area of Focus	Source	Enablement and Website
FLAME Fund	Wildfire suppression	DOI, EPA	http://beta.congress.gov/bill/113th-congress/house-bill/933
Collaborative Forest Restoration Program	Forest Restoration (past projects include efforts w/ Ramah and Torreon/ Star Chapters)	USFS	http://www.fs.fed.us/restoration/CFLR/index.shtml
Arizona Forest Health Council	Works on promoting forest health in Arizona	State of Arizona	http://www.governor.state.az.us/fhc/
National Interagency Fire Center, Southwest Coordination Center	Promotes interagency collaboration	SCC	http://gacc.nifc.gov/swcc/
Forestry on Indian Lands	Protect and maintain tribal forest resources	DOI	https://www.cfda.gov/?s=program&mode=form&tab=step1&id=da9ddb59307033adbe908aca6c3b2e7e
Community Forest Program	Obtain lands to protect as community forest land	USDA	https://www.cfda.gov/?s=program&mode=form&tab=step1&id=1c9139179a87c6b4edf68cd423e3b5b0
Community Wood Energy Program	Assistance for upgrading and/or developing community wood energy sources	USDA	https://www.cfda.gov/?s=program&mode=form&tab=step1&id=98f12af3131618e5339f610883cb9b4c
Rural Development, Forestry, and Communities	Help analyzing and develop rural forest resources	USDA	https://www.cfda.gov/?s=program&mode=form&tab=step1&id=6f1e694d8a0fa8bad8d55a0ffa330911
Emergency Forest Restoration Program	Aid to restore forests which have been impacted by natural disaster	USDA	https://www.cfda.gov/?s=program&mode=form&tab=step1&id=ec329f49e87aed441f5be1cac6442346
Fire Management Assistance Grant	Provides fire control when there is a potential for major disaster	DHS	https://www.cfda.gov/?s=program&mode=form&tab=step1&id=4f2892df4f830f3dce3bf5de2f24d9af

Table 10.4. Federal assisted programs for wildfire management, forest restoration and forest planning.

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Photo: Julie Nania.

CHAPTER 11
COMMUNITY INFRASTRUCTURE AND SERVICES

Community infrastructure and services is integral to maintaining healthy economies and communities. In this chapter, we consider three critical infrastructure elements on the Reservation - transportation, communication and shelter.[1] Climate change impacts on the infrastructure of water and energy resources are discussed in Chapter 4 and Chapter 12, respectively.[2]

Because infrastructure serves a supporting role for many different sectors, impacts on infrastructure can have a variety of cascading consequences. The Navajo Division of Economic Development has identified inadequate or non-existent infrastructure, particularly concerning roads and energy supply, as a major growth-limiting factor on the Reservation (DED, 2004). Additional examples of such cascading effects are seen in public health and emergency response. For example, when improving emergency preparedness, the state of infrastructure on tribal reservations is frequently cited as a significant hurdle to overcome (NCAI, 2010). Essentially every sector mentioned in this report will be affected by infrastructure impacts. In terms of planning, it is therefore important to consider the effects that climate changes will have on infrastructure in conjunction with the other impacts noted in the chapters on resources and sectors.

11.1 Potential Climate Change and Variability Impacts on Community Infrastructure and Services

Anticipated climate and hydrologic changes in the SW include: warmer annual average temperatures, increases in heat wave frequency and severity, and increases in drought frequency, severity, and duration punctuated by more extreme precipitation and storm events (see Chapter 3).[3] If more intense

1 When relevant, we discuss some information related to water and energy infrastructure. Additional water and energy infrastructure information is available in those chapters.
2 Key infrastructure components include water supply, wastewater, stormwater, and energy systems.
3 The SW predicts more extreme precipitation events and storms with medium-low confidence (Garfin et al. 2013).

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Case Study: Sand Dune Movement


Sand dunes at Monument Valley. Photo: iStock,, SumikoPhoto.

Sand dunes are a common feature of the SW deserts, but the stability of these great sand structures are dependent on the soil which supports them. Soil erosion can occur from strong precipitation events. As vegetation cover decreases in response to temperature and precipitation changes, erosion and desertification on the Reservation are likely to increase (see Chapter 3).

Roughly one-third of Reservation is covered with sand dunes. In dry years, or years with low effective precipitation due to high temperatures, sand dunes become more active (USGS, 2012). Dr. Margaret Hiza-Redsteer has documented an increase in sand dune movement on the Reservation during times of drought and predicts that this phenomenon will intensify if temperatures rise and precipitation decreases (USGS, 2012).

Sand dune migration can have serious impacts on Reservation infrastructure. For example, on the Reservation's Teesto Chapter, roughly every two weeks someone must clear the road so that the Head Start bus can reach the Biggambler couple's granddaughter. The dune towers fifteen feet high and is threatening the Biggamblers' home. Hiza-Redsteer is working with a team of Chinese scientists to test structures for stabilizing dunes and for diverting the sand behind the Biggambler household. Just days after the team measured the dune, a windstorm had almost buried their three-foot high markers, leaving only four inches of rebar sticking out of the sand and increasing the dune elevation by almost three feet. A few weeks later, the rebar had completely disappeared. The dune now stands at least three feet closer to the Biggambler house.

precipitation events do occur, incidences of flooding may rise (Garfin et al. 2013). Higher temperatures, increased drought, and longer fire seasons (associated with earlier snowmelt) are predicted to increase wildfire frequency and size (see Chapter 3). Increased drought and flood events could contribute to increases in sand dune destabilization and movement (see Chapter 3).

All of these climate and ecosystem changes can have impacts on transportation, shelter, communication and other infrastructure systems. These impacts on infrastructure, in turn, can have cascading impacts on a variety of other sectors. For instance, public health is reliant on infrastructure systems and effective personnel response during emergency situations. Thus, community health may be particularly impacted by infrastructure impacts of climate change and variability.

Transportation

The USEPA notes that climate changes "could increase the risk of delays, disruptions, damage, and failure across our land-based, air, and marine transportation systems." (EPA, 2013) Here, we focus on impacts on land-based transportation and air travel. Impacts on water infrastructure and energy infrastructure are discussed in Chapters 4 and 12, respectively.

Higher temperatures could cause a variety of transportation impacts. High temperatures can cause pavement softening that could contribute to increased rutting and potholes in roads and lead to shortened pavement lifetimes (Niemeier et al. 2013; EPA, 2013). Thus, paved roads, parking lots and airport runways could all be affected by climate change (Niemeier et al. 2013). Additionally, higher temperatures may lead to thermal expansion, placing stress on bridge joints (Niemeier et al. 2013; EPA, 2013). Outdoor crews may not be able to work during extreme temperatures, which could delay and increase the cost of construction and maintenance activities (Bjune et al. 2009; Savonis et al. 2008; EPA, 2013). Conversely, if higher temperatures lead to more winter precipitation falling as rain rather than snow, mobility could improve, leading to decreases in costs for snow removal, road salting, and airplane de-icing (EPA, 2013). Midwinter storms, including snowstorms, however, may possibly increase in severity (Garfin et al. 2013).

Rail transportation may also be impacted by increased temperatures. The Volpe National Transportation Systems Center reports that extreme heat can cause some types of railroad lines to develop "sun kinks" in which sections of rail buckle (Savonis et al. 2008). Buckled lines can cause derailments or require more frequent repairs to avoid such accidents. Cooling requirements, and thus energy consumption, for both passengers and freight operations may increase (Savonis et al. 2008). Additionally, disruptions in rail infrastructure could have implications for coal extraction on the Reservation (see Chapter 12).

Wildfires and extreme weather events can also disrupt transportation infrastructure. Increases in wildfire frequency and size could affect transportation by decreasing visibility, causing road closures, and threatening road, rail and airport infrastructure (Niemeier et al. 2013). Storms with high precipitation intensities could wash out road foundations, weaken bridge supports, or delay or disrupt road, rail, and air travel and associated freight operations through flooding or landslides (Niemeier et al. 2013; EPA, 2013). Intense rainfall events could also damage some navigation instruments used in air transportation (Niemeier et al. 2013). Transportation disruptions could impact mobility on the Reservation and may stymie the growth of the Navajo tourism industry.

Sandstorms are another concern on the Reservation. Sandstorms already periodically reduce visibility on Navajo roads (sometimes down to zero) and occasionally contribute to road closures. In addition, when moving sand dunes bury fences, livestock are able to walk into roads where they may get hit by vehicles (Yurth, 2010). If sand dune mobilization increases, this could contribute to more closures and accidents on Navajo roads and increased closure of airport runways.

Communication Networks

Few existing studies have assessed potential climate impacts on communication infrastructure. One study by Townsend and Moss (2005), however, did discuss impacts on urban telecommunication infrastructure from disasters such as tornadoes and ice storms. Although not all of the disasters addressed were directly applicable to the Reservation, the impacts described can provide a basis for understanding potential climate change effects on communication systems. The study found three categories of impacts disrupting communications: 1) direct damage to the physical infrastructure of the communication network, 2) damage to infrastructure supporting the communication network, and 3) congestion or overloading of the communication network during emergency situations (Townsend and Moss 2005).

In terms of damage to supporting infrastructure, communication networks often rely heavily on large amounts of electrical power. Power outages affecting communication reliability can be caused by damage to distribution or power plant infrastructure, or caused by disruptions in the supply of fuel to power plants (Townsend and Moss 2005). As explored more in Chapter 12, rising air and water temperatures, increasing stresses on water availability, extreme weather events, and wildfires, can all affect energy production. For instance, the smoke and soot generated by fires can create alternate conductive pathways, resulting in line outages, and the fire retardants dumped by aircraft to combat fires can foul transmission lines (Tidwell et al. 2013). Extreme winds can also interrupt power transmission. In January 2010 on the Cheyenne River Sioux Reservation in South Dakota, severe winds associated with a winter storm downed thousands of power poles and caused massive power outages throughout the Reservation (Elcock, 2010). Such power outages could have subsequent effects on the communication systems.

Impacts Disrupting Communication Systems
Damage to Physical Infrastructure • Severing cables, lines • Flooding equipment • Burning telephone poles
Damage to Supporting Infrastructure • Power outage from damage to infrastructure, fuel disruption • Transmission lines damaged by wildfire retardants • Soot creates alternate conductive pathways and disrupts transmission
Overloading During Emergencies • Emergency and personal communications may overload broadcast systems

Table 11.1. Impacts disrupting communication systems (Townsend and Moss 2005).

In terms of overloading communications during emergencies, responders try to coordinate emergency response and relief efforts, and the public tries to get in touch with family members. As news organizations and individuals try to broadcast information, communication networks may become overloaded, resulting in blocked calls and lost messages (Townsend and Moss 2005). This was one of the complications experienced during Operation Snowfall (see Case Study: Operation Snowfall). However, as discussed more below, the NN has serious efforts underway to expand broadband on the Reservation. Because such emergencies may be climate-related, this could be an indirect impact of some climate changes and variability.

Shelter

Climate change impacts on built infrastructure may include stress on home temperature regulation from extreme temperatures. Direct damage to buildings may increase due to increases in wildfire frequency and flood intensity (Houser et al. 2001; EPA, 2013) (see Chapter 3 for more information on SW flood projections). Sandstorms have already buried houses on the Reservation.

Housing and other buildings are often a first line of defense against climate hazards and can either act as an adaptive capacity factor protecting people from those hazards or as a vulnerability factor, increasing their exposure to climate-related impacts. For example, shelter that is well-designed and of good construction quality can protect residents from extreme heat or cold, from severe storms or flooding, and from disease. Managing shelter can also be considered an adaptation strategy and is discussed more in Chapter 7.

Damage to infrastructure may have substantial implications for people's health and emergency responses. Storms, for example, can down power lines and block transportation and communication pathways. The loss of electricity can result in the inability to refrigerate medicines or to the loss of hospital life support systems. If local heating and cooling systems are damaged during extreme temperatures, vulnerable populations may suffer increased incidences of heat stress and hypothermia (EPA, 2013). Storms can also contaminate water supplies, especially if flooding occurs, by increasing the spread of disease, bacterial infections, and uranium poisoning on the Reservation (NDWR, 2011). Residents may not be able to reach medical facilities in a timely fashion. All of this can cause additional stress on affected communities (Houser et al. 2001). In Chapter 7 we discuss emergency response and infrastructure impacts in greater detail.

The intensity of winter storms may increase with climate change. Climate events impacting transportation and leading to communication failures can hamper emergency response. During a 2010 blizzard on the Navajo Reservation, many roads remained unplowed and impassable, leaving people isolated and

Case Study:
Operation Snowfall 2010

In 2010, a blizzard struck the Reservation, leaving drifts of snow up to five feet in certain areas (N.N. Council, 2010). Unable to get through the snow, members across the Nation were stranded and, in many cases, unable to access basic supplies. The Navajo Nation Commission on Emergency Management declared a state of emergency based on community hardship (AZ Emergency Network, 2010).

