U.S. DEPARTMENT OF ENERGY | Office of Indian Energy

Tribal Energy System Vulnerabilities to Climate Change and Extreme Weather

September 2015

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NOTICE

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DOE/IE-xxxx • September 2015

Cover photos
Background: Wind turbines at the Ayagina'Ar Elitnaurvik School in Kongiganak, Alaska (Energy.gov 2013)
Top row: Navajo Dam and Reservoir (USBR 2011); Solar project on a house on the Grande Ronde Reservation (Energy.gov 2014); Drilling rig on the Osage Reservation (BIA 2010)
Bottom row: Power lines on the Lone Pine Rancheria (Reilly 2008); Diesel fuel bulk storage facility for the Native Village of Teller (Dane 2012)

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KEY ACRONYMS AND DEFINITIONS

ANV	**Alaska Native Villages** (ANVs), for the purposes of this report, refer to the communities, residents, and organizations located within U.S. Census Bureau-designated Alaska Native Village Statistical Areas (ANVSAs) and the Annette Island Reserve.
Bbl	**Barrel**
Blizzard conditions	**Blizzard conditions** are defined as winds of 35 mph or over with heavy snowfall; during blizzard conditions, visibility is reduced to less than 0.25 miles for three hours or longer (NOAA 2013d).
CDDs	**Cooling degree days** (CDDs) are a metric used to represent how much cooling is required over a specific period of time by relating cooling energy demand to temperature. Degree days measure the difference between mean air temperature and a standard baseline temperature at which buildings would begin using air conditioning on warm days and heating on cool days; this standard baseline temperature is typically 65°F. CDDs on a given day of the year can be calculated by subtracting the baseline temperature from the mean temperature on that day. Each degree that a day's mean temperature is above the baseline temperature is one degree-day. For example, if the mean temperature on May 30 is 80°F and the baseline temperature is 65°F, this would correspond to: Mean Temperature – Baseline Temperature = CDDs (80°F) – (65°F) = 15 CDDs CDDs are often reported on an annual basis. In such cases, CDDs for each day are summed over the course of the year to calculate the number of CDDs in a given year (EPA 2014b).
Coastal storms	For the purposes of this report, **coastal storms** are defined as strong storms that form in the North Pacific, Bering Sea, or southern Arctic Ocean. These storms can result in winds in excess of 50 mph along the western and northern coasts of Alaska, the Aleutian Islands, the Alaska Peninsula, and the coastal area of the Gulf of Alaska (WRCC 2015).
Convective storms	**Convective storms** refer to the vertical flow of moisture in certain storms, and can include damaging lightning, large hail, wind, tornadoes, and heavy rainfall. These storms are sometimes referred to as thunderstorms, but "convective storms" includes non-thundering storms that can produce hazardous weather as well as thunderstorms.
DOE	**U.S. Department of Energy**
Drought	For the purposes of this report, **droughts** are defined as extended periods without precipitation that may be exacerbated by low snowpack and high evaporation rates (DOE 2013a).
Extreme precipitation event	For the purposes of this report, an **extreme precipitation event** is one in which more than one inch of precipitation falls over the course of a day (NOAA 2013a).
HDDs	**Heating degree days** (HDDs) are a metric used to represent how much heating is required over a specific period of time by relating heating energy demand to temperature. Degree days measure the difference between mean air temperature and a standard baseline temperature at which buildings

would begin using air conditioning on warm days and heating on cool days; this standard baseline temperature is typically 65°F.

HDDs on a given day of the year can be calculated by subtracting the mean temperature on that day from the baseline temperature. Each degree that a day’s mean temperature is below the baseline temperature is one degree-day. For example, if the mean temperature on January 5 is 30°F and the baseline temperature is 65°F, this would correspond to:

Baseline Temperature	–	Mean Temperature	=	HDDs
(65°F)	–	(30°F)	=	35 HDDs

HDDs are often reported on an annual basis. In such cases, HDDs for each day are summed over the course of the year to calculate the number of HDDs in a given year (EPA 2014b).

kWh	**kilowatt-hours**
LNG	**Liquefied natural gas**
Major energy infrastructure	For the purposes of this report, **major energy infrastructure** includes the following: high voltage (>345 kV) transmission lines; large (>1 MW) electric generation plants; oil, natural gas, or coal production areas; oil refineries; natural gas processing plants; and crude oil, petroleum product, or natural gas pipelines.
MMcf/d	**Million cubic feet per day**
MW	**Megawatt**
NCA	The Third **National Climate Assessment**, developed by the U.S. Global Change Research Program, is the most comprehensive assessment of how climate change is affecting the United States. The report assesses the effects of global climate change on the United States, analyzes current trends in global change, and projects major trends in global change over the next century.
NOAA	**U.S. Department of Commerce National Oceanic and Atmospheric Administration**
SWE	**Snow water equivalent** (SWE) is a common snowpack measurement that is the depth of water that would result if the snowpack was melted instantaneously.
Thermoelectric power plant	**Thermoelectric power plants** generate electricity by producing high-pressure steam that drives turbines. These power plants may use fossil fuels (including coal, natural gas, and oil), nuclear energy, biomass, or solid waste to heat water to generate the steam that then passes through turbines.
TTLs	**Tribal trust lands** (TTLs), for the purposes of this report, include federally recognized Indian reservations, off-reservation trust lands, pueblos, communities, colonies, villages, and rancherias.

EXECUTIVE SUMMARY

Climate change and extreme weather events are already affecting the way that American Indian and Alaska Native tribes are using, receiving, and producing energy. As climate change worsens, energy infrastructure in the United States—including tribal energy infrastructure—is expected to be increasingly threatened by higher temperatures, less available water, and more frequent and intense heavy downpours, floods, heat waves, and droughts. Tribal energy systems are also vulnerable to extreme weather events, such as thunderstorms, tornadoes, and winter storms, which can severely damage infrastructure that tribes rely on to deliver power and fuel (Figure ES-1, Table ES-1).[1]

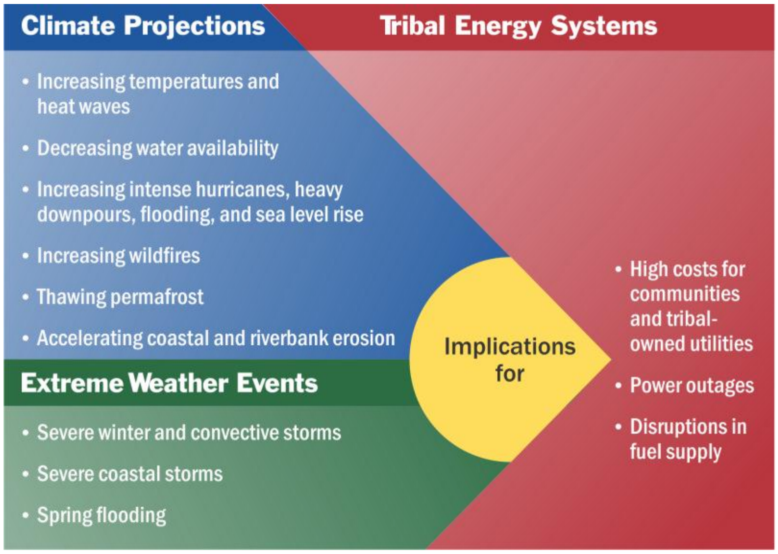

Figure ES-1. Implications of climate change and extreme weather on tribal energy systems.

Like most communities, tribes have a major interest in reliable energy supply even though they are not, for the most part, directly responsible for providing it. Few tribes own and operate the energy infrastructure that their residents depend on; tribal energy systems are primarily vulnerable to events occurring offsite, such as supply disruptions and higher energy costs passed down from external utility providers. Energy infrastructure owned and operated by tribes is subject to vulnerabilities similar to those of energy assets located outside of tribal boundaries, although tribal entities have greater self-determination in building the resilience of energy systems that they control.

Vulnerabilities to tribal energy infrastructure vary significantly by region. For example, tribes on the East and Gulf Coasts may see a greater likelihood of power outages from more intense (e.g., Category 4 and 5) hurricanes, while tribes in the western United States may see a greater likelihood of energy supply disruption from more intense and frequent droughts and wildfires (DOE 2013a, USGCRP 2014). Meanwhile, tribes in parts of northern and central Alaska are vulnerable to permafrost thaw and accelerated erosion (DOE 2013a, NOAA 2013h).

American Indian and Alaska Native tribes have the strength and fortitude to meet these challenges. This report provides an informational resource to assist tribes with understanding their risks, a critical step towards effective planning and management of energy systems in the face of climate change and extreme weather threats.

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[1] This report describes vulnerabilities of tribal energy systems related to both climate change and extreme weather. “Potential climate change impacts” refers to threats to tribal energy systems that are projected to change (increase, in most instances) compared to historical norms. “Potential extreme weather impacts” refers to weather events that threaten tribal energy systems, but quantifying the effects of climate change on the frequency, duration, or severity of these events is still an area of active research. In this report, potential extreme weather impacts are not associated with a trend but rather are discussed as a continuing threat to tribal energy systems.

Table ES-1. Key vulnerabilities of tribal energy systems to climate change and extreme weather.

Climate projection or extreme weather event	Potential impact on tribes			Location of tribes most vulnerable
	Increased costs for communities and tribal-owned utilities	Increased risk of power outages	Increased risk of fuel supply disruptions	
Climate Projections				
Rising air temperatures	• Increased demand for air conditioning in the summer, which could increase summer electricity bills	• Reduced power line transmission capacity and efficiency and increased risk of deformation and damage to electric grid infrastructure • Increased demand and disruptions in power supply during extreme heat events that may lead to power outages	• Increased heat damage to road and rail infrastructure	• Contiguous United States, particularly southern regions
Decreasing water availability	• Increased electricity costs if utilities need to purchase power from more expensive generation sources as a result of reduced capacity from hydroelectric or thermoelectric power plants			• Southern regions(annual water availability) • Great Plains, Northwest, and southeastern Alaska and the Aleutian Islands (seasonal water availability)
Increasing wildfire	• Increased damage to grid infrastructure, which may lead to increased costs of maintenance and repair for tribal-owned utilities	• Increased damage to grid infrastructure and decreased transmission capacity, which may lead to blackouts		• Southern and western regions, including Alaska
Increasing heavy rainfall events		• Increased flood damage to grid infrastructure such as substations	• Increased flood damage to road and rail infrastructure and disruptions in fuel supply routes along critical waterways	• Low-lying areas, particularly in the Great Plains, Midwest, Northeast, and Southeast
Increasing frequency of intense hurricanes and sea level rise-enhanced storm surge		• Increased flood and wind damage to coastal and low-lying grid and generation infrastructure	• Increased flood damage to road and rail infrastructure and disruptions in fuel supply routes along critical waterways	• Coastal regions in the eastern United States
Thawing permafrost	• Increased structural damage to tribal-owned infrastructure		• Increased structural damage to fuel transportation and storage infrastructure	• Northern and interior Alaska
Increasing coastal and riverbank erosion	• Increased damage to tribal-owned infrastructure and increased costs to relocate vulnerable infrastructure		• Increased damage and loss of fuel transportation and storage infrastructure	• Alaska

Climate projection or extreme weather event	Potential impact on tribes			Location of tribes most vulnerable
	Increased costs for communities and tribal-owned utilities	Increased risk of power outages	Increased risk of fuel supply disruptions	
Extreme Weather Events				
Severe storms	• Damage to tribal-owned infrastructure, which may result in high costs of maintenance and repair for tribes	• Damage to generation and grid infrastructure, which may result in power outages	• Damage to fuel transportation and storage infrastructure on both land and critical waterways	• Great Plains, Midwest, and Southeast (convective storms) • Northern United States, including Alaska (winter storms) • Western and northern coastal regions in Alaska (coastal storms)
Spring ice breakup flooding	• Flood damage to tribal-owned grid, generation, and transportation infrastructure, which may result in high costs of maintenance and repair for tribes	• Flood damage to generation and grid infrastructure, which may result in power outages	• Damage to transportation and storage infrastructure and disruptions in fuel supply routes along land and critical waterways	• Alaska

Chapter 1: INTRODUCTION

Tribal trust lands (TTLs) and Alaska Native villages (ANVs) are home to more than one million residents and span over 130,000 square miles in the lower 48 states and Alaska (Figure 1-1).[2] These lands are an important part of an interconnected U.S. energy system that encompasses energy end users, power plants, electric grid infrastructure, oil and gas exploration and production areas, renewable energy facilities, and fuel transportation networks. TTLs, ANVs, and other areas with a high proportion of low-income residents are among the U.S. communities deemed most susceptible to the impacts of climate change and extreme weather. This susceptibility is rooted in the constrained resources of some communities to respond to climate- and weather-related impacts.

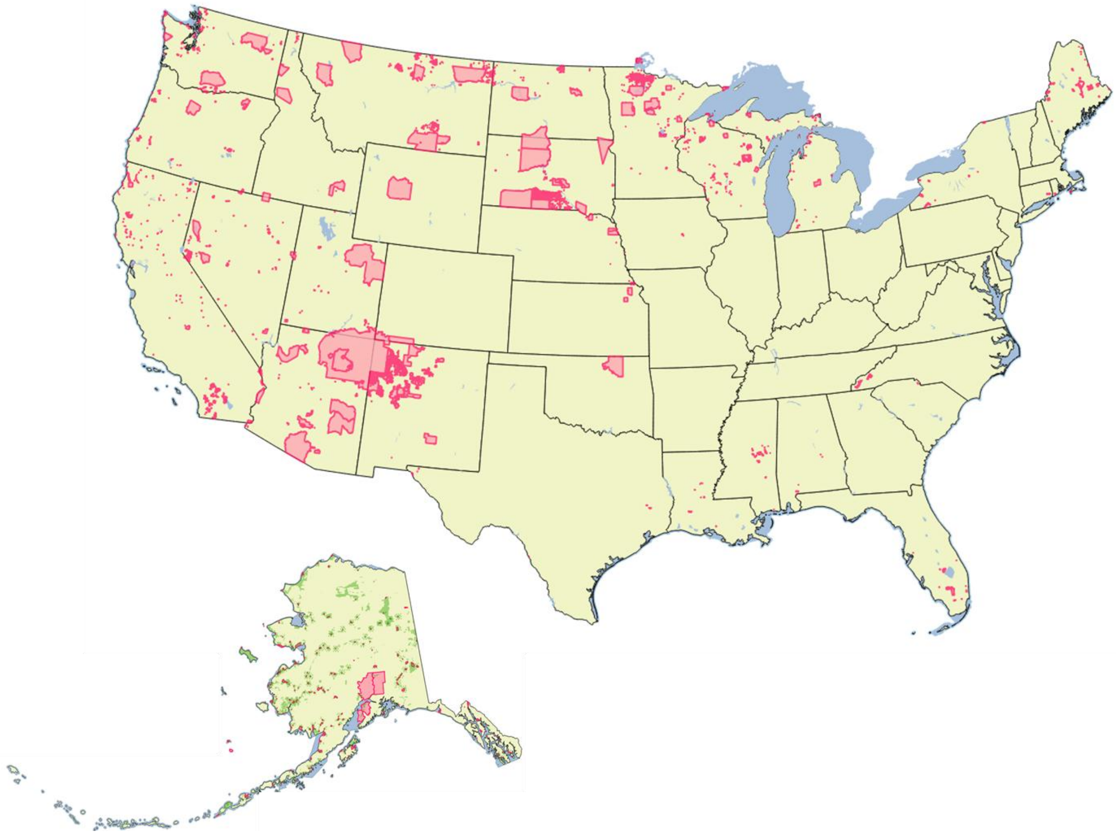

Figure 1-1. Jurisdictional boundaries of TTLs in the United States.
Note: Alaska map shows ANV Statistical Areas (pink) and Alaska Native Corporation lands and subsurface claims (green).
Graphics source: Energetics 2015; Data sources: ASGDC 2015a, US Census Bureau 2014b, 2015

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[2] For the purposes of this document, “tribal trust lands” include federally recognized Indian reservations, off-reservation trust lands, pueblos, communities, colonies, villages, and rancherias in the contiguous 48 United States. “Alaska Native villages” include the communities, residents, and organizations located within U.S. Census Bureau-designated Alaska Native Village Statistical Areas (ANVSAs) and the Annette Island Reserve (for a more detailed description of ANVs, see Chapter 9: Alaska). Impacts unique to the energy sector on Hawaiian Home Lands are not in the scope of this report; refer to the 2015 DOE report *Climate Change and the Energy Sector: Regional Vulnerabilities and Resilience Solutions* for a discussion of climate vulnerabilities of the energy sector in Hawaii.

Many tribes are already feeling the impacts of climate change, including increasing temperatures; decreasing water availability; thawing permafrost; increasing coastal and riverbank erosion; melting sea ice; and increasing frequency of intense hurricanes, droughts, wildfires, and flooding. In addition, extreme weather impacts—including severe convective and winter storms—also affect tribes throughout the United States. Continuation of climate trends, as projected, could restrict the supply of secure, sustainable, and affordable energy critical to the economic well-being of affected communities. Climate change is projected to affect almost every subsector of the production and distribution networks that provide energy to tribes—including businesses that are major income generators for tribes.

This report was developed in support of the mission of the U.S. Department of Energy (DOE) Office of Indian Energy Policy and Programs as a resource for initiatives to enhance and strengthen tribal energy and economic infrastructure against climate and extreme weather impacts. Information on climate change and extreme weather-related energy system vulnerabilities is provided herein to support energy planning, education, and management efforts by tribes on federally recognized TTLs and ANVs.

OVERVIEW OF CLIMATE CHANGE AND EXTREME WEATHER IMPACTS ON TRIBAL ENERGY SYSTEMS

Climate change refers to a change in the mean or variability of a specific climate phenomenon that persists for an extended period. It can manifest either as changes in mean conditions or as changes in extremes (IPCC 2012). Many of the most visible impacts of climate change on energy systems are those associated with the increased frequency and intensity of extreme events, including heat waves, droughts, and floods. Changes in mean conditions can also have severe impacts on energy systems. For example, increasing average temperature and decreasing average annual and summer precipitation in the Southwest has severely decreased water availability on the Navajo Nation (USGCRP 2014). More than 30 major surface features that ran through the Navajo Nation Reservation in the early 20th century are now dry, and tribal leaders report that washes and rivers such as the Little Colorado River that previously ran year-round now serve only as intermittent water sources (Redsteer et al. 2014). Climate change impacts are expected to intensify: warmer temperatures and more frequent and intense heat waves, changing water availability, more frequent and severe heavy precipitation events, rising sea levels, more intense Atlantic hurricanes, thawing permafrost, coastal and riverbank erosion, and greater risk of flooding, drought, and wildfires, depending on location.

As shown in Table 1-1, energy infrastructure important to tribes is susceptible to damage from a variety of climate change impacts. Electric grid infrastructure located both on and off of TTLs and ANVs is vulnerable to damage from intense hurricanes, increased temperatures, wildfire, flooding from heavy precipitation events, and, in the case of some ANVs, thawing permafrost and increasing coastal and riverbank erosion. Grid infrastructure may also operate at lower efficiency and capacity as temperatures increase and as heat waves increase. Oil and natural gas-producing companies, some of which are owned and operated by tribes, are vulnerable to decreasing water availability, increasing frequency of intense hurricanes, and thawing permafrost.

Table 1-1. Potential implications of climate change on TTL and ANV energy systems.[3]

Energy sector	Climate projection	Potential implication
Energy Use		
Energy demand	Increasing air temperatures	Increased total electricity demand for cooling; decreased demand for heating fuels
	Increasing length, magnitude, and frequency of extreme heat events	Increased peak electricity demand
Electricity Supply		
Electric grid	Increasing air temperatures	Reduction in transmission efficiency and available transmission capacity
	More frequent and severe wildfires	Increased risk of physical damage and decreased transmission capacity
	Increasing frequency of intense Atlantic hurricanes; increasing sea level rise and storm surge	Increased risk of physical damage
	Thawing permafrost and increasing coastal and riverbank erosion in Alaska	Increased risk of physical damage
Thermoelectric power generation (coal, natural gas, nuclear, geothermal, and concentrated solar power)	Increasing air temperatures	Reduction in plant efficiencies and available generation capacity
	Increasing water temperatures	Reduction in plant efficiencies and available generation capacity; increased risk of exceeding thermal discharge limits
	Decreasing water availability	Reduction in available generation capacity
	Increasing frequency of intense Atlantic hurricanes; increasing sea level rise and storm surge	Increased risk of physical damage and disruption to coastal facilities
	Increasing risk of flooding	Increased risk of physical damage and disruption to inland facilities
	Thawing permafrost and increasing coastal and riverbank erosion in Alaska	Increased risk of physical damage to facilities
Hydropower	Increasing temperatures and evaporative losses	Reduction in available generation capacity and changes in operations
	Changes in precipitation and snowmelt timing and decreasing snowpack in some locations	Reduction in available generation capacity and changes in operations
	Increased risk of flooding	Increased risk of physical damage and changes in operations
Fuel Supply		
Fuel transport	Reduction in river levels	Disruption of barge transport of crude oil, petroleum products, and coal
	Increasing intensity and frequency of flooding in some locations	Disruption of rail and barge transport of crude oil, petroleum products, and coal
	Thawing permafrost and Increasing coastal and riverbank erosion in Alaska	Increased risk of physical damage to transport infrastructure and disruption of barge, air, and pipeline transport of petroleum products and natural gas
Oil and gas production	Decreasing water availability	Impacts on drilling, production, and refining
	Increasing frequency of intense Atlantic hurricanes; increasing sea level rise and storm surge	Increased risk of physical damage and disruption to offshore and coastal facilities
	Thawing permafrost in Arctic Alaska	Increased risk of physical damage and disruption to facilities

Source: Adapted from DOE 2013a

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[3] For the purposes of this report, energy systems that serve TTLs and ANVs are grouped into three categories: energy use, electricity supply, and fuel supply. Energy use includes electricity, natural gas, fuel oil, and other energy and fuels consumed at homes and businesses; electricity supply includes electric grid infrastructure (transmission lines, substations, and distribution lines) as well as electric power generation; and fuel supply includes fuel transport (i.e., pipeline, rail, road, and barge transport of energy products) and fuel production (i.e., coal, natural gas, and oil).

Every subsector of the energy production and distribution systems that serve tribes will also continue to be vulnerable to extreme weather impacts, including winter storms, convective storms, and some flooding events. Quantifying the effects of climate change on the frequency, duration, or severity of these events is still an area of active research. Nonetheless, these events currently pose a threat to tribal energy systems. For example, heavy snow and ice and extreme cold during winter storms can cause power lines and poles to fall, close roadways, and disrupt barge and rail transport of fuels. Similarly, during convective storms, heavy winds, lightning, and hail can result in power outages, and flooding and tornadoes can severely damage electricity generation and fuel transportation infrastructure. In Alaska, coastal storms and spring flooding can damage electricity generation and distribution infrastructure on ANVs, knocking out power to residents and leading to high maintenance and repair costs. Both coastal storms and flooding during spring ice breakup can also damage fuel transportation and storage infrastructure, which could result in disruptions of fuel supply.

Like most communities and jurisdictions in the United States, few tribes own and operate the energy infrastructure upon which their residents rely. Energy infrastructure tends to be owned and operated by private companies or utilities. The main energy-related impacts of climate change on tribal residents and businesses are likely to be higher costs and the risk of more frequent disruptions in utility-provided services. For example, higher temperatures in the summer are likely to increase electricity use for cooling, which will increase electricity bills.[4] In addition, more frequent damage to utility-owned power plants or sections of the electric grid increases the likelihood of power outages on TTLs and ANVs, and higher air or water temperatures may reduce the electricity transmission and generating capacity of utilities. If utilities must invest in additional capacity, maintenance, and repairs—and pass the associated costs on to customers—tribes may face increasing electricity costs. Additionally, damage to the broader fuel transportation infrastructure could disrupt the flow of fuel supplies (e.g., fuel oil and gasoline) to tribal communities or to electricity generators serving tribes.

Increased electricity costs could have severe impacts on tribal communities, which include some of the most impoverished populations in the United States. Tribal communities have a poverty rate of 28% (compared to 15% nationally), which already constrains access to electricity on many reservations (USGCRP 2014). In 2000, more than 14% of residences on reservations lacked access to electricity, and more than 30% of residences on the Navajo Nation Reservation—the largest TTL in the United States—did not have access to power in 2015 (Landry 2015, USGCRP 2014). Higher costs and increased power outages could exacerbate the already disproportionately high incidence of heat-related sickness and death in such low-income communities (USGCRP 2014).

AN INTERCONNECTED AND INTERDEPENDENT ENERGY SYSTEM

As elsewhere in the country, energy systems on TTLs and ANVs do not operate in isolation; rather, they receive, transmit, and export energy within the broader energy system. Similarly, climate change and extreme weather impacts do not occur in isolation but affect energy demand and supply in multiple sectors.