A blanket of snow gives way just enough for sheep to find their way this past on the Hopi Reservation in January 2010. Photo: Operation Winter Storm.

Transportation on the Reservation was stagnant; families living in remote parts of the Reservation were trapped in their homes, children were unable to reach school, and cars could not traverse the deep snow (Hopkins, 2010). Road conditions were so bad that rescue workers often became stuck when they were sent on missions to aid snowbound rural residents (Hopkins, 2010). When the snow melted, muddy conditions on unpaved roads prolonged difficult transport conditions (Abasta, 2012). Tribal members were advised to travel early in the morning and late in the evening while the ground was frozen to avoid becoming stuck in the mud (Navajo-Hopi Observer, 2010).

A combination of emergency personnel, local police, government employees and community volunteers banded together to offer emergency assistance. The National Guard used helicopters to deliver aid to certain stranded communities (Hopkins, 2010). Employees from the Office of Education gathered food to be distributed to the elderly and assisted with financial reports (ODSMT, 2010). Tribal officials coordinated the distribution of firewood and basic necessities (Abasta, 2012). The National Guard air-dropped emergency supplies to areas of the Navajo and Hopi Reservations too remote to supply otherwise.

The animal population on the reservation was also impacted. Livestock wandered onto highways seeking food (Navajo-Hopi Observer, 2010) and Navajo Agricultural Products Incorporated donated feed for livestock.

Responders came together after Operation Snowfall to discuss complications experienced during relief efforts and to assess opportunities to better respond to similar crises in the future. Responders agreed that rescue efforts had been reportedly complicated by lack of cellphone and Internet communications (Hopkins, 2010). Other difficulties experienced by responders included:

- Difficulty with communications
- Confusion of jurisdiction between different Navajo agencies, FEMA, and the National Guard
- Difficulty delivering medicines to community members
- Lack of attention to local culture by some responders
- Uncertainty about available supplies (the Tribe's Tuba City warehouse was full of USDA foodstuffs but it remained closed while officials tried to determine if it could be used in the response effort)
- Roads that were not BIA roads were left unplowed
- Heavy equipment was not utilized. (Hopkins, 2010)

without access to food and medical services (Hopkins, 2010). The blizzard also contributed to the disruption of cell phone service and the coordination of response efforts.

11.2 Vulnerability and Adaptive Capacity Factors

Climate, hydrologic, and ecosystem changes will interact with socioeconomic, legal, institutional, technological and other vulnerability and adaptive capacity factors (Chapter 2) to help or hinder the ability of the Reservation to ensure accessible and reliable infrastructure. Although we separate vulnerability and adaptive capacity factors into categories for conceptualization, these factors are interrelated and will affect one another. We discuss some examples of vulnerability and adaptive capacity factors below; however, this is not meant to be a comprehensive discussion. Instead, it is intended to serve as a basis for identifying factors as adaptation planning occurs.

Legal/institutional factors

The historical and current relationship between the US federal government and sovereign federal Indian tribes is incredibly complicated and impacts many aspects of tribal infrastructure development. The removal of tribes from their original homelands, their consolidation onto reservations, and the unsettled questions about the status of tribal lands has contributed to difficulties developing the infrastructure on Indian lands which many other parts of the country take for granted (NCAI, 2010).

Obtaining right of ways to construct large infrastructure projects, such as roads or transmission lines, is time consuming and expensive (Yurth, 2010).[4] Federally recognized Indian nations have their own set of federal programs under the BIA and are eligible for many other federal programs. These programs, however, often come with restrictive federal requirements.

Jurisdiction over land is another overarching and complicating factor in developing tribal lands. Although Reservation lands are primarily tribal lands held in trust by the federal government, there are small enclaves of non-Indian fee land within reservation boundaries. For reservation lands within state boundaries, there may also be a small degree of state regulation (NCAI, 2010). Tribal, federal and state laws could all impact a single infrastructure project. Particularly if those projects involve roads, rail lines, transmission lines, or other infrastructure that spans long distances. Therefore, when developing a large-scale project on the reservation, there is the potential that many agencies from various jurisdictions will need to be involved.

Leases of tribal trust lands may require approval by the Secretary of the Interior. Major actions requiring federal approval may spark NEPA review. As noted above, the involvement of federal authorities can result in increased time spent assessing the project before its approval is granted (NCAI, 2010). As seen in the blizzard of 2010, timely and appropriate responses to emergencies can be complicated and delayed by coordination amongst parties, including federal and tribal emergency response teams (University of Oklahoma, 2011).

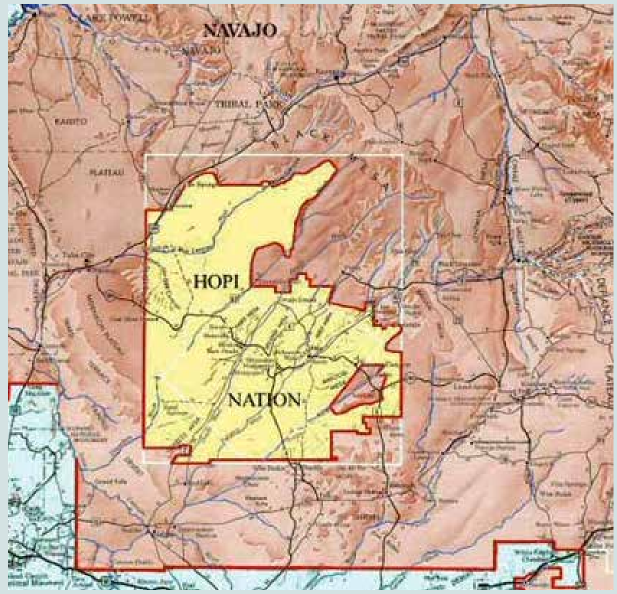
Despite these legal/institutional barriers affecting infrastructure on the Reservation, the Nation has taken significant steps with respect to planning for emergency response. For example, President Ben Shelly declared a National Emergency Preparedness week in 2012 to engage local chapters in training courses coordinated by the Navajo Division of Community Development, the Public Health Emergency Preparedness Program and the Inter-Tribal Council of Arizona. Planning documents have also been compiled to better coordinate disaster response efforts. The Indian Health Services and various Navajo entities have worked together to coordinate the Public Health Emergency Preparedness and Response Plan. Responders have worked out a strategy to distribute vaccine and medical supplies from

4 Cost and legal hurdles have inhibited the development of road infrastructure on the Reservation. Each year, millions of dollars are spent on the Reservation to provide emergency services to communities impacted by road impairments caused by winter storms. Many of these emergency costs could be avoided by simply paving more roads. The cost of building roads and the legal hurdles to gain right-of-ways, however, has proven prohibitive. The cost to pave the eight-mile road to the Black Mesa Chapter House alone was estimated to be $33 million.

Case Study: The Bennett Freeze

Broad federal policies may also directly impede infrastructure development. When a dispute arose between the Hopi and Navajo Tribes over reservation boundaries, Robert Bennett, ex-commissioner of Indian Affairs, instituted a temporary development freeze until the dispute over land ownership was resolved (Tarasi et al. 2011). The so-called "Bennett Freeze" prohibited new development on much of the Black Mesa and prevented communities and families from fixing deteriorated homes and infrastructure (Linthicum, 2004). Over 1.5 million acres of land on the western side of the Navajo Reservation was burdened by these restrictions (Moore, 1993).

The development freeze was repealed by President Obama in 2009 (Pub. L. 111-18, 2009). However, the damage persists. Of the 8,000 residents of the area, only ten percent have running water and only three percent have electricity. The infrastructure needed to run power lines is largely lacking, as are roads needed for new construction (Tarasi et al. 2011).



The map above shows Navajo Nation lands encompassing the Hopi Reservation (inset yellow).

It will be years before the area can reach a level of home electrification equivalent to that of the rest of the Reservation. The BIA has released $5 million from an earmarked escrow account for aiding Navajo people impacted by the Freeze and additional funding has been provided by the Navajo-Hopi Land Commission. Extensive planning and disagreements over how the money should be spent, however, has caused very little work to be completed (Minard, 2012). In 2010, a grassroots group called Forgotten People sued the Navajo-Hopi Land Commission for an accounting of how the available money was being spent (Forgotten People, 2011). There are still almost no reports of significant progress being made on improving the state of the Bennett Freeze lands; in 2012, seventeen families were in emergency need of new homes and thousands of others were living in dangerous conditions (Minard, 2012). It is likely that the struggle for basic infrastructure will continue in this area for some time.

the Strategic National Stockpile and Receiving Staging and Storage Site. Finally, during an Emergency Operations Center drill, the Navajo emergency response received a perfect drill score (Abasta, 2012). These efforts not only help prepare communities for disaster response, but can directly help address many public health concerns (see Chapter 7).

Socioeconomic factors

Tribal income is limited. Tribal governments often cannot levy taxes against individuals so most government income is generated from businesses (NCAI, 2010). Limited income can reduce infrastructure development. The incidence of poverty on the Reservation is quite high. Low incomes can affect the ability of individuals to address even basic housing concerns, including the repair and maintenance of shelter. Without proper maintenance, a shelter might not sufficiently protect against climate hazards such as extreme heat or cold (Houser et al. 2001). In addition, because reservations consist of lands held in trust by the federal government, banks are reluctant to make loans to tribal members because they cannot potentially repossess the land beneath homes as collateral. This affects the ability of residents to purchase quality homes, make home repairs and invest in weatherization.

Land use, environmental, and infrastructural factors

Rural transportation systems are often inadequate or nonexistent for many of the more isolated tribal communities (Houser et al. 2001). As of 2004, 78% of roads on the Reservation were unpaved (USCCR, 2004). Flooding and blizzards can make dirt roads impassable because even after floodwaters subside and snow melts, unpaved roads can remain muddy. Each year, on the Navajo Reservation, millions of dollars are spent on repairing dirt roads and providing emergency services to stranded residents (Yurth, 2010). New roads also need to be occasionally constructed (Nijhuis, 2012). The rural nature of the Reservation can lead to fewer transportation options and fewer redundancies in the transportation system. Thus, there may be less resilience in the system to disruptions, including those called by climate related events (Hale et al. 2013).

Overall, infrastructure on the Reservation is already aging and may be vulnerable to storm events and other climate hazards (NTUA, 2009). In some areas of the Reservation, infrastructure may be lacking entirely or may be inadequate to fully meet residents' needs. One example of this is that many homes on the Reservation lack access to effective heating and cooling systems that are essential to protecting residents against heat waves and cold snaps.

In addition to economic factors, another major factor contributing to the inadequate and nonexistent infrastructure is the dispersed nature of local communities. The cost of running water, electric and other utility lines to these communities is very high. Out of the 2012 federal block grants received, $1.5 million went to bringing water lines to 126 families. Although this was significant for the families that benefited, it constituted a small fraction of the 16,000 homes which need utility services (Landry, 2012).

Community planning may face traditional cultural factors that inhibit certain development scenarios. Many Navajo families have close ties to the land and are hesitant to leave lands that their families have occupied for decades. Additionally, communities are accustomed to the rural lifestyle. The spread-out, rural nature of communities may also mean that utilities require considerable effort to service if damaged.

Low population densities spread out over large distances has also resulted in large areas of the Reservation not having access to Internet services (Mayfield, 2013). The NTUA, together with Commnet Wireless of Atlanta, Georgia, is implementing a $46 million Navajo Nation Middle/Last Mile Broadband Project ($32.2 million from the American Recovery and Reinvestment Act, $11.3 million from NTUA, and $2.2 million from Commnet) (Kane, 2013). The project is expected to bring high-speed, affordable broadband services to over half of the 27,000 square mile reservation reaching as many as 30,000 households, 1,000 business, and 1,100 community institutions. Expanded Internet access will give community members and response teams more time to react to oncoming weather events.

The Nation is also seeking to expand railroads on the Reservation. The NN is in talks with the Burlington Northington Santa Fe Railroad Company about investing significant new resources in coal delivery infrastructure. It has plans to develop a 300-acre industrial park, a railroad depot and rail line which would enable the Nation to move coal from San Juan County through Farmington and Thoreau to an

Key Points: Potential Climate Change Direct and Indirect Impacts on Infrastructure

- Sand dunes may become more active with future climate change impacts, covering roads, houses, and causing a range of damage to infrastructure
- Extreme weather events could disrupt road and air travel
- Increased temperatures can cause pavement softening that could contribute to increased rutting and potholes
- Higher temperatures could lead to expansion of bridge joints
- Extreme temperatures may limit the hours that highway works crews can work
- Potentially warmer winter temperatures could lead to reduced snow removal costs and fewer transportation interruptions from snowstorms. Conversely, mid-winter storms could increase in intensity
- Extreme heat could lead to the development of sun kinks in rail lines, leading to derailments or increased costs of repairs
- Sandstorms could increase, leading to disruptions in transportation
- Communication networks could be damaged or overloaded during emergency response
- Shelter could be damaged due to increases in extreme weather events

Micro-Credit Loans Infrastructure Improvements

Because of limited incomes and the inability to use land as collateral, some Navajo residents may lack the financial means to make repairs that could make their homes more climate-resilient. Basic weatherization can help protect against extreme weather events (discussed in Chapter 7).