Power supply relies on the operation of all electricity infrastructure components along the supply chain prior to end use. These components include the power plants that generate the electricity, high-voltage lines that transmit the power, substations where transformers reduce the voltage, and distribution lines that deliver the power directly to residences and businesses. Impacts on any of these components, as well as on components of the fuel transport infrastructure, are likely to ripple through the supply chain to affect end users. For this reason, this report on the energy vulnerabilities of TTLs and ANVs considers the climate and extreme weather impacts on all major infrastructure components involved in supplying energy to tribal communities, including many components not directly owned or operated by tribes.

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[4] The impact of higher temperatures on cooling energy demand is most pronounced in hotter regions where air conditioning use is greatest. Conversely, TTLs and ANVs located in cooler regions may see reduced annual demand for energy as temperatures increase.

Interdependencies across energy subsectors will amplify the effects of climate change and extreme weather on the energy sector as a whole (see text box). For example, two major components of the fuel transport infrastructure on the Navajo Nation Reservation require electricity to operate: (1) the electric pumps that operate the Running Horse Pipeline, a crude oil pipeline that is owned and operated by the Navajo Nation (NNOGC 2015), and (2) the electrified Black Mesa and Lake Powell Railroad, a private railroad that transports coal from the Kayenta Mine to the Navajo Generating Station, both located on the Navajo Nation Reservation (American Rails 2015). The interdependent vulnerability occurs because a climate or weather impact such as widespread wildfire, a severe storm, or an intense heat wave could disrupt electric service to the Navajo Nation, which would also disrupt pipeline and rail fuel transportation that relies on electricity to operate.

Interdependencies between the energy sector and other sectors of the economy further complicate the effects of climate change on energy. For example, energy and water systems are closely linked. Energy systems require water for such processes as thermoelectric power plant cooling and fuel production and processing, while water systems require energy to pump, transport, treat, and condition water (DOE 2013a). On the Navajo Nation Reservation, two major thermoelectric power plants require substantial amounts of cooling water from two sources, the San Juan River and Lake Powell, and these same power plants provide power to operate two of the largest irrigation systems in the Southwest—the Central Arizona Project and Salt River Project—that deliver water to TTLs in the region (Nania et al. 2014).

Interdependence among energy subsectors is likely to aggravate climate change impacts

Increasing temperatures and heat waves are likely to increase both average and peak energy demand for cooling. At the same time, these high temperatures are likely to lower the efficiency and capacity of power plants and the electric grid to meet this demand.

Electric power systems could be severely taxed as peak demands coincide with reduced generation and transmission capacity. As temperatures and heat waves progressively increase because of climate change, end users such as tribal residents and businesses may be subject to more frequent power outages and increasing electricity costs.

REGIONAL DIFFERENCES

Climate change and extreme weather impacts vary regionally. For example, climate models project that annual precipitation is generally expected to increase across the northern United States but decline in the southern states, especially in the Southwest. Moreover, extreme weather events such as winter storms are more common in the northern United States, hurricanes primarily affect the Gulf and Atlantic coasts, and tornadoes are most frequent in the Great Plains and southern states. Energy systems also vary regionally, as appropriate to the resources and needs of the region. For example, hydropower is common in the Northwest, fossil fuels provide much of the power to the east and south, and wind power is growing most rapidly in the Great Plains. Because of these geographic differences, this report examines relevant climate change projections and energy system vulnerabilities on TTLs and ANVs at a regional level.

Climate change projections used to assess regional energy sector vulnerabilities in this report are drawn primarily from the *Third National Climate Assessment* and associated technical inputs, including the National Oceanic and Atmospheric Administration's (NOAA's) *Regional Climate Trends and Scenarios for the U.S. National Climate Assessment*. These sources, conducted under the auspices of the Global Change Research Act of 1990, provide the most comprehensive scientific assessment of how climate change affects different sectors and regions of the United States.

Snapshot of Selected Energy Subsector Vulnerabilities to Climate Change

Energy Use

As temperatures rise on hot days, demand for cooling energy increases (e.g., air conditioning and refrigeration). A common metric to represent cooling energy demand is the cooling degree day (CDD). A CDD indicates the temperature on a given day relative to 65°F, the standard baseline temperature above which buildings would begin using air conditioning (EIA 2015a). CDDs are determined for a given day by subtracting the baseline temperature (65°) from the day's average. For example, a 75°F day would be 10 CDDs. As shown in Figure 1-2, annual CDDs are projected to increase nationwide.

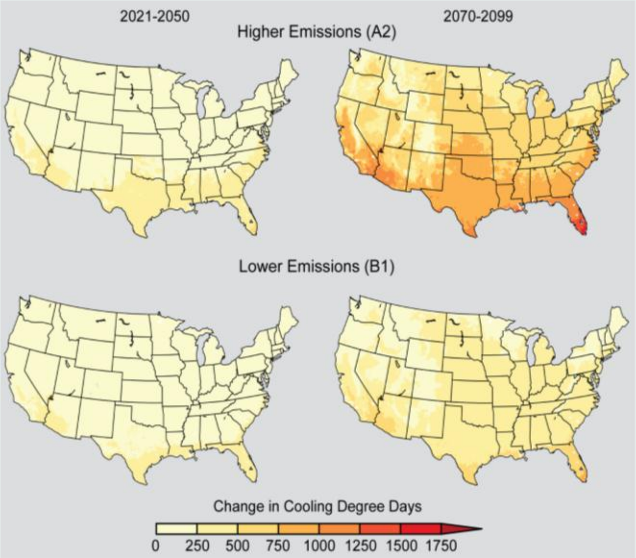

Figure 1-2. Annual cooling degree days (CDDs) are projected to increase throughout the United States as temperatures increase (relative to 1971–2000).
Source: USGCRP 2014

Electric Grid

As temperatures increase, the capacity and efficiency of transmission and distribution lines decrease, and electric grid equipment becomes more vulnerable to damage (DOE 2013a). Higher temperatures reduce the current-carrying capacity of transmission lines and substations (DOE 2013a). High temperature can also cause power lines to sag, increasing the risk of tree strikes or contact between lines, and transformers degrade at a higher rate under high temperatures (Bérubé et al. 2007, DOE 2013a). When possible, operators reduce current loading of grid equipment during periods of elevated temperature in order to protect the equipment. Under normal operating conditions, roughly 6% of power is lost during transmission and distribution, and these losses increase with the temperature of the line (EIA 2014a).

Thermoelectric Power Generation

The efficiency and capacity of thermoelectric power generation decreases with increasing temperatures (DOE 2013a). Thermoelectric power plants generate almost 90% of all electricity in the United States (EIA 2013b). These plants use fossil fuels (including natural gas and coal), nuclear energy, concentrated solar power, and/or biomass to heat water and generate high-pressure steam to spin turbines and generate electricity. The power output of natural gas-fired combustion turbines and combined cycle power plants drops by up to 0.7% and 0.5%, respectively, for every 1.8°F increase in air temperature (DOE 2013a). By mid-century (2031–2060), average summer capacity of thermoelectric power plants is projected to decrease by 4.4%–16%, depending on the emissions scenario, water availability, and cooling system employed (van Vliet et al. 2012).

Hotter temperatures may lead to more frequent power outages on TTLs if generation and transmission capacities are insufficient to meet demand. If utilities install additional capacity or upgrade current capacity to prevent these power outages, these costs may be passed on to their customers. In one recent example of the effect of rate increases on tribal communities, residents of TTLs in the Upper Peninsula of Michigan (e.g., the Sault Sainte Marie Reservation) faced a possible 30% increase in electricity bills if a proposed rate was approved (Austin 2014). The proposed rate increase covers the cost of necessary upgrades to the aging Presque Isle Power Plant. The Sault Tribe of Chippewa Indians opposed the rate increase on the grounds that the effects would be "devastating" to the area, but the rate increase ultimately went into effect in December 2014. While an agreement between energy companies resulted in a reduction in rates beginning in February 2015, the Sault Tribe of Chippewa Indians may still see a $60,000 increase in costs per month. In February 2015, the utility serving the area petitioned the Federal Energy Regulatory Commission for a release from all rate increases (Sault Ste. Marie Evening News 2015).

STRUCTURE OF REPORT

The rest of this report includes region-specific chapters (Chapters 2–8) examining the potential impacts on tribes and concludes with a brief discussion (Chapter 9). The appendices discuss the trends and impacts of climate change and extreme weather and provide further detail on TTLs and ANVs, including summaries of energy infrastructure present on the largest TTLs and ANVs.

Chapters 2–8 focus on the energy end users—tribal residents and businesses. A brief overview of TTLs and ANVs in each region and the energy systems present on tribal lands in the region is provided at the beginning of each chapter. The overview section also highlights any major energy infrastructure located on TTLs and ANVs in the region. Following the overview, implications of climate change and extreme weather for tribal energy systems are discussed. The discussions of implications are organized by subsector—starting with energy end-use; followed by electricity supply, including the electric grid and electricity generation; and concluding with fuel supply, including fuel transport and fuel production, where relevant.

Readers seeking information about energy sector vulnerabilities for a specific tribe may wish to skip directly to the regional chapter where the tribe is located (Figure 1-3). For example, a reader interested in the Flathead Reservation in Montana should skip to Chapter 5—Great Plains.

Readers who would like to understand the climate projections and types of weather impacts that affect energy systems should refer to Appendix A. Appendix B provides a brief overview of the emissions scenarios used to model the climate change impacts discussed in this report.

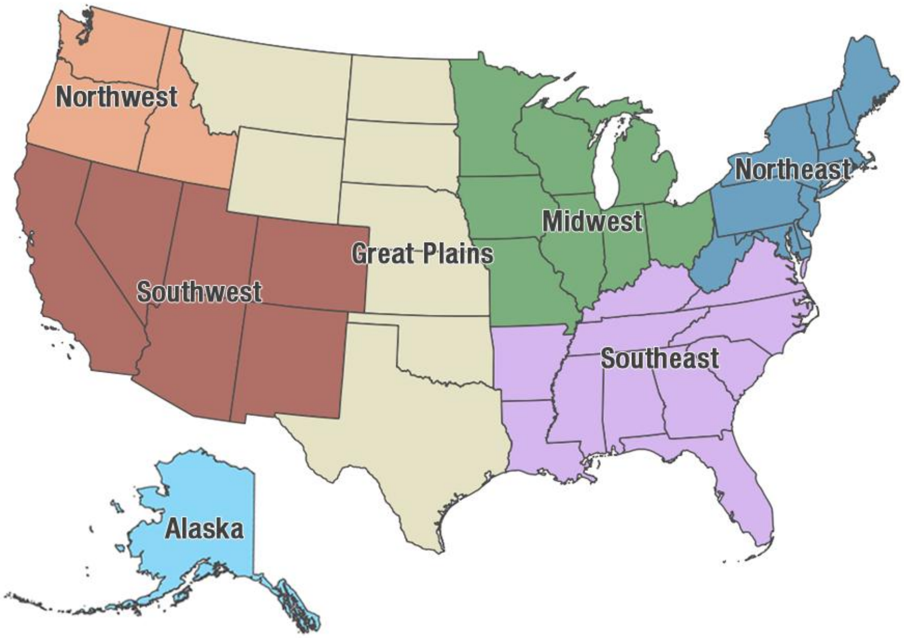

Figure 1-3. Regions of the United States.

Chapter 2: ALASKA TRIBAL LANDS

Key Climate Change and Extreme Weather Hazards Affecting Alaska Native Village Energy Systems

- **Severe storms:** Severe storms and extreme cold may damage electric and fuel transportation infrastructure serving Alaska Native Villages (ANVs), leading to prolonged power outages and increased costs of maintenance and repair as well as disruptions in fuel supply.
- **Thawing permafrost:** Permafrost thaw caused by warmer temperatures may compromise the foundations of energy infrastructure located in and serving ANVs built on permafrost and may increase the cost of construction, maintenance, and repair of energy infrastructure owned by Alaska Native Regional Corporations.
- **River flooding:** Inland flooding may damage electricity distribution and generation infrastructure, leading to power outages and increased costs of maintenance and repair, and may disrupt fuel supply to ANVs.
- **Increasing wildfires:** Increasing duration, size, and severity of wildfires increase the risk of damage to ANV electricity and transportation systems, which may lead to power outages, increased costs, and disruptions in fuel supply.
- **Increasing coastal and riverbank erosion:** Melting sea ice and thawing permafrost increase the rate of coastal and riverbank erosion, which may damage electric and fuel transportation infrastructure serving ANVs, including infrastructure essential for offloading fuel shipments from barges.

OVERVIEW OF ALASKA REGION

The state of Alaska is home to one federally recognized tribal trust land (TTL)—the Annette Island Reserve—and 229 of the 566 federally recognized tribes in the United States (BIA 2015b, U.S. Census Bureau 2012). This chapter focuses primarily on the energy systems serving and located in Alaska Native villages (ANVs) which, for the purpose of this study, include the communities, residents, organizations, and assets located within U.S. Census Bureau-designated Alaska Native Village Statistical Areas (ANVSAs). Present-day ANVs reflect the communities granted claims by the Alaska Native Claims Settlement Act (ANCSA) of 1971 (see “Alaska Native Corporations” on page 12). The Act allowed for the establishment of the 206 Alaska Native Village Corporations (ANVCs) and 12 Alaska Native Regional Corporations (ANRCs) that currently hold and manage Native lands and resources. The ANVSAs and the land holdings of Alaska Native Corporations are represented in Figure 2-1. About 138,000 American Indian and Alaska Natives reside in Alaska, and 35% of this population resides within one of the four most populated cities in the state: Anchorage, Fairbanks, Juneau, and Badger (U.S. Census Bureau 2010a, U.S. Census Bureau 2012). However, the majority of Native populations reside within ANVs—as does the energy infrastructure serving these populations (U.S. Census Bureau 2012).

For the most part, ANVs are located in rural Alaska, across the interior, northern, western, and southern coastlines, and on the Aleutian Islands. Several ANVs and more than 30% of the Alaska Native population are located within the Railbelt region (U.S. Census Bureau 2010a), the densely populated area stretching from the Kenai Peninsula, through Anchorage and north to Fairbanks. However, these ANVs are connected to Railbelt energy infrastructure and are not the primary focus of this chapter.

Although relatively little fuel production occurs on Alaska Native lands, oil and gas production, transportation, and refining in Alaska contribute heavily to the state's economic activity and provide a source of revenue for Alaska Native populations. ANRCs hold mineral rights to property across the state and share revenue from royalties from resource extraction. Most ANRCs are also involved in ancillary business activities associated with oil and gas exploration and production, including logistics, oilfield services, construction, and others (see Table 2-3). As Native populations generate revenue from Alaska's petroleum industry, this chapter also examines fuel production vulnerabilities on ANC territories.

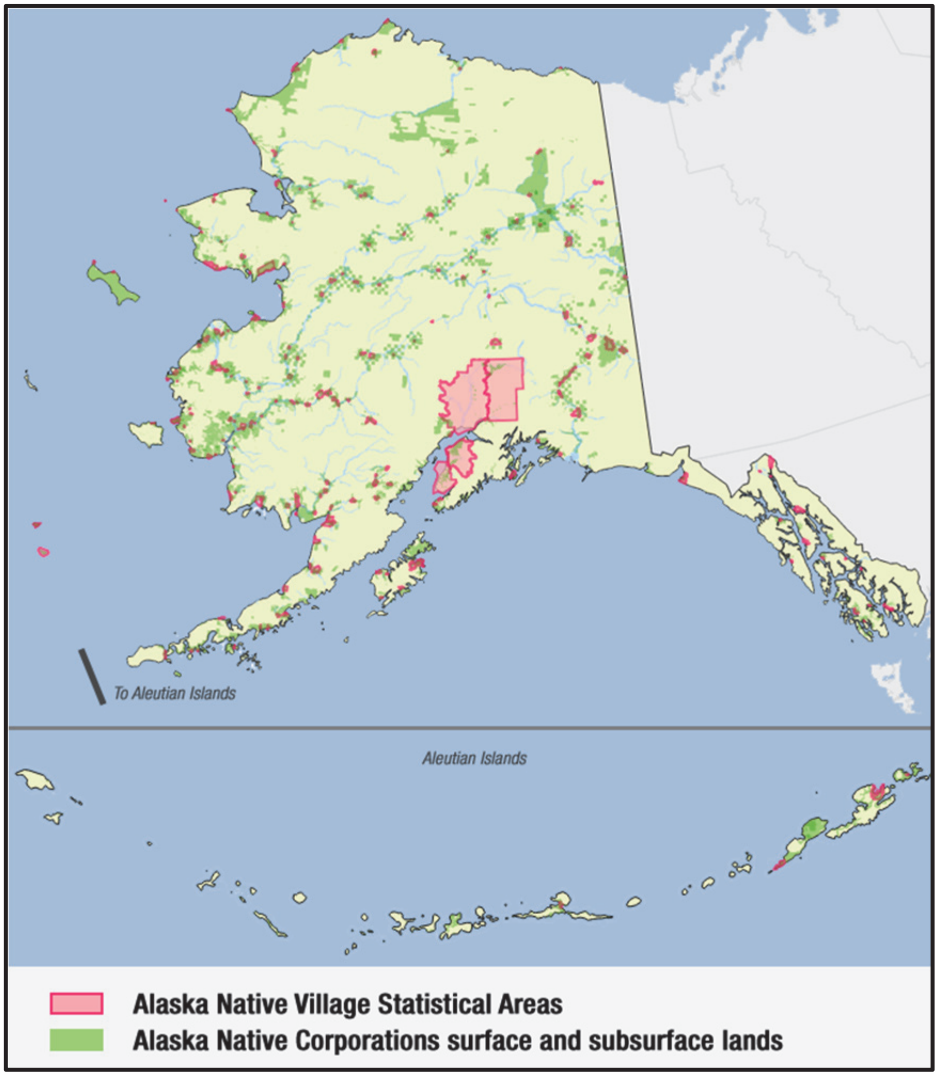

Figure 2-1. ANVSAs and ANC lands across Alaska.
Note: Many ANC lands are not heavily populated. Some ANVSAs are located outside of ANC lands.
Graphics source: Energetics 2015; Data sources: ASGDC 2015a, US Census Bureau 2014b

Electricity Supply

Electricity may be delivered to ANV residents and businesses in one of two ways, depending on the location of the village. Most communities have small, local diesel-fired electric generation facilities with distribution lines to serve ANV residents and businesses, while a number of communities are connected to large, centralized power plants via a high-voltage transmission grid similar to those found in the lower 48 states. ANVs in the Railbelt region are served by transmission and distribution infrastructure operated by the six regional member-owned electricity cooperatives and municipal utilities (ARCTEC 2013, EIA 2013a, EIA 2013i).

ANVs throughout rural Alaska largely depend only on local distribution systems powered by diesel generators with capacities of <5 megawatts (MW), and these localized power networks are sometimes supplemented by renewable resources such as run-of-the-river hydropower, small-scale solar photovoltaic (PV) systems, or wind turbines (Melendez and Fay 2012). This reliance on diesel for power generation, combined with the relatively limited fuel delivery options (see "Fuel Supply" section), can lead to electricity prices of over $1.00 per kilowatt-hour (kWh) for

ANV residents and businesses (Melendez and Fay 2012). In some ANVs, distribution interties (low-voltage power lines connecting two or more villages) have been built in order to reduce costs and increase reliability, and many ANVs rely on the Power Cost Equalization (PCE) program to reduce electricity costs (see textbox) (AVEC 2013). Interties currently exist between Bethel and Napakiak; Bethel and Oscarville; Dot Lake and Tok; Shungnak and Kobuk; Naknek, King Salmon, and South Naknek; and Iliamna, Newhalen, and Nondalton (for a comprehensive list of interties, see Appendix E) (NANA Pacific 2008).

Power Cost Equalization (PCE) program

The PCE program was established in 1985 to provide economic assistance to customers in rural Alaska, where prices for electricity can be three to five times those in urban areas of the state. Under this program, the state pays eligible utilities part of the price of electricity for residential customers and community facilities, which in turn reduces the price of electricity for these customers (Melendez and Fay 2012). Only community facilities and residential customers of eligible utilities, which do not include utilities in the Railbelt, in Juneau, or that receive power from the Four Dam Pool facilities, can receive credit on electricity use (AEA 2014).

The PCE program can apply to approximately 30% of all kilowatt-hours of electricity sold by eligible utilities that participate in the program. Each year, the Regulatory Commission of Alaska (RCA) determines the eligible utilities and the cost per kilowatt-hour, or PCE level, based on fuel expenses, such as the cost of fuel and transportation, and non-fuel expenses, such as salaries, insurance, taxes, and parts and supplies (AEA 2014). The Alaska Energy Authority (AEA) then determines the number of eligible kilowatt-hours (AEA 2014).

In 2014, the PCE program distributed over $36 million to eligible utilities operating in ANVs (AEA 2015). However, even with the PCE program in place, rural customers pay high prices for electricity. For example, in 2011, the price paid in Lime Village was $465 per 500 kWh (Melendez and Fay 2012). This is significantly lower than the pre-PCE price of $760 per 500 kWh, but is still much higher than the $65 per 500 kWh price that customers in Anchorage paid (Melendez and Fay 2012).

Fuel Supply

While Alaska imports crude oil and petroleum products, the state supplies much of its own fuel with crude oil produced on the North Slope and in Cook Inlet and refined in Nikiski, Valdez, and Fairbanks and on the North Slope (EIA 2014b). How Alaska’s Native villages obtain their fuel depends on how connected they are to the extensive transportation infrastructure of the Railbelt region (Figure 2-2). Over 80% of Alaska's communities have populations smaller than 1,000 people, and for the large majority of ANVs, no over-land routes are feasible for fuel delivery; instead, barge delivery is the primary means of fuel supply for almost all energy needs (AFN 2012, Bradner 2012, US Census Bureau 2014a, USGCRP 2014). The size, frequency, and difficulty of barge deliveries for ANVs can differ greatly depending on the region, resulting in widely differing delivery costs (Bradner 2012, ISER 2008a). For example, facilities in Klawock in southeastern Alaska may pay $0.20 per gallon for fuel delivery by ice free barge, while facilities in Naknek in the Bristol Bay region pay $0.93 per gallon for fuel delivery by seasonal barge (ISER 2008a). Some communities, such as Alatna, Arctic Village, and Lime Village, do not have access to fuel delivery by barge and instead rely on air delivery of fuel, which can carry a fuel delivery charge of $1.00–$2.00 per gallon of fuel (ISER 2008a, ISER 2008b).

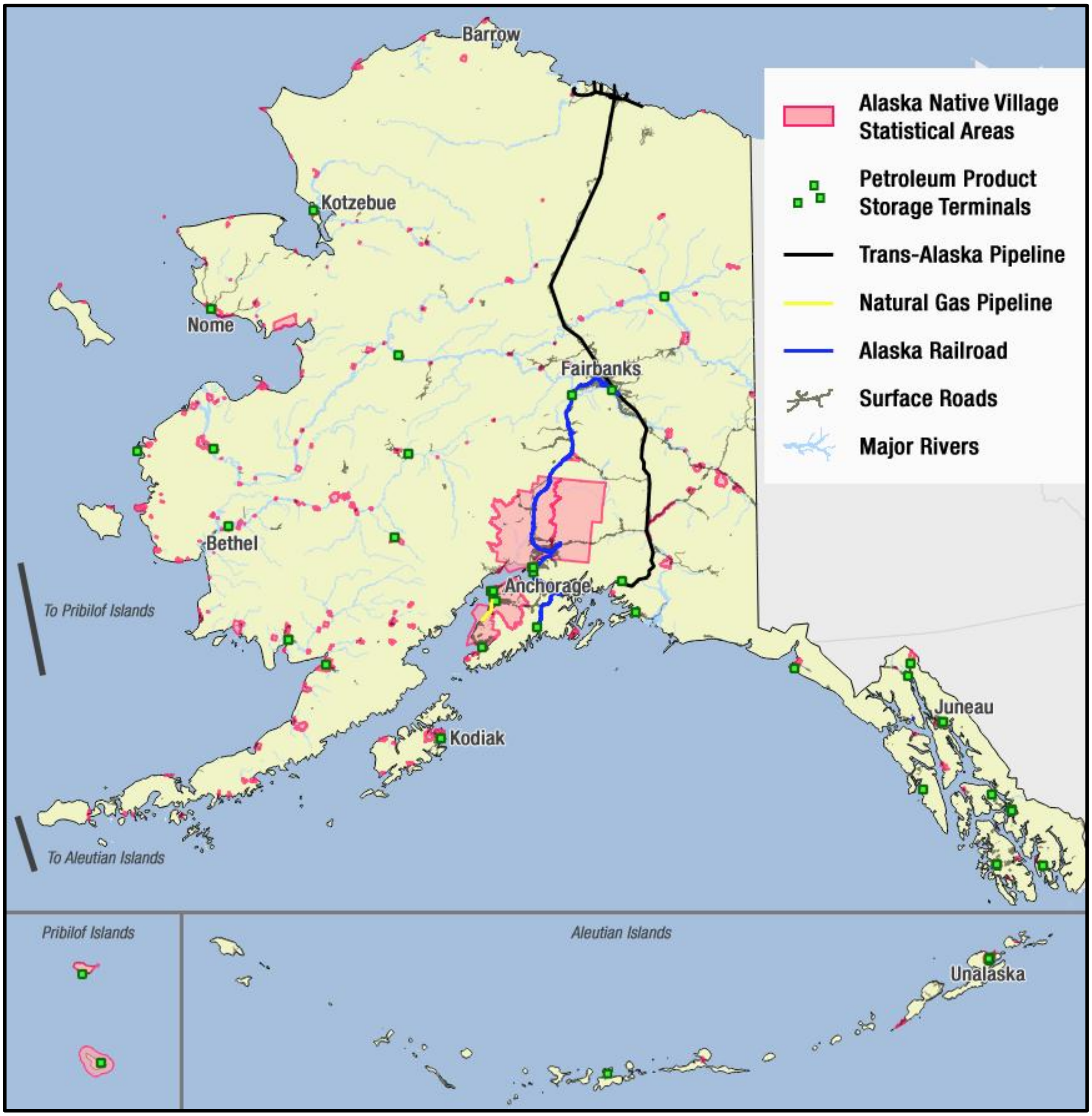

Figure 2-2. Fuel transportation infrastructure and critical waterways located on ANVSA lands across Alaska. Graphics Source: Energetics 2015; Data Sources: ASGDC 2015a, ASGDC 2015b, ASGDC 2015c, EIA 2012b, EIA 2014h, EIA 2014i, US Census Bureau 2014b