Photo: Creative Commons, Steve White

The Nuestra Casa Home Improvement Lending Program is an example of an innovative program being implemented along the US-Mexico border in Texas to address home improvement needs for low-income residents. The Nuestra Casa Program is run by the nonprofit Community Resource Group and uses a revolving fund, short-term micro-credit loan system. Low-income homeowners can borrow $2500 for home improvements to be repaid over a two-year period at a 9% interest rate (Squires and Korte 2009; Giusti, 2008). There is no penalty, however, if the loan is not repaid. Instead, there is an incentive. Homeowners who make timely payments over the first 12 months can borrow an additional $1000 at the same interest rate. Delinquency rates are low; when the program first started in 2000, rates were 8% and had decreased to 3% by 2005 (Giusti, 2008).

international market. Eventually the rail would be expanded throughout the McKinley and San Juan counties (Tri-City Tribune, 2013).

11.3 Potential Adaptation Strategies for Community Infrastructure and Services

Physical infrastructure is often designed to last for decades. Transportation infrastructure, for example, is planned to last 50 years or more (EPA, 2013). Thus, the infrastructure choices made now will have consequences for future climate adaptation efforts. Infrastructure adaptation strategies can fall into a variety of categories including: 1) retrofitting current infrastructure and altering operations and maintenance, 2) adapting new infrastructure design and construction, 3) improving emergency response, and 4) engaging in long-term planning and land management (ICF International, 2013). We provide examples of such strategies below for transportation, communication and housing infrastructure as well as for overall infrastructure planning and land management.

Transportation

Departments of transportation are implementing a variety of measures to address extreme weather events, including extreme heat. For instance, during very hot days, the Alabama Department of Transportation shifts the start times for construction and maintenance activities to cooler times of day to minimize the exposure of work crews to excessively warm temperatures (ICF International, 2013). Reservation work crews could be coordinated to work on infrastructure repairs during cooler (or warmer) periods of the day.

Other adaptation strategies for addressing extreme heat include: deploying quick maintenance crews on hot days to locate and repair potholes (ICF International, 2013), updating standards for work crews exposed to hot temperatures (Schwartz, 2010), planting vegetation that is both heat and drought-resistant for erosion control (ICF International, 2013), retrofitting highway and bridge expansion joints (Schwartz, 2010), increasing the lengths of airport runways to account for lower air densities during hot weather (Schwartz, 2010), and supporting research into pavements that are more heat resistant (Schwartz, 2010).

Transportation agencies are also implementing strategies to address high precipitation intensity events and increased extreme storms. The Vermont Agency of Transportation is now trying to match the slope design of roads adjacent to streams to mirror slopes needed for stable stream channel dimensions. This landscaping strategy will reduce stream-related erosion impacts on roads (ICF International, 2013).

Other adaptation strategies that help preserve the capacity of storm drainage systems include: prioritizing maintenance activities such as culvert cleaning and tree-trimming (ICF International, 2013); enlarging culverts to increase hydraulic capacity of storm drainage systems (ICF International, 2013); increasing safety margins when reconstructing infrastructure that has repeatedly failed (ICF International, 2013); ensuring that the precipitation records used for designing hydraulic infrastructure are up-to-date and encompass a historic period of adequate length that considers whether they include periods that were unusually wet or dry (ICF International, 2013); and, developing new design standards for hydraulic infrastructure (Schwartz, 2010).

Transportation departments are also trying to better prepare for emergencies by improving monitoring systems to provide more real-time data on road conditions, increasing cooperation within and among agencies dealing with transportation, permitting flexible resource allocations, and training personnel on emergency response before extreme weather occurs (ICF International, 2013). Integrating emergency response planning into transportation operations and providing for emergency response in transportation budgets could help to buffer communities from some of the impacts from storms (TRB, 2008).

On the Navajo Reservation, improving communication between chapters and the Navajo national government on how federal funding is applied to road maintenance could allow for more sections of the Nation's roads to be paved or repaired to meet winter conditions (Yurth, 2010).

Key Points: Adaptation Strategies for Infrastructure on the Reservation

- Land planning and monitoring (continue research on sand dune migration and flooding)
- Increase local utility access (both large-scale and small; consider local options with fewer transmission requirements)
- Home weatherization and improvement of heating/cooling options
- Improving road quality and transportation options
- Integrated emergency planning between local, state and federal agencies and land owners
- New strong and 'green' building

For additional strategies and more in depth discussion on climate change impacts on transportation infrastructure, we refer readers to a December 2013 report put out by the US Department of Transportation Federal Highway Administration, *Assessment of the body of knowledge on incorporating climate change adaptation measures into transportation projects*.

Communication

Effectively communicating community needs is essential to providing adequate emergency response. As noted above, communication impacts can result from direct damage to communication infrastructure, damage to the infrastructure of systems supporting communication networks and from the overloading of communication networks. One adaptation strategy could be to protect wooden utility poles from wildfire effects by regularly clearing, trimming and removing brush around the pole bases or by treating the poles with fire-retarding coatings or wraps (Marquandt, 2013).

Having backup generators with adequate fuel supply for power communication equipment could prevent the potential failure of systems supporting communication networks in the event that other energy sources are cut off. Amateur radio has repeatedly been one of the few communication systems to work effectively when electrical systems fail. Amateur radio, however, cannot address the demand by emergency responders for broadband data (Townsend and Moss 2005). The current efforts underway and discussed above will help to improve communications.

Shelter

Given the likelihood of significant changes in severe weather events, when homes are remodeled, they should be designed for increased resilience to weather conditions (Houser et al. 2001). Weatherization and strengthening of homes can include: sealing cracks in doors, windows and walls, and identifying

The Windcatcher House

The Windcatcher House, built on the Navajo Reservation in southeastern Utah, is an example of a sustainable house designed to protect residents against extreme cold and heat. The focal point of the home is a hearth with a wood stove at the base and a chimney leading outside. The hearth provides warmth during the winter and cooling during the summer through a passive evaporative cooling system involving wetted media in the chimney (UCD Design Build, 2010). Compressed earth bricks, handmade from local clay and placed around the stove and rammed earth walls on the south and east sides of the house, create thermal mass to help regulate home temperatures (Meinhold, 2011; UCD Design Build, 2010). A rainwater catchment system provides irrigation water for the home's garden (Meinhold, 2011). The house was designed and built by University of Colorado-Denver students for a course led by Rick Sommerfeld and Rob Pyatt, one of the founders of the Native American Sustainable Housing Initiative.

weaknesses in buildings such as old foundations (EPA, 2013). Many homes on the Reservation are not equipped with air conditioners that could help residents cope with extreme heat (Houser et al. 2001). Programs like the Nuestra Casa Program, discussed above, could be used to develop climate resiliency at the household level. In addition to adapting existing buildings, plans for new buildings should be designed with increased resilience to extreme weather. Suggestions for building to better adapt to increasing temperatures and potentially increased storm intensities were identified at the 2011 Southwest Tribal Climate Change Workshop and are summarized in table 11.2 below (Wotkyns, 2011).

Building Adaptation Strategies from the 2011 SWTCCW
Overloading During Emergencies
• Ensure consultation of cultural committees
• Identify the priorities of individual communities
• Research green building techniques that can be integrated with traditional structures
• Incorporate storm water pollution plans
• Leave as much vegetation as possible in place at construction sites
• Develop "green" construction codes

Table 11.2. Building Adaptation Strategies from the 2011 SWTCCW.

Planning and land management

Bringing clean water, electricity and other services to far-flung Navajo communities will be an important part of future development planning. The development must be innovative to adapt to cultural and historical factors unique to the Reservation. Developing new adaptive and updated infrastructure goals could help allocate already stressed funding go towards the most impactful projects. Recommendations for better climate change and infrastructure planning include: identifying the most vulnerable zones (such as flood plains), avoiding investing in risky areas, strengthening core utilities before beginning new projects, and adapting infrastructure standards to be more resilient to extreme weather. Floodplain mapping could identify areas at risk for flooding and associated impacts such as washed out roads and damage to homes and infrastructure. Continuous research also needs to be conducted on how infrastructure is being impacted by weather events (Neumann, 2009). Comprehensive planning can help avoid costly future updates and repairs and allow more funding to go towards expanding infrastructure.

Monitoring, mapping and planning projects, such as the floodplain mapping noted above, can help communities plan for future floods (Kousky et al. 2011). Methods for mitigating the impacts of future flooding on a variety of infrastructure include: creating plant cover (e.g., with wood chips), using sand bag placement, strengthening water holding sites which can include well covers, raising buildings, and building protective walls if flooding (or sand dune movement) is not predicted to be severe (Kousky et al. 2011). Key to decreasing sand dune movement and soil erosion "from water and wind—is a healthy, deep-rooted cover of native vegetation." (Parrill, 1981) This will require continued monitoring of soil quality and plant cover, as well as possible re-vegetation projects, if feasible (see chapter 6 for potential difficulties with vegetation restoration). Both small-scale community efforts and large-scale reservation infrastructure improvements will need to be included in a long-term plan to prepare the Reservation for the possible impacts of climate change.

11.4 Potential Funding and Other Support

Funding Opportunity	Area of Focus	Source	Website
Indian Housing Block Grants	Housing assistance funneled through tribal authority	HUD	Department of Housing and Urban Development (HUD), Office of Public and Indian Housing http://portal.hud.gov/hudportal/HUD?src=/programdescription/ihbg
Section 184 Indian Home Loan Guarantee Program	Federal guarantee of home loans to increase access to ownership	HUD	HUD, Office of Public and Indian Housing http://portal.hud.gov/hudportal/HUD?src=/program_offices/public_indian_housing/ih/homeownership/184
Indian Community Development Block Grant	Assistance to improve housing and community facility quality, land acquisition, infrastructure building and economic development	HUD	HUD, Office of Public and Indian Housing http://portal.hud.gov/hudportal/HUD?src=/program_offices/public_indian_housing/ih/grants/icdbg
Title VI Loan Guarantee Program	Federal loan guarantee for IHBG recipients	HUD	HUD, Office of Public and Indian Housing http://portal.hud.gov/hudportal/HUD?src=/program_offices/public_indian_housing/ih/homeownership/titlevi
Community Connect	Provides broadband services to foster economic and community development	USDA	US Department of Agriculture (USDA), Rural Development http://www.rurdev.usda.gov/utp_commconnect.html
Rural Community Development Initiative	Aid to improve local housing, community facilities and economic development	USDA	USDA, Rural Development https://www.cfda.gov/?s=program&mode=form&tab=step1&id=77d7add2d3e374b260f063e114a0d04d
Indian Tribes and Tribal Corporation Loans	Enable tribes to acquire land within reservations	USDA	USDA, Farm Services https://www.cfda.gov/?s=program&mode=form&tab=step1&id=54d9c33a66b4981fd09975a31cc214e7
Community Facilities Loans and Grants	Aid to improve important local services and facilities	USDA	USDA, Rural Housing https://www.cfda.gov/?s=program&mode=form&tab=step1&id=9c3a9599b3d8b786e4e1d267e0e31170

Rural Electrification Loans and Loan Guarantees	Provide electricity to low income areas	USDA	USDA, Rural Utilities Services https://www.cfda.gov/?s=program&mode=form&tab=step1&id=79226bcc7b4ff6197774c7782a6d14fd
Investments for Public Works and Economic Development Facilities	Assistance for rehabilitation of public infrastructure and facilities	DOC	Department of Commerce (DOC), Economic Development Administration https://www.cfda.gov/?s=program&mode=form&tab=step1&id=bb43024afbdae1a42b2b4ffa8fa5aec9
Road Maintenance, Indian Roads	Aid to maintain roads, bridges, and airstrips	DOI	Department of Interior (DOI), Bureau of Indian Affairs (BIA) https://www.cfda.gov/?s=program&mode=form&tab=step1&id=913e654d0f5d026261476a231095996a
Indian Housing Assistance	Provide improved housing in low income tribal areas	DOI	Department of Interior (DOI), Bureau of Indian Affairs (BIA) https://www.cfda.gov/?s=program&mode=form&tab=step1&id=37cc674dbe645f263363ecefc8a6c332
Native American Programs	Support for community development and self-sufficiency projects	DHHS	Department of Health and Human Services (DHHS) https://www.cfda.gov/?s=program&mode=form&tab=step1&id=cfa1d17d327aa18b634428112fcdbf9b
Flood Mitigation Assistance	Help strengthen flood infrastructure, land integrity, etc.	DHS	Department of Homeland Security (DHS) https://www.cfda.gov/?s=program&mode=form&tab=step1&id=7346590a1c7acc21a1ce191ed9be8c7a
Pre-Disaster Mitigation	Assistance to plan for and prevent damages from natural disasters	DHS	Department of Homeland Security (DHS) https://www.cfda.gov/?s=program&mode=form&tab=step1&id=1400ddd5e9367ae9e4363c1a15da3114

Table 11.3. Federal assisted programs.