ANV communities in Alaska benefit from the state's oil and gas resources through ownership of some resources, and through business services provided by ANRCs and their subsidiaries. Oil production in Alaska first became a major economic driver for the state in the early 1970s following the completion of the Trans-Alaska Pipeline System (TAPS) and commercial production of North Slope oil. The majority of oil exploration and production in the North Slope does not occur on lands owned by ANRCs, but approximately half of the resources in the Alpine Oil Field are owned by Arctic Slope Regional Corporation (ASRC) (ASRC 2013). ANRCs also play a major role in producing North Slope oil through business lines ranging from drilling and oilfield construction to pipeline maintenance and spill remediation (see Table 2-3). Additionally, ANRCs and ANVCs (see textbox below) own claims to potential future resources: ASRC and six North Slope ANVCs purchased an equity share of Shell's development of offshore oil in the Arctic Ocean, and large quantities of untapped natural gas also occur in the North Slope, although infrastructure to bring it to market does not yet exist.

Alaska Native Corporations

The current system of Alaska Native Corporations, instituted by ANCSA, consists of two types of corporations —ANRCs and ANVCs (see below). ANCSA settled Native claims to land and resources in Alaska that were collectively owned by approximately 80,000 Alaska Natives, and the Act transferred land titles collectively comprising approximately one ninth of Alaska's land area to these new organizations. The Native corporations also received $962.5 million as part of the settlement. The two types of corporations have different disbursements of resources and different purposes.

Alaska Native Regional Corporations (ANRCs) – ANRCs represent twelve regions of Alaska. ANCSA established the regions, each represented by a regional corporation and granted a quota of surface and subsurface (mineral rights) property. ANRCs are owned by Native shareholders who were resident at the time the Act was passed in 1971, with 100 shares distributed to each enrolled member. Currently, the twelve land-holding regional corporations are owned by approximately 111,000 shareholders (GAO 2013). ANRCs share 70% of the revenues generated from resource extraction with the other regional corporations. ANRCs also distribute revenues to village corporations within their region.

ANRCs vary widely in their size and revenues and have diversified business lines that include government contracting, construction, manufacturing, oilfield services, information technology, communications, logistics, environmental services, and many others. As of 2010 (the latest year for which comparable revenue results are available), Arctic Slope Regional Corporation (ASRC) collected $2.3 billion in revenue, while Koniag, Inc. collected $131 million (GAO 2013).

ANCSA established a thirteenth entity—the 13th Regional Corporation—for Alaska Natives who are no longer resident in Alaska. The 13th Regional Corporation received a monetary settlement but did not receive any land. This corporation does not receive revenue shared from resource extraction.

Alaska Native Village Corporations (ANVCs) – ANVCs were created to support the needs and settlement claims for specific communities. ANCSA created 220 village corporations, with 206 independent and active today. Since the founding, some have merged with other village corporations or with their regional corporations (GAO 2013). ANVCs own and manage resources for rural communities and, like ANRCs, are owned by enrolled members of native communities. ANVCs vary widely in their size, revenue, and business lines, with some pursuing wider business opportunities outside their communities, and others focusing primarily within the community.

IMPLICATIONS FOR ENERGY SECTOR

Alaska Natives' energy-related vulnerabilities to climate change and extreme weather are in many ways unique among U.S. native populations. Depending on its location, energy infrastructure serving ANVs is vulnerable to extreme weather events such as inland flooding, extreme cold, and severe storms, the damaging effects of which

Table 2-1. Examples of extreme weather events and climate change that could adversely affect the energy infrastructure serving ANVs in Alaska.

Extreme weather event or climate change trend affecting energy infrastructure	Potential implications for tribes
Severe storms and extreme cold	
• Risk of flooding and ice, wind, and snow damage to power generation, transmission, and distribution infrastructure	• Power outages and damage to energy infrastructure on ANVs
• Risk of damage and disruption to fuel transportation and storage infrastructure on both land and critical waterways	• Disruption in fuel supply; need for high-cost emergency resupply
Increasing permafrost thaw	
• Increased risk of damage to power generation, transmission, and distribution infrastructure	• Greater likelihood of power outages and damage to energy infrastructure on ANVs in northern and interior Alaska
• Increased risk of structural damage and disruption to fuel transportation and storage infrastructure	• Potential disruption in fuel supply; potential increase in costs associated with protecting infrastructure and revenue impacts if TAPS is affected
Spring and ice jam flooding	
• Risk of damage to low-lying power generation, transmission, and distribution infrastructure	• Greater likelihood of power outages and damage to energy infrastructure on ANVs
• Risk of damage and disruption to fuel transportation and storage infrastructure on both land and critical waterways	• Potential disruption in fuel supply; need for high-cost emergency supply
Increasing frequency and size of wildfire and duration of wildfire season	
• Increased risk of damage to power transmission and distribution infrastructure	• Greater likelihood of power outages and damage to energy infrastructure serving ANVs in southern and interior Alaska, especially in Railbelt
• Increased risk of damage and disruption to fuel transportation infrastructure	• Potential increase in costs of protecting infrastructure; revenue impacts if TAPS is affected
Increasing coastal and riverbank erosion	
• Increased risk of damage to power generation, transmission, and distribution infrastructure	• Greater likelihood of damage to energy infrastructure on ANVs
• Increased risk of damage to fuel transportation and storage infrastructure	• Potential disruption in fuel supply; potential increase in costs of maintaining infrastructure
Changing river flow patterns, including shifts in streamflow timing and accelerating glacial melt	
• Increased risk of a decrease in water availability for hydropower generation in the summer	• Potential decreased seasonal hydropower capacity and increased costs of electricity
• Increased risk of decline in hydropower production in long term for glacier-fed streams	• Potential decreased seasonal hydropower capacity and increased costs of electricity

may be worsened through increasing coastal and riverbank erosion due to permafrost thaw and declining sea ice. Energy infrastructure serving ANVs may also be increasingly susceptible to climate change impacts, including thawing permafrost, increasing wildfire, and changing water patterns.[5]

Energy End Use

Potential climate change impacts:

- Decreased energy demand for fuel oil, propane, wood, and natural gas for space heating in the winter

Energy use in Alaska is dominated by heating during the cold winters in the state, and Native populations pay some of the highest costs for energy in the United States. According to one study of several communities across Alaska, 80% of total residential energy use in communities in the Railbelt is used for home heating, and 90% of the energy used in the rural ANVs is used for space heating (WH Pacific et al. 2012). While Native residents in Anchorage and on the Kenai Peninsula are more likely to use natural gas as their primary heating fuel, most ANV communities in rural Alaska and in the Fairbanks North Star Borough use expensive heating oil, specifically heating fuel #1, for space heating (Fay et al. 2013a, WH Pacific et al. 2012). The price of heating oil can range from $1.40 per gallon in northern Alaska to $11.00 per gallon in interior Alaska. A home in a rural village can use up to five 55-gallon drums of heating oil in a month, putting the monthly cost of home heating at $385–$3025 (ADCCED 2015, AFN 2012).

ANVs also pay extremely high prices for electricity, particularly in rural villages where diesel is the primary fuel for power generation. In 2011, the average price of residential electricity in the United States was $0.12 per kWh, but the price of electricity in rural Alaska ranged from $0.30 to over $1.00 per kWh (Fay et al. 2013a, EIA 2015d). However, electricity use in Alaska, particularly rural Alaska, is much lower than electricity use throughout the lower 48 states, primarily because of the high prices (Fay et al. 2013a).

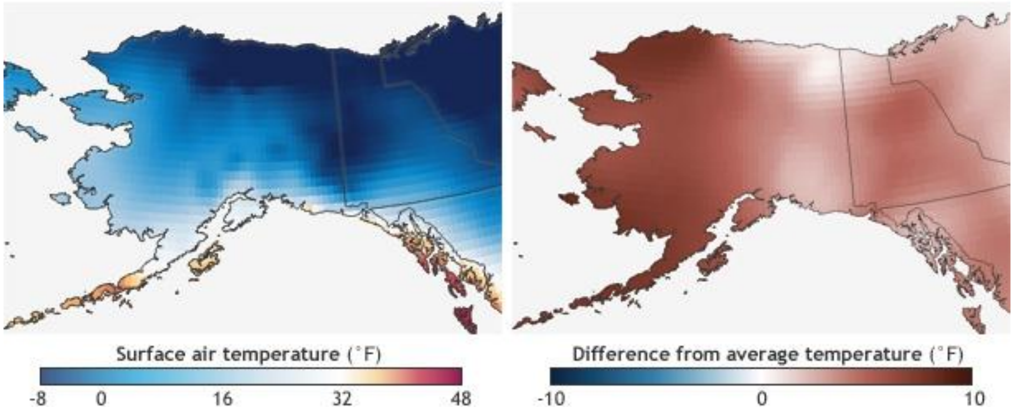

Figure 2-3. Maximum surface air temperature (left) for December 2014–February 2015 and difference from long-term average winter temperature (1981-2010) (right).
Source: NOAA 2015d

Warmer temperatures are expected to decrease demand for heating energy. Temperatures in Alaska are projected to increase, with winter temperatures expected to increase more than any other season (NOAA 2013h). Average winter temperatures have increased in recent years (Figure 2-3) and may increase by more than 12°F by

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[5] This report describes vulnerabilities of tribal energy systems related to both climate change and extreme weather. “Potential climate change impacts” refer to threats to tribal energy systems that are projected to change (increase, in most instances) compared to historical norms. Climate change impacts in Alaska include increasing permafrost thaw, increasing wildfire, and increasing coastal and riverbank erosion. “Potential extreme weather impacts” refer to weather events that threaten tribal energy systems, but quantifying the effects of climate change on the frequency, duration, or severity of these events is still an area of active research. Such extreme weather impacts include coastal and winter storms and spring and ice-jam flooding. In this report, potential extreme weather impacts are not associated with a trend but rather as a continued threat to tribal energy systems.

2085 in the Arctic region under a high emissions scenario (2090–2099, compared to average temperatures from 1971–1999) (NOAA 2013h). While projections for heating degree days in Alaska are not available, increasing winter temperatures may decrease the need for heating energy. As a result, ANV residents and businesses may see a decrease in energy bills during the winter.

Electricity Supply

ELECTRIC GRID

Potential extreme weather impacts:

- Storm damage to grid infrastructure located in or supplying ANVs
- Inland flood damage to grid infrastructure located in or supplying ANVs

Potential climate change impacts:

- Increased coastal erosion-related and riverbank erosion-related damage to grid infrastructure located in or supplying ANVs
- Increased risk of wildfire damage to grid infrastructure located in or supplying ANVs
- Increased permafrost thaw-related damage to foundations of grid infrastructure located in or supplying ANVs

Many ANVCs directly own and operate the electric grid infrastructure on which their residents rely through municipal utilities or member-owned cooperatives (for a comprehensive list of utilities serving ANVs see Appendix E). With the exception of those in the Railbelt (see Figure 2-4), these villages largely use a power generation and distribution system that is very different from that in the lower 48 states. In rural ANVs, generation is largely village-based, and residents and businesses rely on local distribution grids (microgrids)

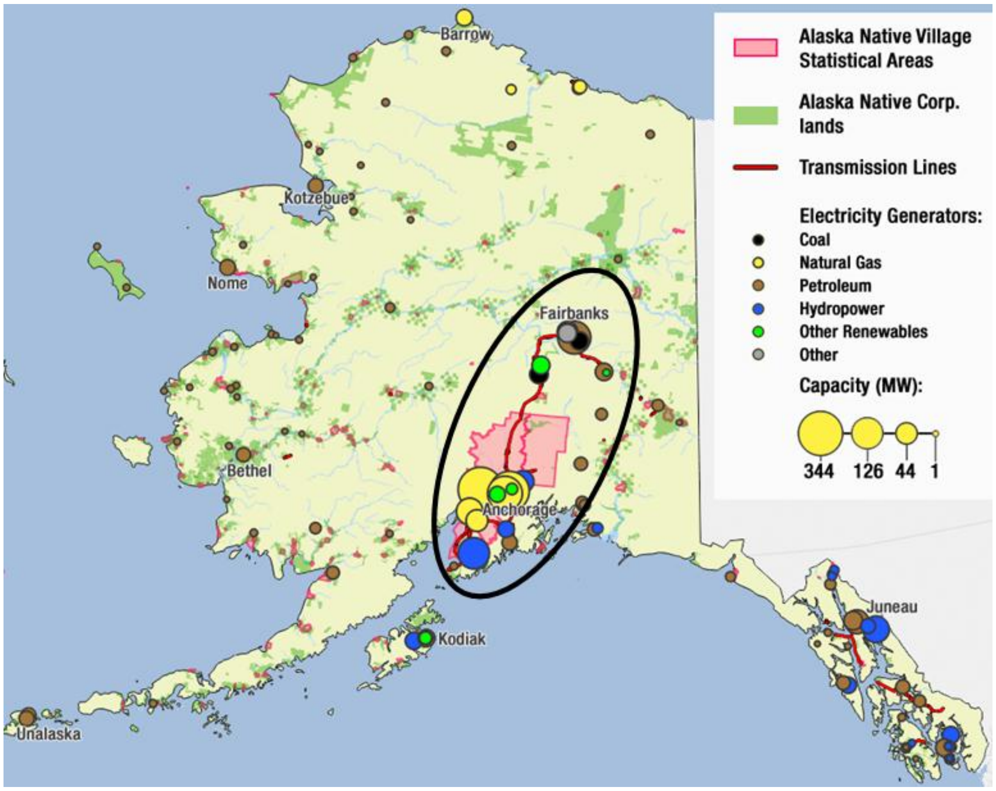

Figure 2-4. Most major electricity generation, transmission, and distribution infrastructure in Alaska is located in the Railbelt (circled).
Graphics Source: Energetics 2015; Data Sources: ASGDC 2015a, ASGDC 2015b, ASGDC 2015c, DOE 2015e, EIA 2014i, EIA 2014j, US Census Bureau 2014b

that do not connect to other communities or large centralized power plants. In a few ANVs, short-distance distribution interties have been constructed to both increase reliability and reduce costs in nearby ANVs (AVEC 2013).

Villages located in the Railbelt, such as Cantwell and Nenana, receive power through the region's transmission grid (GVEA 2015). Six member-owned cooperatives and municipal utilities across the region operate an interconnected transmission and distribution network similar to the system in the contiguous United States, although the transmission lines in Alaska are comparatively low-voltage (ARCTEC 2013, EIA 2013a, EIA 2013i).

Both the isolated distribution systems serving rural ANVs and the Railbelt region's transmission and distribution grid are vulnerable to damage and disruption from extreme weather events, such as coastal and winter storms, and impacts of climate change, including increasing wildfire, thawing permafrost, and flooding and coastal erosion. Damage to grid infrastructure (including power lines and poles, substation equipment, and switching yards) can lead to prolonged power outages and increases in the already very high cost of electricity in the region through increasing costs of maintenance and repair, particularly for rural ANVs. Remote rural villages in Alaska may have limited access to replacement equipment and technical expertise, and many have limited transportation options for supplying equipment and technicians on short notice (Colt et al. 2003, Rose 2009). Equipment and technicians would have to be flown or brought by boat to villages, an expensive and time-consuming process that may leave ANVs without power for prolonged periods of time (Rose 2009).

Winter storm damage to Kaktovik

During a winter storm in January 2005, the power lines connecting the community of Kaktovik to the community's North Slope Borough power plant were damaged, knocking out the only source of power to the community for three days (CNN 2005). Residents went without power while wind-chill temperatures dove to -70°F (CNN 2005, Pemberton 2005). During this period, low temperatures and lack of electricity caused water and sewage pipes to freeze, and the community's school, city hall, and police station were damaged (CNN 2005).

Severe storms, including coastal storms and winter storms, and coastal erosion can damage distribution systems and interties serving rural ANVs, and severe winter weather can damage Railbelt infrastructure (DOE 2015a, GAO 2003)**.** Damage from severe weather events could lead to prolonged power outages and increased maintenance and repair costs. Electric grid infrastructure on ANVs in the Aleutian Islands, Alaska Peninsula, and northern and western coasts are most vulnerable to damage from coastal storms (WRCC 2015). These severe storms, which can form in the North Pacific, Bering Sea, or southern Arctic Ocean, may bring heavy rain or snow and produce winds in excess of 50 miles per hour and storm surge along the Alaskan coast (USGCRP 2014, WRCC 2015). While extreme winter weather, including snow, ice, and severely cold temperatures, is most likely to affect grid infrastructure in northern and interior Alaska, where average winter temperatures range from 10 to 20 degrees below zero, winter storms can also affect infrastructure in the Railbelt (WRCC 2015). For example, severe winter storms in December 2011 and January 2012 tore down lines and damaged infrastructure, leading to power outages that lasted for weeks in some communities (CEA 2012).

Extremely high winds during coastal and winter storms can down power lines and poles and can cause tree branches or debris to blow onto power lines, shorting the line and leading to automatic closure of the circuit. A severe coastal storm in 2011 destroyed the Alaska Village Electric Cooperative's (AVEC's) new Brevig Mission-Teller Intertie before the line could even be energized (AVEC 2014). AVEC, which serves 56 communities in western and interior Alaska and is the largest utility in Alaska by service

Figure 2-5. Distribution lines in the village of Shishmaref are at risk of damage due to shoreline erosion during coastal storms.

Source: NOAA 2006

area, was not able to repair the intertie before it was again damaged during a coastal storm in 2013 (AVEC 2014).

During winter storms and coastal storms, ice accumulation can cause branches to fall onto lines or cause the lines to sag, increasing the risk that lines will come into contact with the ground or trees (USACE 2014). Distribution lines located in coastal ANVs in northern Alaska can become coated with frozen salt spray during storms with high winds, leading to dangerous electrical arcing that can damage lines and lead to power outages (Coffey 2011). If power lines are overloaded by ice or snow, poles may snap, initiating a long line of pole failures (USACE 2014). Ice-coated lines may be more susceptible to damage from high winds when the lines are driven to oscillate violently (a condition known as “galloping”) (USACE 2014). Lines may also suffer from post-storm damage; when ice on the lines melts, they sometimes rebound quickly and come into contact with tree branches (USACE 2014).

While the link between coastal storm activity in Alaska and climate change is an area of active research, melting sea ice and thawing permafrost associated with climate change may increase the risk of damage to grid infrastructure from these storms. Storm surge associated with coastal storms can damage low-lying coastal infrastructure (USGCRP 2014), and flooding from these storms may be worsened by climate change. As sea ice melts and the southernmost extent of sea ice moves northward, coastal storms can produce larger waves, and coastal erosion may occur more rapidly. Climate change is expected to cause sea ice to melt earlier in the year and reduce permafrost, exposing coastlines to increased risk of erosion (USGCRP 2014) (See Figure 2-5).

Increasing extent and severity of wildfires increases the risk of damage to electric grid infrastructure (DOE 2013a, USGCRP 2014)**.** Distribution systems and interties serving rural ANVs in southern and interior Alaska and grid infrastructure in the Railbelt are vulnerable to increasing wildfires. Alaska has had one of its worst wildfire seasons on record in 2015. As of August 10, wildfires had burned 5.08 million acres, the second highest burn area in history (Shalev 2015). Fires can burn wooden power poles and destroy substations and transformers. Heat and smoke generated by fires and the fire retardants used to combat wildfires can foul lines and degrade their capacity (DOE 2013a). Additionally, during wildfires, operators may shut down power lines to prevent leakage currents and arcing between lines or between lines and the ground (DOE 2013a).

Thawing permafrost may damage transmission and distribution infrastructure serving ANVs in northern and interior Alaska (ACIA 2005, DOE 2013a, USARC 2003, USGCRP 2014). Thawing permafrost, particularly in northern and interior Alaska, may compromise the foundations of grid infrastructure used to transmit electricity to ANVs in the Railbelt region and may damage local distribution lines and equipment—including distribution interties—in rural ANVs. When permafrost thaws, the tundra can lose its weight-bearing capabilities, and frost heave and uneven settlement associated with thawing permafrost can damage infrastructure foundations (USARC 2003). One study projected that permafrost warming of 5°C at a 10-meter depth in Barrow, Alaska (in the continuous permafrost zone)[6], would correspond to a decline in load-bearing strength of 23% (ACIA 2005). The study also projected that permafrost warming of only 2°C in Bethel, Alaska (in the discontinuous permafrost zone), could be sufficient to reach thawing temperatures, resulting in the potential complete loss of permafrost and a projected 40% drop in load-bearing soil strength (ACIA 2005).

Power poles serving ANVs in regions with discontinuous permafrost (see Figure 2-6) are already vulnerable to damage due to uneven settlement and frost heave, in which water refreezes in the permafrost active layer and expands upward. For example, power poles that support distribution lines in the ANV Atmautluak have already shown signs of tipping and frost jacking, in which frost heave lifts piles out of the ground (Atmautluak Traditional Council 2010). Similarly, electric utility poles and power lines in the village of Kiana have begun to lean and sag owing to an increase in permafrost thaw (Brubaker and Chavan 2011).

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[6] Continuous permafrost zones are defined as those with >90% of the land area underlain by permafrost, typically north of the Brooks Range or in mountainous regions. Discontinuous zones are those with 50%–90% of the land area underlain by permafrost and occur across Alaska’s interior. Sporadic permafrost regions are those with 10%–50% of the land area underlain by permafrost. Isolated permafrost zones are those with 0%–10% of the land area underlain by permafrost (ACIA 2005, Jorgenson et al. 2008).

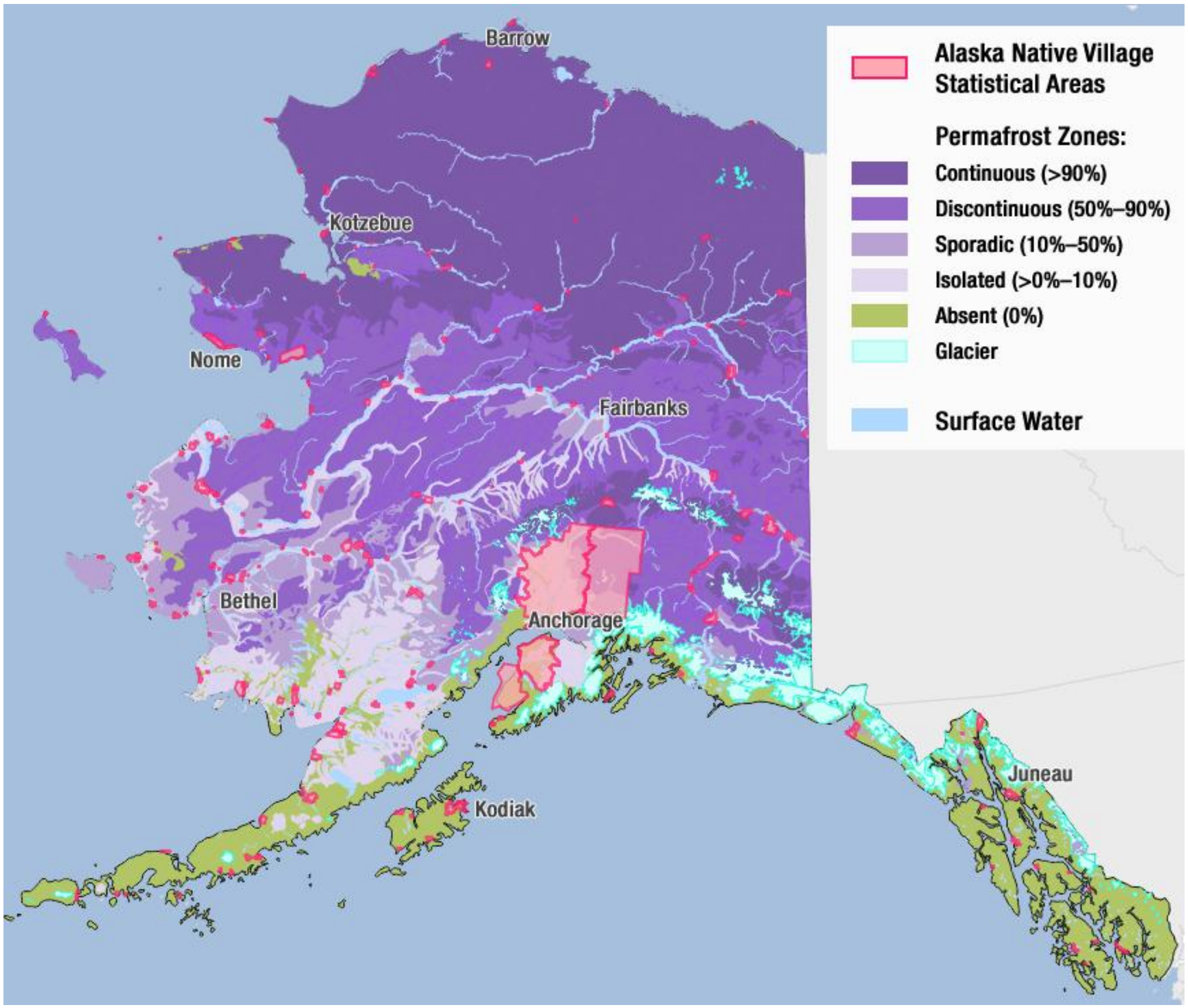

Figure 2-6. ANVSA lands underlain with permafrost.