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Photo: Julie Nania.

CHAPTER 12
ENERGY

The energy sector on the Navajo Nation (NN) has had a varied history which includes mining, thermoelectric power plants, renewable energy sources, and concerns of energy justice for the thousands of families living without utility services on the Reservation. How the Nation shapes its future energy development will be driven by domestic development needs, health concerns, available energy resources, the changing political and regulatory landscape, climate change implications, the energy-water nexus, and greenhouse gas (GHG) emission considerations.

To understand potential impacts climate change and variability may have on the Reservation's energy sector, it is critical to know the background of the NN energy sector. The first section of this chapter provides this context. Potential climate change and variability impacts on the Reservation's energy sector are presented next. Vulnerability and adaptive capacity factors that may interact with climate changes and variability to impact the ability of the energy sector to provide a safe and reliable power supply are also discussed.

The energy sector contributes significantly to GHG emissions. Renewable energy sources and carbon sequestration provide options to reduce overall sector emissions and mitigate climate change. Because of this, we have included a special section providing more in depth information on both topics including the regulatory landscape influencing the implementation of renewable energy projects. Finally, we discuss some potential adaptation strategies for the energy sector and opportunities for funding such strategies.

12.1 Background Information on the Navajo Energy Sector

This section describes the current status of energy provision to on-reservation residents. We then discuss the state of the energy industry and explain how the industry provides significant revenue and jobs for the Nation.

Provision of energy to on-reservation residents

The Navajo Tribal Utility Authority (NTUA) is the primary electrical and gas utility company serving the Navajo reservation. NTUA provides electrical services to approximately 39,400 reservation

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customers and serves approximately 7,900 natural gas customers (NTUA, 2013). Although the NTUA is a private company, it is tribally owned and has a public service obligation similar to that of a government body. Other utility providers serving the Nation include: Arizona Public Service Company (APS), Continental Divide Electric Cooperative, Jemez Electric Cooperative, the City of Gallup, the City of Farmington, and Rocky Mountain Electric. Some utilities, such as NTUA, purchase all their electricity from other utilities and independent power providers. Others, such as APS, have ownership stakes in the electricity generating facilities from which they receive their electricity. NTUA offers rates to residential customers that are lower than the national average (NTUA, 2010) and rates in neighboring states (DOE, 2011).[1]

Photo: Julie Nania.

According to available state data, the on-grid portion of the Reservation receives most of its electricity from coal, with significant contributions from nuclear power and natural gas (DOE, 2009). To track GHG emissions, the NN has developed an inventory emissions program. The Navajo Nation Emission Inventory seeks to establish an emission baseline while categorizing sources of pollution (NEPA, 2014). Recently, the NTUA has also begun pursuing renewable energy technologies for residential household use and large-scale production (see below).

Transmission of energy on the Reservation is complex. Most energy infrastructure was constructed in the 1960s and is now considerably dated (NTUA, 2010). Because transmission lines must be replaced an average of every forty to seventy-five years, much of the Navajo infrastructure will soon need to be replaced (McAllister, 2011). NTUA, however, reports that it does not have sufficient revenue to invest in line maintenance or replacement.

Information about energy access on the Reservation is difficult to obtain. An estimated 16,000 families on the Navajo reservation do not have utility services (Battiest, 2010).[2] Certain areas, including those lands on Black Mesa that were part of the Bennett Freeze development prohibition, are almost completely off-grid (see discussion in Chapter 11). Rural electrification is thus a pressing issue.

Reservation communities often consist of small clusters of households located relatively far apart from other clusters and far from established grid access. Individual residences may also be spaced far apart from one another within a cluster (Tarasi et al. 2011). Electrifying these communities via on-grid transmission would require expensive and long power distribution lines. It costs $27,000 on average to extend a single transmission line one mile (NTUA, 2010). Furthermore, about fifty percent of NTUA's revenues go to purchasing electricity from other suppliers, ultimately increasing the cost to Reservation consumers and limits funding for new power lines (Tarasi et al. 2011). Additionally, it is unlikely that transmissions could be privately funded; many families connected to the grid are already struggling to afford monthly electricity bills and would not be able to pay for the cost of transmission (Tarasi et al. 2011). The cost of grid installation would be high because of the lack of roads and installation capacity to facilitate development.

1 Note: NTUA industry rates are competitive and lower than residential rates. Both demand and energy charges utilize a declining block rate scheme.

2 That current number is unknown, but 16,000 is likely a conservative estimate.

Photo: Julie Nania.

For families off the grid, energy sources vary. A popular source of heating fuel is wood. Some families also use tank gas. A very small percentage of families use coal or solar energy (Census Bureau, 2000).

Providing residents with energy access remains a priority for the Reservation. Section 806 of the 2013 Energy Policy Act states: "the Nation supports the development of distributed electricity generation and community scale electricity generation for use on the Nation" (The Navajo Nation Council, 2013). It remains unclear, however, what the long-term plan for providing energy access will be.

The Energy Industry

Large-scale thermoelectric coal-fired power plants have historically provided energy and formed the cornerstone of energy and economic development on the Reservation. Oil and natural gas extraction still occurs on Reservation lands, and uranium used to be mined. The Nation has also started to pursue both small and large-scale renewable energy projects.

Some of the key Navajo entities in the energy industry are the Diné Power Authority (DPA), the Renewable Energy Task Force (RETF) and the newly established Navajo Energy Office. The Navajo Energy Office serves as a clearinghouse for energy projects and is tasked with developing a strategic, long-term energy plan (The Navajo Nation Council, 2013). The RETF, established by the previous Navajo Nation President, Joe Shirley, has formulated a comprehensive tribal energy policy that utilizes traditional and renewable energy options. The RETF, established by the previous Reservation President, Joe Shirley, has formulated a comprehensive tribal energy policy that utilizes traditional and renewable energy options. The RETF provides an in-house source of information analysis and policy consideration to improve the tribe's ability to assess and negotiate partnerships with outside developers (Trujillo, 2010). Renewable energy development is also supported by federal policies; in 2001 the EPA explained that the "Nation will continue to develop a renewable portfolio of power generating facilities that balances coal, gas or oil-fired generation with economically viable renewable energy generation from such sources as wind, solar, hydro, geothermal and biomass" (The Navajo Nation Council, 2013).

Thermoelectric power plants

On or adjacent to the Reservation are three power plants fueled primarily by coal mined on the Reservation. The Four Corners Power Plant, located off of the Reservation just west of Farmington, New Mexico, began operating in 1963 and is one of the largest generating stations in the United States (US) with a power generation capacity of 2,040 megawatts (MW).[3] The 1,848 MW San Juan Generating Station is located on the Reservation close to the Four Corners Power Plant (Sourcewatch, 2010e).[4] Lastly, the Navajo Generating Station (NGS) is located on the Reservation near Page, Arizona (Arizona Public Service, 2010). NGS has a generating capacity of 2,250 MW from three 750-MW units (SRP, 2013). The future of the NGS, however, is uncertain (see below, Gosar, 2011).[5]

3 The Plant can produce 2,040 MW.

4 It is owned and operated by the Public Service Company of New Mexico. The San Juan Plant is one of the region's power plants that may be greatly impacted by the EPA's more stringent haze regulations under the Clean Air Act.

5 The EPA is currently utilizing the Best Available Retrofit Technology (BART) determination under the Regional Haze Rule of the Clean Air Act to guide the station into compliance with regulations protecting air quality

These plants provide power for a variety of users, including large water delivery systems such as the Central Arizona Project (CAP) and the Salt River Project (SRP). The plants also withdraw huge amounts of water. The NGS withdraws an average of 24,551 acre-feet (af) of water annually from Lake Powell for cooling (Sourcewatch, 2012 d).

In addition to the three active existing stations, there has been a concentrated push to develop yet another coal-fired power plant near Farmington, the Desert Rock Generating Station. However, development on the Desert Rock Generating Station has stalled.[6] Although the EPA initially approved air quality permits for Desert Rock in 2008, it reversed this decision and revoked the permit in 2009. Many Navajo officials are still pushing for the revival of the Desert Rock Energy Project. Two additional power stations near the Reservation have recently shut down. The 995-MW Cholla Power Plant near Joseph City, Arizona, which was supplied by coal from the McKinley Mine in New Mexico, shut in 2009. The Mohave Generating Station, formerly a 1,580 MW power plant located in Laughlin, Nevada, also recently closed.

The future of NGS is one of the most divisive issues on the Reservation. On one hand, NGS provides approximately $25 million per year from NGS royalties and lease fees to the Nation (Nelson, 2013). NGS is also a major employer on the Reservation, directly providing jobs for roughly 450 Navajo and indirectly providing jobs for roughly 375 Navajo working at Kayenta Coal Mine, (see below), one of the major mines supplying NGS. On the other hand, many Navajo are concerned about the health impacts of NGS emissions, wary of continuing the relationship with non-Navajo coal companies, and displeased that the Nation is receiving only royalties instead of the majority of profits from coal extracted from Navajo lands.

Even without public opposition, the future of NGS is tenuous. On January 18, 2013, the EPA issued a proposed rule that would require additional emission control technologies at the plant to reduce haze issues. The owners of NGS have protested that these retrofits will cost a minimum of $1.1 billion dollars to meet EPA standards. NGS has a series of leases and rights-of-way for the plant, railroads, water pipes and transmission lines. Six owners have stakes in NGS. Two of those owners, the Los Angeles Department of Water and Power and Nevada Energy, are divesting from the plant to meet renewable energy portfolio standards (SRP, 2013). Remaining stakeholders in NGS include the SRP, the BOR, APS, and Tucson Electric Power (Minard, 2013). The Reservation recently renewed its lease with NGS until 2044 (Minard, 2013). The Energy Policy Act of 2013 also emphasizes the intent to move forward with coal development on the Reservation. In section 901, the Act expresses the intent that "the Nation will pursue federal coal fuel legislation and adapt to the new federal regulatory environment." (The Navajo Nation Council, 2013)

Large-scale transmission

With respect to large-scale transmission projects, the DPA has been pursuing one of the most ambitious long distance transmission projects in the country,[7] the Navajo Transmission Project (NTP) (Hoisington, 2004). The NTP is a proposed 478-mile, 500 kV transmission line between the generation facilities near the Four Corners area and the energy markets in southern California and Arizona. However, the NTP project has been suspended for further planning (Western Electricity Coordinating Council, 2010).

Fuel extraction

The Reservation also supplies fuel for the energy sector. On the Reservation are significant deposits of coal, uranium, oil and natural gas. Several major coalmines are currently operating on the Reservation.

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in the Grand Canyon. Imposing these requirements would force the station to spend over one billion dollars to retrofit; an amount the plant's owners maintain would make the plant economically impossible to operate.

6 For nearly a decade, the DPA and Sithe Global Co. were pursuing the Desert Rock Energy Project, a proposed 1,500 MW coal-fired power plant. The project was halted due to an EPA Appeals Board decision that the project's environmental permit was deficient (Desert Rock, Project Status, 2009).

7 The DPA was established by tribal statute in 1985 with the mandate to develop transmission and generation projects on the reservation.

Photo: Julie Nania.

In the coal-rich Black Mesa area in northeastern Arizona, the Kayenta Coal Mine, operated by Peabody Coal, can produce approximately eight million tons of coal annually to fire the NGS (Sourcewatch, 2010 b). In New Mexico, the Four Corners plant uses Navajo coal from Farmington, and the nearby San Juan Coal Mine produces an annual seven million tons of coal annually to feed the San Juan Generating Station (Arizona Public Service, 2010).

Coal on the Reservation, however, has suffered substantial blows in recent years. In 2006, the Back Mesa Mine, near Kayenta Mine, was shut down after the closure of its sole customer, the Mohave Generating Station (Sourcewatch, 2010).[8] Near Window Rock, Arizona, the McKinley Coal Mine also closed in 2009 in response to the closure of the off-reservation Cholla Power Plant (Sourcewatch, 2010 c). It is possible that the scaling down of the Four Corners Power Plant could cause the Navajo Mine to close. APS is taking three of the oldest units at the Four Corners Power Plant out of production to avoid updating equipment to meet EPA standards (Dahl, 2013).

Despite these recent setbacks, the Nation is directing capital and policy decisions towards a coal-oriented future (Energy Policy Act, 2013). The Reservation just purchased Navajo Mine for $85 million from, BHP Billiton despite the risk of an immense cleanup project. The mine produces 8.5 million tons of coal annually. The Navajo Transitional Energy Co. now owns the mine (Associated Press, 2013).

Like power plant operations, coal mining on the Reservation has been subject to considerable controversy in recent decades. Lengthy litigation concerning mineral lease rights between the Reservation and the federal government as a trustee is ongoing (United States v. Navajo Nation, 2009). Despite the ongoing litigation, the Reservation receives substantial portions of its operating budget from the sale of coal. Many Navajo workers are employed by the mining and power plant industries, and there is concern that increased regulation of power plants would negatively impact many jobs at the coal mines and the plants (Shelly, 2011).[9] Please see the discussion of coal production on Black Mesa in the Water Resources Chapter (see Chapter 4).

Large-scale uranium mining on the Reservation began during WWII and continued through the 1980s. Navajo mine workers were not told of the health risks associated with radon exposure from working around uranium (Wasserman and Solomon 1982).[10] As a result, the Nation has suffered severe and long-lasting health and environmental impacts from uranium mining activities. Congress has since

8 The owners of the Mohave plant decided to close it down rather than spend the money to upgrade it in order to comply with pollution standards.

9 At the same time, tribal members are concerned that, while the installation of solar or wind power plants could initially provide jobs, once the plants were constructed there would be a significant decline in job opportunities. In May of 2011, an oversight hearing addressing the importance of the NGS, President Ben Shelly emphasized that the plant employs "roughly 449 Native American workers and that the Kayenta Mine employs another roughly 375 Native American workers" stressing that the plant "both directly and indirectly supports the Nation's overall economic viability, the health and welfare of the Navajo people and its communities, and the sustainability of the Navajo Nation as an independent sovereign nation."

10 In 1979, a retaining dam broke at the Church Rock mine, flooding the lower Rio Puerco River communities with contaminated water. This catastrophic tailings dam failure was the largest radioactive accident in the history of the US.

passed measures to try and compensate the Navajo people for damages (42 U.S.C, 2010). Responding to the continued concerns of the Navajo people, Navajo President Peterson Zah issued an executive order Moratorium on Uranium Mining in 1992; in 2005, the Navajo Tribal Council passed a resolution banning uranium mining and milling on the Reservation altogether (Navajo Nation Code, 2005). Navajo President Joe Shirley reinforced the prohibition when he issued an executive order prohibiting Navajo officials from even entering into conversations with uranium companies (Hardeen, 2005).

Photo: Julie Nania.

Despite former decisive actions condemning further uranium mining on the NN, in the 2013 Energy Policy, there is a provision which states the Nation will "continue to monitor uranium mining technologies and techniques, as well as market conditions for uranium mining and nuclear electricity generation to assess the safety, viability and potential of these activities for the future," indicating that nuclear power or uranium mining could be revived in the Nation's energy future (The Navajo Nation Council, 2013).

Renewable energy projects

The Nation already has a long tradition of using renewable energy. There are over 1,000 windmills on the Reservation that provide energy to pump groundwater. Recently, the Nation has increasingly pursued solar and large-scale wind energy projects. In 2011, the Crownpoint Chapter installed a 16 panel PV system (Smith, 2011), and St. Michael's Indian School built one 2.4 kW wind turbine (Hughes, 2011). Up to this point, NTUA has also installed around 200 PV units in residential areas (NTUA, 2013). Since 2000, Sandia National Laboratories, the Reservation, and the Department of Energy (DOE) have been working together to bring affordable PV solar panels to families off the grid (NTUA, 2013). There have also been several small-scale projects completed by various non-profits and non-reservation groups (Elephant Energy, 2010).

Large-scale projects have been much more difficult to get started, but the Nation has initiated several wind projects which have yet to take off. In December 2009, the NN voted nearly unanimously to approve the construction of the Big Boquillas Wind Project, west of Flagstaff. A significant portion of the project would be owned by the Nation. Although the first phase of the project was scheduled to start in December 2010, construction has been delayed.[11] The NN believes that this project will provide clean electricity and jobs for the people of the Reservation as well as government revenue. NTUA also is negotiating with the SRP to purchase power from the project for its Navajo customers, according to Terry Battiest, NTUA's renewable energy engineer (Romano, 2009).

12.2 Potential Climate Change and Variability Impacts on Energy Development on the Navajo Nation

The changing climate has broad implications for energy use and development. There are a variety of ways

11 Phase one will involve installing 85MW of capacity from 48 turbines. The anticipated cost of this phase is $199 million. Project plans include a potential 150MW second phase. In addition, NTUA intends to acquire at least 10MW of project capacity at a target of $80-$85 per megawatt hour.

Photo: Julie Nania.

in which climate change may affect the energy sector. Many of these impacts are related to the energy-water nexus. The energy-water nexus describes the two resource's interdependency because water is needed to provide energy, and energy is needed to provide water (Drobot, 2011; Ojima et al. submitted). In 2009 alone, the US energy sector used approximately 98 trillion gallons of water in processes related to energy generation (Brosius, 2008). Every traditional and new form of fuel supply or energy production uses water and thus has a water footprint.

Water footprints vary greatly between different energy sources. In coal mining, water is used for transporting coal in slurries, for dust suppression, and to wash coal to remove noncombustible material. Thermal electric power plants also rely on access to large quantities of water for cooling steam driven turbines (Feeley, 2008). Water is used in emissions scrubbing and in the construction of energy-related infrastructure. When nations lack access to water, they lack access to an essential component of energy generation and fuel production (Drobot, 2011).

Just as water is needed to provide energy, energy, in turn, is needed to treat and move drinking water and wastewater. The amount of energy required depends on the water quality, the intended use or discharge standards, and the distance over which the water must be conveyed (Ojima et al. submitted). For example, large quantities of electricity are needed when pumping raw water over long distances as is done in the Central Arizona Project that supplies water to cities such as Phoenix (Ojima et al. submitted).

Below we discuss how climate change may affect the supply and demand of energy and water. Many of these impacts stem from rising air and water temperatures, changes in the timing of water regimes, increasing stress on water availability, and increasing intensity of weather events. For reasons discussed below, a combination of extended heat and drought can be particularly problematic (Averyt et al. 2011). Because of the energy-water nexus, many of the impacts are interrelated.

Energy demands

Rising air temperatures and increases in the frequency, duration, and spatial extent of heat waves will require more electricity to maintain safe household living environments through cooling. Similarly, climate change will lead to greater electricity demand for industrial cooling for activities such as food production and food storage to meet operative standards (McAllister, 2011). In addition, climate changes could lead to decreased cooling water efficiency (see below), reducing a power plant's output when increased power generation is necessary to meet increased energy needs (Drobot, 2011).

Climate change may cause increased energy demands from the water sector. As discussed below, water stress in the SW is anticipated to increase in the future. If this leads to the use of poorer quality waters, then energy demands for treating water to safe drinking or industrial standards may increase (Ojima et al. submitted). If water must be pumped from deeper depths or transported over greater distances, associated pumping needs could lead to increased energy demands (Ojima et al. submitted). Reduced streamflows could result in increased pollution concentrations. Wastewater treatment plants treating more polluted water would require more energy to treat the water (Ojima et al. submitted).

Energy supply

This section describes potential climate change and variability impacts on thermoelectric, hydroelectric, and natural gas turbine power plants and the transmission portion of the energy supply infrastructure. Although climate change impacts on fuel extraction are not specifically described here, potential water allocation conflicts due to water scarcity as noted below are also applicable to the fuel extraction industry.

Thermoelectric power generation

In thermoelectric power plants, a fuel (such as coal, natural gas, nuclear fission, biomass, concentrating solar power, or geothermal energy) is used to boil water, which creates steam that turns turbines to generate electricity (Averyt et al. 2011). The steam is then cooled so that it condenses. Some types of cooling systems use large quantities of water.

In the SW, droughts are expected to increase in frequency, severity, and duration, which could impact thermoelectric generation if the level of a cooling water supply drops below that of a power plant intake structure (Tidwell et al. 2013). Decreased water supply could thus lead a plant to reduce its power production or shutdown. The NGS obtains its cooling water from Lake Powell. In 2005, the depth of the intake structure was 220 feet below the surface (NETL, 2009). In contrast, the Four Corners Power Plant obtains its cooling water from the San Juan River; in 2005, the depth of the intake structure was only five feet below the River's surface (NETL, 2009).

Elevated water temperatures could also affect thermoelectric generating stations. Rising air temperatures and increasing droughts could lead to lower flows, likely resulting in warmer waters (Drobot, 2011). More winter precipitation falling as rain rather than snow would lead to reduced snowpack. A reduced snowpack combined with earlier snowmelt may lead to lower flows and warmer water temperatures in the late summer. Elevated water temperatures lower cooling water efficiency requiring generating stations to reduce power output or use more water (Drobot, 2011). Increased need for cooling water can lead to increased competition among water users (see water demand and supply section, below).

Because of water quality standards set to protect aquatic life, waters can be designated too warm to receive heated power plant return flows (Averyt et al. 2011; Drobot, 2011; NETL, 2009). Thus, it is possible that even before water levels fall below intake structures and require power plants to curtail production or shutdown, elevated water temperatures could cause plants to shutdown (NETL, 2009). In the past when this occurred, power was typically obtained from other generators on the grid. Increased energy costs, however, were passed on to consumers (NETL, 2009).


Photo: Julie Nania.

Natural gas turbine, hydroelectric, and solar photovoltaic energy generation

Climate change could also affect natural gas turbines, hydroelectric power production, and solar PV systems. Some natural gas turbines use exhaust gases rather than steam to run turbines and do not require cooling (Averyt et al. 2011). Rising air temperatures could decrease the capacity and efficiency of natural gas turbines, however, in several other ways. Warmer air is less dense than cooler air. Because density is equivalent to mass per unit volume, for a given volume of air taken in, the air mass is lower for warmer air than for cooler air. In addition, warmer air temperatures may affect the pressure ratio within the turbine and the power consumed by the compressor (Tidwell et al. 2013).

As discussed in Chapter 4, climate change and variability may affect water quality, quantity. The extraction of natural gas may also be impacted by water scarcity.

Hydroelectric power production, created by flowing water driving turbines to create electricity, may decrease due to a considerable amount of evaporative loss (Hass, 2009). Hydropower production could also be affected by anticipated increases in drought frequency, severity, and duration. More winter precipitation falling as rain rather than snow and earlier snowmelt are anticipated to lead to changes in the timing and amounts of runoff, which would affect reservoir storage and thus hydroelectric power plant operations (Drobot, 2011; Tidwell et al. 2013).

Some PV systems, such as crystalline silicon modules, may be affected by rising air temperatures because they do not perform as well under warmer conditions. Other PV systems, however, are less sensitive to temperature changes (Tidwell et al. 2013). Because natural gas extraction also requires water resources it may also be impacted by water scarcity.

Transmission

Additionally, climate change may affect the transmission of energy via the grid. Higher temperatures can decrease transmission line substation and transformer capacities. More energy must be produced to compensate for the resulting energy loss. The development of conductor hot spots could lead to the failure of transformers and to the start of wildfires (Tidwell et al. 2013)

Higher temperatures, increased drought, and longer fire seasons associated with earlier snowmelt are expected to increase wildfire frequency and size (see Chapter 3). Wildfires can directly affect energy transmission by burning wooden power poles. Fires can have indirect effects as well. The smoke and soot generated by fires can create alternate conductive pathways resulting in line outages. Fire retardants dumped by aircraft to combat fires can foul transmission lines (Tidwell et al. 2013).

Photo: Julie Nania.

Climate change impacts could lead to increased weather variability and extremes. Extreme weather events can wear down transmission infrastructure more quickly and frequently cause disruptions in transmission (McAllister, 2011).

Water demand and supply

Just as climate change will likely lead to increased energy demands, anticipated climate changes in the SW will also likely lead to increased water demands and, during certain times, decreased water supplies.