Graphics source: Energetics 2015; Data sources: Jorgenson et al. 2008, US Census Bureau 2014b

Inland flooding and riverbank erosion, which is exacerbated by permafrost thaw, may damage inland transmission and distribution infrastructure (ACIA 2005, USACE 2006, USARC 2003). Grid infrastructure serving inland ANVs is vulnerable to damage from inland flooding, and climate change contributes to conditions favorable to riverine flooding and may increase erosion, potentially damaging grid infrastructure located along riverbanks. Permafrost thaw can accelerate erosion of riverbanks, and the rate of erosion may further increase if river flow increases with accelerating glacier melt or increased precipitation (ACIA 2005, USACE 2006, USARC 2003). Riverbank erosion poses a threat to infrastructure along riverbanks. For example, a 2009 report on potential erosion damages in the community of Nuiqsut found that utility poles and power lines were threatened by erosion because of their position along the bank of a branch of the Colville River (USACE 2009).

The influence of climate on flooding is complex, but accelerating glacial melt may increase the risk of glacial outbursts that can result in flooding and landslides, damaging grid infrastructure (ADNR 2014, IPCC 2014, NOAA 2013h, USGCRP 2014). Glacier retreat may cause unstable glacial lakes to form, which may increase the risk of damaging glacial lake outburst floods (ADNR 2014, IPCC 2014, NOAA 2013h, USGCRP 2014).

Ice jams that form when floating ice obstructs stream flow may result in severe flooding that can damage infrastructure serving riparian ANVs. For example, an ice jam in 2011 caused severe flooding and a power outage in the Alaska Native village of Crooked Creek (Rosen 2011).

ELECTRICITY GENERATION

Potential extreme weather impacts:

- Storm damage to generation equipment located in or supplying ANVs
- Inland flood damage to generation equipment located in or supplying ANVs

Potential climate change impacts:

- Increased coastal and riverbank-related erosion damage to generation equipment located in or supplying ANVs
- Decreasing summer hydropower production in southern Alaska due to declining snowpack and earlier snowmelt
- Increased risk of damage to foundations of infrastructure on ANVs in northern and interior Alaska from permafrost thaw

ANVs located in the Railbelt rely largely on offsite power generation from major thermoelectric and hydroelectric power plants in the region, while ANVs in rural Alaska are largely dependent on small-scale, in-village power generation. Despite the difference in scale, the electricity generation infrastructure serving ANVs in both the Railbelt and rural Alaska is vulnerable to severe storms and may be increasingly at risk from thawing permafrost; changing water availability, including declining snowpack, earlier snowmelt, and accelerating glacial melt; and coastal erosion and flooding.

In rural Alaska, tribes rely primarily on diesel electricity generators, which serve as the sole power source or operate in tandem with renewable energy sources in a hybrid system (Melendez and Fay 2012). To operate these generators, ANVs require expensive shipments of diesel fuel over very long distances, most often by barge, but in some cases by airplane. As a result, the price of electricity is high and volatile.

Some rural ANVs supplement diesel generators with hydropower or wind power resources (Melendez and Fay 2012). Renewables in rural Alaska can help reduce expenditures on fuel, but may also require expensive capital and construction costs. Given the high price of delivered diesel fuels, wind generation may be economical in some villages despite the high costs of complex and remote construction (EPA 2012, Milkowski 2009). For example, TDX Power's wind-diesel power system on St. Paul Island cost approximately $1.2 million to install but has eliminated $200,000 per year in utility electric charges and $50,000 per year in diesel fuel charges (AK Energy Wiki 2012). In 2011, twenty ANVs had installed wind capacity, but one study found that as many as 100 ANVs could find installing wind turbines economically feasible (Fay et al. 2013a, Milkowski 2009). Most ANVs with installed wind capacity are located in the southwest, Arctic and northwest, or Yukon regions of Alaska, and these projects are typically relatively small with installed wind capacity ranging from 0.02–4.5 MW (Table 2-2) (Fay et al. 2013a). ANVs that utilize run-of-the-river hydropower are in the southeast parts of the state, near Bristol Bay, or in the Aleutian Islands (Melendez and Fay 2012).

Railbelt ANVs rely on power generated at major thermoelectric and hydroelectric power plants (Figure 2-7). Many of these plants are located in Anchorage and are natural gas-fueled. Coal and petroleum serve as the major sources of fuel for plants around Fairbanks, and hydropower in the southern portion of the Railbelt provides about 13% of total capacity (Fay et al. 2013a). Wind power also provides some capacity to utilities operating in the Railbelt; for example, the ANRC Cook Inlet Region Inc. (CIRI) operates a 17.6 MW wind turbine project on Fire Island that sells power to the Chugach Electric Association (Fire Island Wind LLC 2015).

Table 2-2. Installed wind capacity on ANVs, 2011.

ANV	Installed wind capacity (kW)	ANRC	Region
Pilot Point	20	Bristol Bay	Southwest
Perryville	24	Bristol Bay	Southwest
Nikolski	65	Doyon	Southwest
Wales	130	Bering Straits	Arctic & North
Mekoryuk	200	Calista	Southwest
Savoonga	200	Bering Straits	Arctic & North
Selawik	260	NANA	Arctic & North
Gambell	300	Bering Straits	Arctic & North
Hooper Bay	300	Calista	Yukon
Kasigluk	300	Calista	Southwest
Chevak	400	Calista	Yukon
Emmonak	400	Calista	Yukon
Toksook Bay	400	Calista	Southwest
Kongiganak	450	Calista	Southwest
Unalakleet	600	Bering Straits	Arctic & North
St. Paul	675	Aleut	Southwest
Sand Point	1,000	Aleut	Southwest
Kotzebue	1,140	NANA	Arctic & North
Nome	1,170	Bering Straits	Arctic & North
Kodiak	4,500	Koniag	Southcentral

Source: Fay et al. 2013a

Severe winter and coastal storms, accompanied by worsening coastal erosion, may damage rural generation infrastructure on ANVs in northern Alaska and along the western coast. High winds, ice and snow, and flooding during severe storms can damage electricity generation equipment and support structures, particularly small-scale diesel-fired power plants supplying power to rural ANVs. Damage to generation infrastructure may lead to power outages in rural ANVs that rely on local generation, and maintenance and repair costs will likely be high.

Storm surge-driven coastal flooding may damage generation facilities, and climate change may increase the risk of flood damage to coastal generation facilities. Coastal ANVs may experience larger waves during storms as the sea ice that previously buffered these communities continues to disappear. Increased exposure to waves and flooding as well as thawing permafrost in some coastal communities may accelerate coastal erosion, which may result in damage to electric power infrastructure located along the shoreline (USGCRP 2014).

High winds during both coastal and winter storms can also damage generation infrastructure. For example, a wind turbine providing electricity to the city of Unalaska was damaged when 125-mile-per-hour winds dislodged the turbine blades and shaft, blowing the parts into the ocean (KUCB News 2009).

Winter storms and extremely low temperatures may also cause ice accretion on wind turbines, which can disrupt production and damage the turbine. In addition to the safety risks associated with ice thrown from wind turbines, ice accretion on turbines can collapse measurement towers and lead to aerodynamic imbalance on rotor blades, increasing the loading and reducing the lifetime of equipment. Ice accretion may also make repairs to turbines more difficult (Baring-Gould et al. 2012).

Figure 2-7. AVEC installed wind turbines in Gambell in 2009 to supplement diesel generation.
Source: NPS 2013

Inland flooding and riverbank erosion, which is exacerbated by permafrost thaw, may damage inland generation facilities (ACIA 2005, USACE 2006, USARC 2003, USGCRP 2014)**.** Seasonal spring flooding resulting from high discharges or from ice jams that occur during ice break-up can damage generation equipment and structures located adjacent to riverbanks. Additionally, if unaddressed, erosion of riverbanks can threaten infrastructure previously safe from flooding. Climate change may increase the risk of riverine flooding and accelerate erosion along riverbanks, thus increasing the risk of damage to infrastructure from inland flooding. Increasing precipitation, earlier spring thaws, and accelerating glacial melt may lead to increased river flow. Thawing permafrost contributes to erosion along riverbanks previously held in place by thick layers of permafrost (ACIA 2005, USACE 2006, USARC 2003). Warmer temperatures may increase the risk of damaging glacial lake outburst floods, as glacial melt can cause unstable glacial lakes to form, and accelerating glacial melt may increase the risk of flooding and landslides due to glacial outbursts (ADNR 2014, IPCC 2014, NOAA 2013h, USGCRP 2014).

Declining snowpack and earlier snowmelt may reduce water availability for hydropower generation in the summer, and accelerating glacial melt may affect future hydropower potential (ACIA 2005, DOE 2013a, USGCRP 2014)**.** Hydropower is an important electricity generation source for ANVs in southeastern Alaska, Bristol Bay, and the Aleutian Islands; rural ANVs can supplement diesel generation with hydropower to reduce generation costs. ANVs in the Railbelt rely partially on electricity generated at large hydropower facilities in the state. Changing water availability and shifting snowmelt timing due to increasing temperatures may lead to an increase in water availability in the spring and a decrease in summer water availability for hydropower generation. Warmer temperatures may also cause more precipitation to fall as rain rather than snow and result in an earlier spring thaw, which may shift peak streamflow timing and reduce water availability for hydropower generation in the summer (ACIA 2005, DOE 2013a, USGCRP 2014). While precipitation is projected to increase in southern Alaska, this may not result in an increase in hydropower generation serving ANVs in the region, as higher temperatures may reduce water availability through increasing evaporation and a longer growing season (DOE 2013a, USGCRP 2014). The effects of declining seasonal water availability may have a particularly acute effect on ANVs that supplement diesel generation with run-of-the-river hydropower generation, as these facilities typically do not have any storage capabilities and rely entirely on streamflow (Blackshear et al. 2011, IRENA 2012).

Glacial melt may increase hydropower potential on glacier-fed streams in the near term, but in the long term glacial melt may result in a decline in hydropower production on these streams (ADNR 2014, DOE 2013a, USGCRP 2014).

Thawing permafrost may damage existing wind generation infrastructure and affect development of future wind generation infrastructure (Fay et al. 2010, Petrie et al. 2008)**.** Thawing permafrost can compromise the foundations of generation equipment such as wind turbines, which cannot operate if permafrost thaw causes the foundation to settle, tilt, or lift. For example, designing foundations for construction in permafrost increases the cost of constructing turbines, and anticipating future thaw or changes to permafrost depth may increase costs. Installing turbines in Alaska in areas of discontinuous permafrost is significantly more expensive than installing wind turbines in the lower 48 states or urban areas. The higher cost is due in part to the remote nature of the communities, which forces developers to fly or barge in all supplies, but the risk of thawing permafrost also increases installation costs (Fay et al. 2010). When permafrost thaws, the active layer moves, and the permafrost no longer provides lateral support to the pilings, creating an “extended” turbine tower. This extended tower may be vulnerable to destructive frequencies created by strong winds and the rotating wind turbine itself. When installing a turbine in discontinuous permafrost, utilities construct towers that are on a slightly elevated foundation over pilings that are buried as deep as two thirds the height of turbine tower itself (Petrie et al. 2008).

Other electricity generating equipment support structures are also vulnerable to permafrost thaw. For example, spurred by concerns of toxic releases due to permafrost thaw and erosion in ANVs, a site visit to Newtok ANV in 2013 revealed that one corner of the community’s generator building was being supported by discarded fuel barrels (ADEC 2013b, DeMarban 2012). The community is coping with both permafrost thaw and rapid coastal/riverbank erosion and is in the process of relocating to a new location (DeMarban 2012, USGCRP 2014).