As noted above, warmer water temperatures decrease cooling water efficiency. To compensate for decreased cooling efficiency, power plants may need to withdraw more water, increasing water demands (Drobot, 2011). Furthermore, higher air temperatures will lead to greater energy demands for industrial and domestic cooling, which in turn will lead to greater water demands by the energy sector (Drobot, 2011). Higher air temperatures and longer growing seasons will also likely result in greater water demands from the agricultural sector (Drobot, 2011). Drought could exacerbate these agricultural water demands. In addition, other non-climate related factors such as population growth, will likely increase water demands in the region. Anticipated increases in drought frequency, severity, and duration will further constrain available water supplies. Water supplies could also be diminished due to more winter precipitation falling as rain rather than snow and an earlier snowmelt that could cause less runoff in the late spring through late summer.

Because increased water demands together with constrained supplies will likely exacerbate water stress, energy production could be limited by water availability. Increased demands for summertime cooling could intensify energy-water nexus issues during periods of extended heat combined with extended drought because of potential water shortages (Averyt et al. 2011). In the SW, constraints on electricity production in thermoelectric power plants because of water shortages are already predicted for Arizona and Utah by 2025 (Drobot, 2011). Water constraints will likely have implications on fuel extraction of oil, natural gas and coal production in addition to implications for power production (Drobot, 2011).[12]

12.3 Vulnerability and Adaptive Capacity Factors

Climate, hydrologic, and ecosystem changes will interact with socioeconomic, infrastructural, political, and other vulnerability/adaptive capacity factors to enhance or diminish the ability of the Navajo energy sector to provide a safe and reliable power supply. Although we separate vulnerability/adaptive capacity factors into categories for conceptualization, these factors are interrelated and will affect one another.

Although not directly addressed in this section, we also note that impacts on health, tribal revenue, job creation, and fish and wildlife associated with different energy choices are also of great concern and need to be considered in the development of an energy policy. In addition, different types of energy systems will emit different levels of GHGs that exacerbate climate change. Renewable energy sources that can be used to decrease GHG emissions are discussed in more detail below.

Socioeconomic factors

Socioeconomic factors, such as population growth, will further pressure energy resources. Between 2000 and 2030, the population of Arizona is projected to increase 108.8% (Drobot, 2011). States and municipalities are already predicting water shortages within the next ten years due to rising populations (Drobot, 2011). In addition, economic development on the Reservation (including energy sector development) will increase the Nation's energy and water demands. The change in demand will partially depend on choices made as to the types of development created and technology employed. Increased energy demands and water shortages can exacerbate the energy-water nexus concerns described above. Ensuring that energy choices are affordable for residents is important because an energy source is only dependable if people can pay for it.

Federal, state and regional legislators may impose a tax on carbon or may pass similar legislation to reduce energy production that is CO_2 intensive. In the US, there have been many proposals, but few carbon taxes actually implemented. Boulder, Colorado was the first to pass a municipal carbon tax in 2006 to decrease emissions. Additional green legislation could promote certain adaptation strategies. For instance, to aid in promoting efficiency, in 2009 the Navajo Nation Council passed the Navajo Green Commission Act to stimulate green jobs on the Reservation and support efficiency efforts (Chen, 2009). Future federal and state laws and policies may also have implications for the cost of energy resources on the Reservation.

Infrastructural factors

12 Depending on the source of the coal, estimates for water use in coal mining vary between 10 to 100 gallons per ton or coal mined. Water is used for transporting coal in slurries and to wash coal to remove noncombustible material. Additionally, if ambient air temperatures rise, more water may be required for the cooling process. This will decrease the capacity of cooling water efficiency can also reduce a power plant's power outputs, thus requiring increased power generation to meet power production demands.

Key Points: Potential Climate Change Impacts on Energy

- Impacts on water resources (see Chapter 4), particularly water scarcity, will directly impact energy production
- Increases in energy demand for cooling and water supply delivery
- Decreases in cooling efficiency for power plant cooling
- Potential difficulties meeting discharge standards if water temperatures rise
- Compounded water quality issues
- Rising air temperatures may impact efficiency of PV systems
- Higher temperatures may decrease transmission line substation and transformer capacities
- Increased wildfire occurrences could lead to a corresponding increase in transformer failures
- Increased wildfires can burn transmission infrastructure and soot can interrupt transmission
- An increase in extreme weather events can lead to increases in power outages from transmission disruption
- Cooling may require increased water quantities
- Energy production could be limited by water availability

Different types of energy systems will use different amounts of water and energy and will emit different levels of GHGs. To successfully adapt to a future with climate change, the NN must compare the tradeoffs between various energy systems. Water requirements for energy production can be withdrawn from a specific source such as a river, lake, or groundwater aquifer. Withdrawn water can either be returned to a water body or consumed and not subsequently available for other uses (Averyt et al. 2011).

To cool the steam used to drive the turbines, thermoelectric power plants generally employ an open-loop system, a closed-loop system, a dry cooling system or some combination of the three. Once-through or open-loop systems use water once for cooling and then discharge it (Feeley, 2008). These systems typically withdraw much more water than the other two types of cooling systems (Averyt et al. 2011). Recirculating or closed-loop systems recycle the water they use for cooling, thus withdrawing significantly less water than open-loop systems. Because they lose much of the cooling water to evaporation, however, they can consume twice as much water as open-loop systems (Averyt et al. 2011). Dry cooling uses almost no water because it utilizes air rather than water for cooling. As air temperatures increase, however, dry cooling efficiency decreases. Both closed-loop and dry cooling systems also use more energy than open-loop systems for the cooling process. Some power plants use a combination of cooling systems, making use of dry cooling much of the time but changing to one of the two wet-cooling methods when temperatures get hotter (Averyt et al. 2011).

According to a Union of Concerned Scientists' report (Averyt et al. 2011), when comparing water withdrawal for thermoelectric power generation to other energy production methods, withdrawals range from "almost zero for solar photovoltaic, wind, and dry-cooled natural gas plants to hundreds of gallons for an efficient plant using recirculating cooling to tens of thousands of gallons for a nuclear or coal plant using once-through cooling." Water consumption can "range from almost zero for solar, wind, or gas plants using dry cooling to around 1,000 gallons for coal, oil, or concentrating solar power (CSP) [plants] with recirculating cooling." (Macknick et al. 2011)

Although some types of energy, including renewable energy, that produce low GHG emissions (a.k.a. are low carbon-intensity) also have very low water usage, others are quite water intensive. Wind turbines and solar PV, for example, are both low carbon and water intensity forms of energy. In contrast, although nuclear fission produces low GHG emissions, for any given cooling technology, it is on average more water intensive than coal and natural gas (Averyt et al. 2011).

Concentrating solar power using a recirculating cooling system is also low carbon intensity but more intensive in terms of water consumption (Averyt et al. 2011). Although the amount of water used in biofuel production varies widely depending on climate and the type of agricultural production system used, biofuel production can also be quite water intensive (Drobot, 2011). For example, the water needed for ethanol production can be significantly greater than that needed for gasoline production (Drobot, 2011). Estimates for water use in coal mining vary between 10 and 100 gallons per ton of coal mined and depend on factors such as the source of the coal (Drobot, 2011).

As noted above, PV systems could provide a source of energy for those parts of the reservation for which on-grid transmission may be prohibitively expensive. Technological considerations related to PVs include choosing systems that are less temperature sensitive and systems that are accessible and affordable to repair and expand. It may also include creating a knowledge base on the Reservation for how to install such systems and repair them if they break down.

Photo: Julie Nania.

As technology continues to develop, perhaps further improvements in reducing water usage or in increasing the energy efficiency of devices will be able to provide additional adaptive capacity (Tidwell et al. 2013).

Policy factors

Planning for water scarcity is crucial to sound energy policy planning. In the National Energy Policy Act of 2005, the DOE emphasized that the "lack of integrated energy and water planning and management has already impacted energy production in many basins and regions across the country." (McAllister, 2011) While a lack of planning is a vulnerability, creating a powerful adaptation strategy that integrates energy and water planning and considers municipal, agricultural, industrial, environmental, climate change mitigation and extended heat and drought issues could guide the Reservation's transition to an uncertain climate future.

Federal legislation is important because of the support it may generate for certain adaptation strategies. The Obama administration has issued directives encouraging tribal participation in climate adaptation and resilience actions. Last November President Obama issued the Executive Order "Preparing the United States for the Impacts of Climate Change." The executive order emphasized climate preparedness, resilience and adaptation efforts. Section 7 of the order explicitly noted that tribal leaders should be included in a task force on climate preparedness and resilience to provide recommendations to the President (Obama, 2013). The inclusion of tribal leaders in national efforts and continued federal funding may provide important opportunities for NN climate adaptation efforts.

The NN has also been working to establish policies to guide the Nation's energy future. The NN has recently revised its energy policy and enacted the Navajo Energy Policy of 2013. The Energy Policy Act "sets forth principles relating to the exploration, development, sustainable management and use of energy resources on the Nation". (The Navajo Nation Council, 2013) The 2013 Energy Policy addresses a range of energy sector factors, including fuel resources, mines, generation facilities, transmission and distribution infrastructure, and pipelines (The Navajo Nation Council, 2013). It also addresses "resources assessment, exploration, severance, development, production, preservation, management, protection and distribution." (The Navajo Nation Council, 2013)

Certain provisions in the 2013 Energy Policy Act may provide a strong foundation for adaptation efforts. For instance, it incorporates Navajo Fundamental law to "strive to maintain a proper balance with the natural world" and defines a sustainable energy economy as one that "ensures an acceptable quality of life for Navajo people; proper planning and management by governmental officials; energy security; environmental stewardship." The Energy Policy Act explains that "energy developments on the Nation will be designed to be sustainable over the long-term based on economic considerations and environmental and community impacts." (The Navajo Nation Council, 2013)

Other provisions in the 2013 Energy Policy will have more direct implications for managing the energy sector. For instance, lesees of land for energy projects must return the land "to its original condition, or better, at the end of the projects." Additionally, "[n]ew energy projects shall minimize negative impacts on other scarce and valuable resources of the Nation and manage such impacts in accordance with the Nation's laws, policies and plans for its resources, and will mitigate adverse impacts where necessary." (The Navajo Nation Council, 2013)

Policy considerations also include regulations within which power plants or mines must operate. These regulations may be designed to protect human and environmental health (e.g., the Clean Water Act), maintain visibility within scenic areas (e.g., USEPA's Haze Rule) or limit GHG emissions (e.g., USEPA's GHG Emissions Standards). Regulators may require certain pollution control equipment or set a limit on the output of a power plant under certain conditions. For example, the Clean Water Act sets temperature limits on cooling water discharges to protect aquatic health. During heat waves, when water temperatures may be elevated, this could potentially force power plant operators to reduce output or even to temporarily shut down (Averyt et al. 2011). The NN must therefore consider current and future regulations when looking at the overall picture of the reliability of energy sources under climate change.

12.4 Potential Energy Sector Strategies for Climate Change Mitigation

Renewable energy sources and carbon sequestration can mitigate climate change. Certain types of renewable energy are also much less water intensive than traditional power sources and thus can be an adaptation strategy as well. Here we discuss potential energy adaptation strategies that the NN may want to consider.

Renewable energy production

In a world where climate change is already a reality, and where the US may begin to develop more significant climate change and renewable energy policies, tribes will have unique opportunities and face unique challenges. Indian reservations occupy only 5% of the total US land base but contain 10% of the total federal energy resource (DOE, 2004).[13] The infrastructure and revenue from tribal renewable energy projects could create jobs for tribal communities, contribute to energy justice, and bolster tribal economies. Renewable energy projects could also make a significant contribution to climate change mitigation.

Solar is one of the most promising energy options on the Reservation. The major categories of solar power are passive solar, solar thermal, and PV. The Navajo reservation is endowed with solar resources sufficient to utilize all categories of solar energy technologies (DOE, 2010).[14] As noted above, some solar thermal systems do require water for cooling and are mainly used for large-scale projects.[15] PV, however, converts sunlight directly into electrical charge and require very little water, especially for local small-scale projects (NREL, 2010). In non-rural settings where grid electricity is readily accessible cost can be a major limiting factor for implementing solar technologies. However, in rural settings, where transmission costs can be quite high, residential-sized solar technologies could potentially be more affordable. The NN

13 In 2004, the DOE reported that tribal lands have a wind energy potential of approximately 535 billion kWh/yr and that tribal lands have an annual solar energy potential of 17,600 billion kWh/yr.

14 Passive solar design is the use of natural sunlight for heating, cooling, and lighting of structures and can be accomplished using many different types of materials and building configurations.

15 A solar thermal system is a device designed to receive solar radiation and convert it to thermal energy. Low-temperature systems can use sunlight for heating and cooling. Large-scale Concentrating Solar Power systems use concentrators to create thermal energy that runs a commercial electrical generator. CSP is still an expensive option and requires large qualities of water which, as discussed above, is not ideal in water stressed areas.

has maintained a consistent partnership with the federal government and private companies to develop residential-scale solar power on the Reservation and to alleviate the expense of small-scale distributed solar. A variety of local organizations have also received grants for solar pilot projects, including the native-owned solar company Sacred Power (Norrell, 2005).


Photo: Julie Nania.

Wind is also a very promising renewable energy source on the Reservation. Windmills convert the kinetic energy of wind to mechanical energy that powers machinery such as groundwater pumps. Wind turbines convert the kinetic energy of wind to electricity. Between 2005 and 2007, the DOE awarded the Tribe $200,000 to conduct a comprehensive wind farm feasibility study (Ahasteen, 2007). The study monitored six sites in Arizona and New Mexico to determine their potential for wind-energy development and focused on the promising Grey Mountain and Aubrey Cliffs sites (Ahasteen, 2007). Generally, in order to make it economical to build wind farms, wind energy in an area must be rated at least a class three out of the seven classes. The study found that class three wind resources are available on 950 acres of Navajo land (Ahasteen, 2007). Furthermore, over 200 acres of Navajo land have a wind resource of class four or higher (Ahasteen, 2007).

Other energy options, such as biomass, and hydropower, are limited by feasibility on the Reservation. Biomass can be produced locally to support energy demand and uses fewer GHG emissions than fossil fuels. It creates local jobs and reduces waste product (EPA, 2007). While large-scale biomass potential on the Reservation is small, it is a viable option for small-scale use.

Hydropower technologies use the force of flowing water to create electricity (EIA, 2008).[16] Opportunities for hydropower development on the Reservation are limited. The potential for hydropower increases in Upper and Lower Colorado River basins are more feasible. In recent years the NN has proposed the joint development of a hydropower expansion project at Navajo Dam. The Nation must take into account feasibility, cost, cultural considerations and federal regulations (International Rivers, 2008).[17]

Project developers working on tribal lands must abide by federal law, tribal law and under some circumstances, state law. The table below provides a basic overview of select federal laws that may impact renewable energy policy planning and implementation. Each law could have unique applications and consequences depending on the type of renewable energy development and the location.

16 The three primary types of hydropower systems include impoundment systems, run-of-river systems, and pumped storage systems. Dam impoundment holds a reservoir of water and uses controlled releases to spin a turbine which generates electricity. Run-of-river facilities channel a portion of the river through a canal or penstock where a turbine generates electricity. Pumped storage systems are used when utilities have excess energy.

17 Hydroelectric power projects on navigable waterways have specific federal regulations, and federal lands must be licensed by the Federal Energy Regulatory Commission. FERC hydropower licensing requires consideration of water consumption and the possible impact on wildlife habitat. However, an exemption from licensing applies to small conduit hydroelectric facilities up to 15 MW or small hydroelectric projects of 5 MW or less.

Federal Policies with Potential Implications for Tribal Energy Development Projects	
Tribal Sovereignty	Tribes are sovereign nations with "inherent powers of a limited sovereignty which has never been extinguished." (Cohen, 2005) Tribes need to consider if they wish to wave their sovereignty immunity for energy projects partnerships with private companies.
Indian Commerce Clause	Tribes cannot unilaterally transfer trust property to non-Indians (Johnson v. McIntosh, 1823) and thus may need to receive approval from the Secretary of the Interior for a range of resource development agreements.
National Environmental Policy Act (NEPA)	Requires that federal agencies complete an extensive environmental review process prior to taking a "major federal action" that could "significantly affect" the environment where the project will take place. NEPA will most likely be evoked for projects on trust lands or requiring secretarial approval. Note: Wind projects may be able to "tier" (streamline) their NEPA documents by relying on a broad federal study (BLM, 2000).[1]
Indian Tribal Energy Development and Self-Determination Act	Amended several sections of the Energy Policy Act of 1992 to expand tribal control over energy resources on the reservation; provided federal financial support for research, analysis, and development of reservation resources; requires that "each Administrator shall encourage Indian tribal energy development . . . ." and shall consider the unique relationship that exists between the United States and Indian tribes." (DOE et. al 2008) Other important provisions include: • Tribal power purchasing preference • Tribal Energy Resource Agreement s (TERAs) which allow tribes to negotiate business agreements without further approval by the SOI • Established tribal energy programs in the DOI and DOE (25 U.S.C. 3502) • $20 million each year through 2016 for energy education, research, and development; energy, energy efficiency, and energy conservation programs; and acquisition of energy supplies, services, and facilities, including the creation of tribal utilities to promote electrification of tribal land (25 U.S.C. 3502). • Support for tribes to participate in carbon sequestration practices on Indian land, including geologic, forest, and agricultural sequestration (25 U.S.C. 3502).
Endangered Species Act (ESA)	Requires consideration of protected species when planning a federal action,[2] Section 9 prohibits any person from "taking" endangered or threatened species.[3] Section 10 requires permits for actions that might 'take' a species.[4] Section 7 says federal actions should not "jeopardize the continued existence" of a threatened or endangered species. Page:178 ESA: Other considerations for large-scale renewable energy development include project ownership and coordination and consultation between Navajo national level and local chapter governments.
Clean Water Act (CWA)	Regulates discharges in the "waters of the United States" and, important for energy use, limits thermal cooling discharges which can harm river species (Drobot, 2011).[5] Could impact thermal power plants, dam construction, and thermal solar projects.

National Historic Preservation Act	Under Section 106, federal agencies must consult with the tribal historic preservation officer to evaluate the effect of a project on the historical and cultural resources in the area.
Migratory Bird Treaty Act	Makes it illegal to take, capture, or kill over 800 species of listed migratory birds. This is especially important for wind power as wind farms are estimated to kill over 300,000 birds per year in the US (50 CFR 10.13).
Bald and Golden Eagle Protection Act	Makes it unlawful to "take" any bald or Golden Eagle, their parts, nest or eggs. Also important for wind power production.

1 The USFS and BLM have recently completed a Programmatic Environmental Impact Statement evaluating the general impacts of wind development on federal lands to help streamline the NEPA process. Project managers can "tier" their subsequent NEPA documents to this broad study, which should reduce the costs and time spent complying with NEPA.

2 In addition, the ESA requires federal agencies to consult with the federal agency responsible for that species if any project occurs in the habitat of a listed species.

3 Taking includes: "harassing" the species or disturbing their breeding, feeding, or habitat.

4 If a project is anticipated to "take" an endangered species the project permittee must hold an "incidental take" permit (issued by the USFWS under ESA Section 10).

5 Section 316(b) of the CWA is designed to prevent entrainment of aquatic life at cooling water intake structures.

Section 303(d) of the CWA requires states to identify impaired waters and Total Maximum Daily Loads for those particular waters. These waters are then incorporated into the National Pollution Discharge Elimination System permitting process and monitored it for quality compliance. A Section 404 permit is required prior to discharging dredge or filling material into the wetland. See also Rapanos v. United States, 547 U.S. 715 (2006).

The CWA also regulates storm water from construction projects, requiring permits and the formulation of a plan to prevent runoff. See, 40 CF.R. Part 122.26.

Table 12.1. Federal policies with potential implications for tribal energy development projects.

Funding for energy development will be a decisive factor for the NN's energy future. Renewable energy policy decisions made by the federal government, the NN, and states can substantially influence project viability. For all large-scale energy projects, the Nation wants "majority ownership by Navajo entities of large-scale energy projects." (The Navajo Nation Council, 2011) Specifics as to what this exactly implies, however, are unclear. How the Nation plans to deal with revenue and chapters will need to be further planned, and consideration for outside partners and federal incentives also need to be addressed (Eitner, 2013).

Creating renewable energy sources on the Reservation will require changes in the way that energy projects are approached from the federal and state levels.[18] Energy development incentives must be constructed such that they do not infringe on tribal sovereignty. Tribes will need assistance with funding to get projects underway. Additionally, legislation that offers incentives for projects that directly benefit tribes, such as granting significant carbon offsets or financial incentives, such as the new market tax credits or the community development investment fund breaks, could make certain projects more attractive on tribal lands.

Taxes and federal renewable energy incentives could help make some renewable projects more feasible. As sovereign nations, tribal partnerships with non-tribal partners are uniquely positioned to take advantage of certain tax incentives. Tribal sovereign immunity from federal and state taxation requires that tribal entities found to be "arms of the tribe" are not subject to federal income taxes for their stake in an energy development project (Taylor, 2005). Non-tribal partners, however, must still pay income taxes on any profits they earn from the project. By establishing a development company as a

18 For example, federal financial incentives often involve tax breaks, which do not apply to tribes because they do not pay federal income tax.

limited liability corporation (LLC), the non-tribal company can use the advantages of a "flow-through" structure to reduce their tax liability by offsetting the balance of their profits by attributing all capital depreciation and losses to themselves (Taylor, 2005). Examples of available tax incentives are provided in table 12.2 below.

Available Tax Incentives for Energy Development	
Energy Tax Credits	Credits up to 30% of the project cost for start-ups
New Market Tax Credits – (Community Development Investment Fund)	Eligible projects must cost more than 5 million dollars and be located in low-income community HUB zones.
Production Tax Credits (renewed in the American Recovery and Reinvestment Act of 2009)	Incentivizes the development of independent renewable energy producers. Can be used to decrease renewable energy production costs to the point at which renewable energy production is competitive with traditional coal-fired or gas-fired electricity generators.
The Energy Policy Act of 2005	Offers PTCs for efficiency improvements or capacity increases and authorizes Clean Renewable Energy Bonds

Table 12.2. Available tax incentives for energy development.

The Obama administration enacted legislation removing a major tax impediment to tribal renewable energy development, rendering renewable energy options even more attractive. With the passage of The Indian Energy Promotion and Parity Act of 2010 (IEPPA), production tax credits (PTCs) became transferrable from tribal business owners to their non-tribal partners. The tax credits provide an extra incentive to be paired with a statutory preference for purchasing from tribal independent power producers (IPPs) that are at least 51% owned by the tribe.

Other considerations for large-scale renewable energy development include project ownership and coordination and consultation between Navajo national level and local chapter governments. A lack of coordination and consultation between the two levels of government concerning proposed projects can cause significant delays or even derail projects (Navajo-Hopi Observer, 2009). An example of this problem can be seen in the current conflicts over wind power on the Reservation. As noted above, the potential for wind power is huge on the Reservation (Ahasteen, 2007). Yet, complaints in nuisance lawsuits from neighbors can include objections to the "shadow flicker" caused by wind farms (Noble Power), the tendency of some turbines to shed ice projectiles (Seifert, 2003), and the noise disturbance from older wind turbines. Grey Mountain, west of the town of Cameron, is considered to have the best wind resource on the Reservation. Grey Mountain has average wind speeds of 17 mph and available transmission lines nearby to connect projects to cities (Brummels, 2006).

In March 2008, the Navajo central government announced its plan to partner with Citizen's Energy to develop a 250-500 MW wind energy project at Grey Mountain. The proposed partnership would have granted a 20 percent ownership stake to the Diné Power Authority (DPA) and would have produce over $10 million annually in taxes and other revenue for the tribal government. Although Sempra, the partnering entity, and the Cameron Chapter repeatedly called for a land lease agreement, they were unable to finalize a lease because of political disagreement.

Carbon sequestration

Carbon capture and sequestration helps to mitigate the impacts of climate change by capturing carbon either terrestrially or in underground formations (Congressional Research Service, 2009).[19] Although

19 Storing CO_2 lowers the amount of GHGs in the atmosphere and so mitigates some of its impacts. Geologic carbon sequestration projects typically involve the capture of CO_2 directly out of power plant emissions, transportation of the CO_2 to the injection site, and then sequestration of the CO_2 in underground geologic formations. There are three methods to capture the CO_2 out of power plant emissions: post-combustion capture, pre-combustion capture,

this technology has obvious benefits for reducing CO_2 emissions, it increases plants' water demand, due "both to a reduction in the plant efficiency [ ] and to the cooling water and process water requirements associated with carbon dioxide capture and compression." (DOE, 2009). Using carbon capture technologies can increase water consumption by nearly 100% (DOE, 2009). There are possibilities for geologic carbon sequestration projects on the Reservation, but funding has been the limiting factor (NETL, 2009). A more promising future project, which may have available financial incentives, is terrestrial carbon sequestration through improved forest management and agricultural activities (Dine Power Authority, 2009).[20]

Summary of Energy Sector Adaptation Strategies

- Renewable energy sources (small-scale residential solar institutions)
- Energy efficiency (weatherization, appliance updates, power strips, CFLs or LED lights, etc.)
- Sustainable building (passive solar and wind cooling design, local energy retrofits
- Long-term considerations (transmission and weather, water conservation, etc.)

12.5 Potential Adaptation Strategies for Energy

Climate change has the potential to negatively impact the energy sector, as described above. The NN has been blessed with many energy resources, but must address the complex issues of domestic electrification, power transmission, and water shortages. Creating an energy plan with a more accessible and diversified energy base will help to protect against the possible impacts of climate change and simultaneously address national energy issues. Adaptation strategies include: small-scale solar and wind project implementation to increase energy access on the reservation, energy efficiency to reduce energy demand, reducing water usage, transmission resilience, and integrated energy, water, and climate change planning.

Small-scale solar and wind to increase energy access for off-grid residents

Small-scale solar PV and wind turbines could improve energy access for off-grid residents. In many cases, the expense of solar panels or wind turbines is cheaper than extending transmission lines to off-grid homes (WAPA, 2000). As described above, small-scale residential solar projects are already being pursued for communities and homes that are currently not connected to transmission lines. Given anticipated rises in air temperatures, choosing PV technologies that are less sensitive to ambient temperatures could maximize performance (Tidwell et al. 2013). In addition, increasing capacity on the Reservation to install and repair solar PV systems could increase access, ensure functionality of the systems even if extreme weather events occur, and potentially provide economic opportunities. Additionally, enhancing capacity on the Reservation for windmill repair could decrease any disruptions to windmill provided power.

Energy efficiency to reduce energy demand

Utilizing energy efficiency measures in homes and administrative and industrial buildings is likely the most cost effective way to adapt to climate change (Goldman et. al 2012). Efficiency adaptation can include updating lighting and appliances, weatherizing, retrofitting and designing sustainable buildings. These techniques can help conserve energy while saving consumers money. Coordination between the

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or oxy-fuel combustion capture. Geologic formations capable of storing CO_2 are generally oil and gas reservoirs, deep saline reservoirs, or un-mineable coal seams. However, it is important to note that these technologies are still new, and further studies are being conducted.

20 Terrestrial sequestration is the process of CO_2 being absorbed by trees, plants, and crops through photosynthesis and stored as carbon in biomass and soils. The DPA, in coordination with Navajo Agricultural Products Incorporated (NAPI), is developing a terrestrial carbon sequestration project in the form of an afforestation/reforestation project located on NAPI farmlands. The funding for this project comes from the Energy Efficiency and Conservation Block Grant Application. The project's first phase involves planting 50 acres of poplar trees on cropland irrigated using drip irrigation. The second phase would be more involved and would require planting more trees along return flows to eliminate drip irrigation costs.

many reservation groups and possible assistance programs will be important to ensure that efficiency is included in future energy planning (NCHID).[21] The 2013 Energy Policy Act supports energy efficiency to manage demand and cost of electricity on the Nation (The Navajo Nation Council, 2013).

The DOE has additional recommendations for homeowners to reduce their energy usage (DOE, 2011). Some of their simplest ideas are summarized in the following table. Maximizing energy efficiency in buildings is best viewed as a total energy system. For example, if you make heating systems more efficient indoors through cleaning filters and turning down the heat, energy can still be lost through poorly insulated walls and ceilings. Therefore, it is important to consider cost and effectiveness of solutions and combine the energy efficiency measures which, together, will make the most impact (DOE, 2011).

Energy Use	Efficiency Measure
Phantom Energy Use	Phantom energy use is energy use from appliances like cell phones, televisions, etc. that when plugged in and turned off still draw energy. Power strips can be used as central turn-off points to ensure that devices are not drawing electricity.
Old Appliances	Replace with Energy Star or other products which have been certified to be more efficient.
Air Leaks and Insulation	Minimize energy loses from window cracks, empty spaces, or building materials through insulating homes (cover single pane windows, weatherize doors and cracks, etc.).
Heating and Cooling	Use programmable thermostats. Make full use of passive heating and air cooling. Use drapes and shades on windows. Use landscaping to increase or decrease shade. Isolate rooms not in use.
Water	Keep water heaters at 120 degrees. For a more long- term solution, consider solar water heaters.
Lighting	Compact fluorescent lamps use 75% less energy and last 10 times longer than incandescent lights. LED bulbs use even less energy than CFLs and last 25 times longer.

Table 12.3. Energy Efficiency Measures.

Weatherization techniques for buildings can include weather-stripping, floor insulation, ceiling insulation, wall insulation, and window caulking (DOE, 2009). These strategies prevent homes losing energy to the outside. Every county is serviced by a weatherization agency, which can be located on the DOE site map (Lee, 2009).

Sustainable buildings can also improve efficiency. Green building typically involves maximum efficiency for the following five aspects of building practices: site, water, energy, materials, and indoor environmental quality (Jicarilla Apache Nation Utility, 2008). For example, passive solar design uses natural sunlight rather than mechanical systems for heating and lighting structures (DOE, 2009). When rebuilding is not a viable option, simple home retrofits will identify places in homes where energy could be used more efficiently. Sustainable building features that can maximize energy efficiency include, energy efficient lighting, increased monitoring and maximizing of energy performance, programmable thermostats, occupancy sensors, HVAC improvements, insulation, and upgraded windows. Tree shading can also help reduce cooling requirements. There are several national programs that provide assistance for home retrofits (see Chapter 11).

21 Key players in the area of renewable energy and energy efficiency on the NN include the DPA, NTUA, the Renewable Energy Task Force, the Navajo Transit System, the Navajo Housing Authority, and the NN Community Housing & Infrastructure Department.

Reducing water usage in the energy sector

In water scare regions such as the SW, reducing water usage in the energy sector can contribute to greater reliability of the energy-water system. Various strategies can be implemented during construction of new facilities or retrofits of existing facilities. For example, covering open pipes will reduce loss from evaporation. Capturing grey water in energy systems and reusing it is another option but will require additional infrastructure (DOE, 2012). Using low water, no water or hybrid cooling options in thermoelectric power plants can reduce water use although there are tradeoffs in terms of efficiency, energy usage within the cooling system, and water consumption (Averyt et al. 2011). Some power plants are also starting to use non-traditional, nonpotable cooling water sources. For example, the 1,080 MW Harrington Generating Station in Amarillo, Texas has begun using treated wastewater for cooling (Averyt et al. 2011). Finally, as noted above, the Reservation has considerable renewable energy development potential for energy sources that require minimal water such as wind turbines, solar PV and geothermal heating (Wagner and Randazzo 2008).

Transmission

To successfully implement a broad energy policy, the Nation must consider creating more extensive transmission across the Reservation. Developers must also plan for climate-related damages from wildfires and extreme weather events when planning new pipe and transmission lines. Burying power lines can protect transmission lines from windstorms, ice storms and wildfires, and could improve utility quality in the long term (DOE, 2012). Increasing fire corridors around transmission lines and using transmission line materials that are more resistant to the effects of heat and soot make transmission more resilient to fire (Tidwell et al. 2013). Also, improved monitoring of conductor temperatures can prevent extremely hot temperatures disrupting energy service. Transmission line capacity requirements can be reduced by decentralizing generation and thus decreasing distances from the power source to the point of use (Tidwell et al. 2013). Examples of decentralizing generation include using windmills and capturing and reusing methane onsite.

Integrated energy, water, and climate change planning

Integrated energy, water, and climate change planning can be a powerful adaptation and mitigation option. To properly plan, the Reservation must consider the interplay between the supplies and demands of energy and water and the effect energy choices will have on climate change (Drobot, 2011). Energy and water demands include municipal, agricultural, industrial, and environmental needs. Supply considerations can include the power plant mix (e.g., thermoelectric, hydropower, etc.), the fuel mix (e.g., solar, wind, coal, etc.), and the water source mix (e.g., groundwater, rivers, lakes and reservoirs, wastewater, etc.). Reducing regional demand for water decreases the demand for energy to pump, convey and treat water and wastewater and reducing regional demand for energy reduces the amount of water required for the energy sector. A full life-cycle analysis of energy, water, and climate change costs should be part of the planning process.

Planning can be conducted at various spatial and temporal scales and can incorporate energy adaptation strategies such as the ones noted above and water adaptation strategies such as the ones noted in Chapter 4. The Nation can conduct its own planning and should be included in any broader regional planning that takes place as well.

Energy Sector Adaptation Strategies
Small-scale renewable energy sources to increase energy access for off-grid residents
• Residential PV projects • Increasing Reservation capacity to install and repair solar PV systems • Increasing Reservation capacity to repair windmills
Energy efficiency
• Weatherization • CFL or LED lights • Appliance updates • Power strips as centralized turn-off points
Sustainable building design
• Passive solar heating and lighting • Tree shading • Passive wind for cooling
Reducing water usage
• Covering open pipes • Using no water (if temperatures remain low enough), low water, or hybrid cooling systems (Averyt et al. 2011) • Using nonpotable water sources for cooling (Averyt et al. 2011) • Considering the use of technologies such as wind turbines and solar PVs that use essentially no water (Averyt et al. 2011)
Transmission adaptation strategies
• Placement of transmission lines underground (Tidwell et al. 2013). • Increasing fire corridors around transmission lines (Tidwell et al. 2013) • Using new transmission line materials more resistant to the effects of heat and soot (Tidwell et al. 2013) • Improved monitoring of conductor temperatures (Tidwell et al. 2013) • Decentralized generation to decrease distances between power source and power use. (Tidwell et al. 2013)
Integrated energy, water, and climate change planning

Table 12.4. Energy sector adaptation strategies.

12.6 Potential Funding and Other Support

There are several federal programs that the Reservation could utilize to fund adaptation strategies, energy efficiency projects, and renewable energy projects. Select programs are noted in the table below. Additional resources may exist at the federal and state levels.

Program	Description	More information
Clean Renewable Energy Bonds	Tribes may issue tax credit bonds to investors for renewable energy development project funding	The Department of Treasury http://energy.gov/savings/clean-renewable-energy-bonds-crebs
Qualified Energy Conservation Bonds (QECB)	Like a broader version of CREB, tribes may also issue federal tax credits to fund efficiency and renewable energy developments	The Department of Treasury, amendments http://www.commerce.wa.gov/research-publications/researchservices/bcap/qecb/Pages/default.aspx
Energy Efficiency and Conservation Block (EECB) Grant Program	Funds for renewable energy projects. 2% (approximately $54 million)of all funds are set aside for projects on tribal lands	DOE http://www1.eere.energy.gov/wip/eecbg.html
Weatherization Assistance Program (WAP)	Provides free or low-cost improvements for home efficiency	DOE http://www1.eere.energy.gov/wip/wap.html
Loan Guarantee Program	Guarantees loans for projects that aim to reduce greenhouse gas emissions and other clean technologies (focuses on projects over $25 million)	DOE http://www.lgprogram.energy.gov
Tribal Energy Program (TEP)	Support both community and large-scale clean energy projects	DOE, Office of Indian Energy Policy and Programs http://energy.gov/indianenergy/office-indian-energy-policy-and-programs
The Strategic Technical Assistance	Assist with tribal renewable energy development	DOE, Office of Indian Energy Policy and Programs http://energy.gov/indianenergy/resources/start-program
Energy Technical Assistance	Provide technical support for energy efficiency and renewable projects	DOE, Office of Indian Energy Policy and Programs http://energy.gov/indianenergy/technical-assistance
Indian Environmental General Assistance Program (GAP)	Aids in developing environmental protection on tribal lands	Environmental Protection Agency (EPA) http://www.epa.gov
Rural Energy for America Program (REAP) Grants	Assistance rural renewable energy development, energy efficiency projects, and energy audits	USDA Rural Development http://www.rurdev.usda.gov/BCP_ReapResEei.html
Rural Utilities Service (RUS) Electric Program	Aims to expand electric services to rural zones	USDA Rural Development http://www.rurdev.usda.gov/UEP_HomePage.html
Public Housing Environmental and Conservation Clearinghouse	Aid in energy efficiency projects for homes on tribal land (can include energy efficient technologies such as energy stat products)	U.S. Department of Housing and Urban Development (HUD) http://portal.hud.gov/hudportal/HUD

Indian Housing Block Grant (IHBG) Program	Provides a range affordable housing options on tribal lands	HUD, Indian Housing's Office of Native American Programs (ONAP) http://portal.hud.gov/hudportal/HUD?src=/program_offices/public_indian_housing/ih/grants/ihbg
Energy and Mineral Development Program (EMDP)	Assists with research into energy potential (conventional, renewable, and mineral resources)	The U.S. Department of Interior (DOI), Bureau of Indian Affairs (BIA) http://www.bia.gov/WhoWeAre/AS-IA/IEED/DEMD/TT/TF/index.htm
Tribal Economic Development (TED) Bonds	Provides bond incentives for tribal economic development projects	Internal Revenue Service (IRS) http://www.irs.gov/Tax-Exempt-Bonds/IRS-Announces-Tribal-Economic-Development-Bonds-Allocations

Table 12.5. Federal assisted programs for adaptation strategies, energy efficiency projects, and renewable energy projects.

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