Fuel Supply

FUEL TRANSPORT

Potential extreme weather impacts:

- Coastal storm and flooding damage to transportation infrastructure in coastal ANVs and possible disruptions in fuel supply due to severe winter storms
- Inland flooding damage to transportation infrastructure and possible disruptions in fuel supply due to spring thaw and ice jam flooding

Potential climate change impacts:

- Increased damage to transportation and storage infrastructure located in or serving ANVs due to accelerated coastal and riverbank erosion and shoreline loss
- Increased risk of structural damage to fuel supply and storage infrastructure as a result of permafrost thaw and differential settling
- Increased risk of damage and disruption to fuel supply and storage infrastructure for gasoline, diesel, fuel oil, and propane, due to increasing wildfires

Owing to the distributed nature of ANVs, fuel transport is a persistent topic of pressing concern. Petroleum fuels are essential for village economies and ways of life, enabling heating, transportation, and electricity generation. Delivery of fuels can be logistically complicated and, for some villages, can occur only once or twice per year, requiring villages to maintain large fuel storage capacity (Bradner 2012, ISER 2008a). No long-distance over-land transportation is available for most ANVs, so villages on the coastline or on navigable portions of rivers typically rely on fuel shipment barges for fuel delivery during the summer thaw (ISER 2009). For many villages, the cost of fuel can be several times higher than in the lower 48 states, or even in the Railbelt (ADCCED 2015, ISER 2008a, ISER 2009). In a small number of villages, fuel delivery by barge is not possible and airplanes are used, further increasing costs (ISER 2009).

Fuel deliveries by barge in coastal communities in the Aleutian Islands and along Alaska’s southern coast can occur year-round, weather permitting, as ports in the region are free of sea ice. Fuel for these communities can be shipped from refineries in Nikiski or Valdez, from the Port of Anchorage, or from refineries in Washington or California (ISER 2008a). Coastal communities farther north may be limited to deliveries during the ice-free season, although recent years have seen record-low sea ice coverage (NSIDC 2015). For communities on the Kuskokwim River and nearby coast, fuel is first transported via large barges to the Native village of Bethel, where it is stored and transferred to smaller barges capable of navigating the Kuskokwim and its tributaries (ISER 2008a). On the Yukon River, the village of Nenana serves as the regional hub, with primary supply coming from the Petro Star refinery in North Pole (near Fairbanks) and potentially via rail from the Anchorage terminal (which is connected to the Nikiski refinery via pipeline) (ADNR 2015b, Cole 2014, ISER 2008a, ISER 2008b). Like barge shipments in the Bering and Chukchi Seas, river supply routes can only operate during the ice-free season. River shipments may also face navigational challenges including low water levels, adverse weather conditions, or high currents (Bradner 2012, Enoch 2014). In some cases, fuels are transferred from larger to smaller ships (called “lightering”) in order to access shallow-water ports (Bradner 2012). Lengthy and complicated fuel supply chains can mean very high fuel costs for village residents (Bradner 2012, ISER 2008a). For example, ANVs on the Kobuk River rely on fuel that must be shipped through the Bering Strait to the Kotzebue sound, transferred to a lightering barge in order to access the Kotzebue hub, and finally placed on another barge for deliveries upriver (Bradner 2012, ISER 2008a). Finally, a small number of communities are out of the reach of fuel barges, and these ANVs must rely on flights to provide fuels (ISER 2008b). These communities consistently face the highest fuel prices in Alaska (ISER 2008a, ISER 2008b, ISER 2009).

Climate change and extreme weather can disrupt fuel transport in these communities in a number of ways. Thawing permafrost affects soil stability, causing differential settling that may damage structures in permafrost zones across the state, including fuel storage tanks, roads and highways, air strips, and the TAPS. Coastal storms, combined with reduced sea ice and permafrost thaw, are increasing rates of coastal erosion and the risk of damage to barge landings, fuel storage facilities, and air strips. Inland flooding, permafrost thaw, and riverbank erosion similarly threaten fuel transportation and storage infrastructure in interior communities. Wildfire is an emerging risk in Alaska that threatens extensive fuel transportation infrastructure in the state's interior forests, including the TAPS.

Thawing permafrost across Alaska may undercut the foundation of fuel transport and storage infrastructure, including storage tanks, airstrips, roads, and other facilities (ACIA 2005, NOAA 2013a, USARC 2003, USGCRP 2014). The stability of important transport infrastructure could be affected by thawing permafrost or reduced permafrost thickness. Alaska has over 160 communities in continuous or discontinuous permafrost zones (Figure 2-6), and for many of these communities, permafrost thaw threatens fuel transport and storage infrastructure, including fuel storage tanks, airstrips, and local roads (USARC 2003). In these communities, thawing permafrost can cause the foundations of structures to settle inconsistently, leading to loss of support or damage to the structures (ACIA 2005, DeMarban 2012). For example, in Newtok, Alaska, thawing permafrost is contributing to the subsidence of land under fuel tanks and generators (Figure 2-8) (ADEC 2013b, DeMarban 2012).

Runways in communities built on discontinuous or continuous permafrost face risks of uneven land settling and loss of foundation strength, and may require major repairs or may have to be entirely relocated (USARC 2003). Damage to airstrips in communities that rely on air shipments of fuel could cause costly disruptions to fuel supply. The village of Noatak in Alaska's northwestern interior relies exclusively on air transport for fuel shipments since falling water levels in the Noatak River have made barge shipments impossible (ANTHC 2011, USA Today 2012). Because of the high cost of shipping fuel by air, Noatak also sees the highest electricity costs in Alaska's northwest region and is developing plans for an over-land winter road for fuel delivery (NANA Regional Corporation 2010, Native Village of Noatak 2015).

Figure 2-8. Shifting fuel tanks in Newtok.
Source: Newtok Planning Group 2014

Although most of Alaska's road miles are located in areas where permafrost is less common, roads within and around Alaska's ANVs are vulnerable to permafrost thaw and land settling (USARC 2003). Roads underlain with ice-rich permafrost may require substantial rehabilitation or relocation if thawing occurs (USARC 2003). In zones of warm, discontinuous permafrost, thawing beneath road embankments may occur in the next 20–30 years, within the lifetime of most embankments (ACIA 2005). While roads built on lower-ice permafrost may not necessarily require relocation, expensive, continuous repairs are likely to be necessary (ACIA 2005, USARC 2003).

Permafrost thaw may also affect the business of subsidiaries of ANRCs (see Table 2-3 for a list of ANRC activities related to fuel production). For example, the Dalton Highway—like many of Alaska's long-distance highways—is located in interior regions with discontinuous permafrost that are more vulnerable to thaw and resulting instability (ACIA 2005, USARC 2003). The Dalton Highway is an essential corridor for North Slope oil and future natural gas development and is an important transportation link for regional corporations providing oilfield services. Thawing permafrost may also affect the TAPS. Permafrost thaw can reduce the load-bearing capacity of the ground under the TAPS supports, and frost heave and uneven settlement may damage TAPS segments (DOE 2013, USARC 2003).

Any disruptions or damage to the pipeline can affect the business of regional corporations involved in pipeline construction and maintenance, as well as indirectly affect the revenues of corporations that receive royalties from North Slope oil production.

The Alaska Railroad (the state's only operating railroad) is also used for fuel delivery. The railroad operates a line that extends from Seward on the southern coast to the Fairbanks area in the state's interior. The railway line transits several tracts of Native lands in the Railbelt (ASGDC 2015a, EIA 2014b). The Alaska Railroad crosses sporadic and discontinuous permafrost zones and has historically been affected by differential frost heave and thaw settlement (USARC 2003). Continuing thaw of permafrost may escalate these challenges, including increasing the risk of damage to track and rail bed, and may increase maintenance costs (USARC 2003). Oil products shipped by rail are increasingly important since the closing of the Flint Hills refinery outside of Fairbanks in 2014, and petroleum products for Alaska's interior—including ANVs served by barge along the Yukon River or by air from Fairbanks—are now refined in Kenai and are shipped north to the Fairbanks area on the Alaska Railroad (Cole 2014, ISER 2008b).

Natural gas is locally produced and consumed in two North Slope ANVs: Barrow and Nuiqsut (ADNR 2015a). Barrow's natural gas supplies are used for electricity production and heating, and are transported from three nearby natural gas fields via over-land pipelines (Lidji 2013). Nuiqsut is the latest village to receive natural gas supplies, transported to Nuiqsut from the nearby Alpine Field operated by ConocoPhillips; the Nuiqsut Natural Gas Pipeline began operations in 2008 (ADNR 2015a). The Nuiqsut pipeline is constructed both above and below ground and, like the TAPS and Barrow pipelines, relies on permafrost for structural support for almost its entire course (ACIA 2005, North Slope Borough 2014). Natural gas is also produced from the Kenai Peninsula and the Cook Inlet, where some pipelines transit Alaska Native Corporation lands (ASGDC 2015a, EIA 2012b). Some of the natural gas produced from the region is exported to Asian markets through a liquefied natural gas (LNG) export terminal in Nikiski (EIA 2012a, EIA 2014b, EIA 2014g). Nikiski is also the likely location for a future export terminus of a proposed gas pipeline from the North Slope gas fields (Bradner 2013).

Declining shore-fast sea ice, combined with thawing permafrost and powerful winter storms, may increase coastal erosion and threaten fuel supply infrastructure important to coastal villages (ACIA 2005, USARC 2003, USGCRP 2014). Coastal erosion enhanced by declining sea ice and permafrost thaw can undercut the structural footing of energy infrastructure in coastal communities that rely on barge shipments for fuel delivery (Alaska AAG 2010, USGCRP 2014). In previous years, essential infrastructure such as barge landings, fuel storage tanks, and coastal fuel headers have been damaged or destroyed by encroaching coastlines (Alaska AAG 2010, USACE 2008a, USGCRP 2014).

Figure 2-9. Shoreline erosion in Newtok.
Source: USACE 2008b

Coastal erosion, exacerbated by receding sea ice in Alaska, is threatening fuel transport infrastructure for numerous small ANVs on islands in the Arctic Ocean and Bering Strait. Erosion can destroy barge landings, fuel connections, storage tanks, and other infrastructure used for offloading fuel shipments from barges. In cases in which fuel barges cannot offload, communities must transfer fuel to smaller, shallow draft ships capable of landing, adding to the cost (Bradner 2012, USGCRP 2014). In some cases, communities must rely on air shipments of fuel, which is extremely expensive (Bradner 2012, USARC 2003). For example, the village of Newtok is facing erosion threats that have already destroyed its barge landing and disrupted fuel shipments (USACE 2008a, USGCRP 2014). Located on the tidal Ninglick River just inland of the western coast of Alaska on the Bering Sea, the village is experiencing thawing permafrost and loss of sea ice that increases its vulnerability to rapid erosion during storms (USACE 2008b, USGCRP 2014). In 2005, the village's barge landing on the Ninglick was destroyed, and in April 2006, a fuel barge was grounded for three days, after which deliveries were suspended and the fall 2006 fuel delivery was not made (USACE 2008a). The village experienced a fuel crisis in the winter of 2006–2007, and emergency shipments of fuel were flown in to supplement dwindling supplies until a solution could be found (D'Oro 2007, USACE 2008a). Fuel storage tanks—including tanks for the village's generator station and school, for home heating, and for marine and aviation fuel—are also threatened by erosion of both the Ninglick and the Newtok rivers (ADEC 2013b, DeMarban 2012).

Ice jam flooding in Galena

In 2013, an ice jam on the Yukon River formed 20 miles downstream from Galena, producing unprecedented flooding in the central Alaska village that destroyed approximately 90% of the village’s structures (ICTMN 2013). The flood damaged almost every structure in the town, including many fuel storage tanks, which were displaced, were knocked over, and in some cases leaked into the flooded river (Figure 2-10) (ADEC 2013a, Andrews 2013). The downriver communities of Nulato and Koyukuk were also threatened by the flooding as the ice jam moved downstream (Andrews 2013).

Figure 2-10. Galena power plant fuel storage tank shifted by ice jam flooding in 2013.
Source: ADEC 2013a

In the Bristol Bay communities of Port Heiden and Levelock, erosion of local shorelines may require that the fuel headers (connections used for refilling fuel storage tanks from barges) may need to be relocated inland (ADEC 2012, ANTHC 2014, LPB 2013).

Air strips in coastal communities may also be vulnerable to coastal erosion and flooding. The community of Point Hope on the Bering Strait relocated to higher ground in the 1970s, but climate change-related erosion and flooding remains a threat to the community's air strip (ANTHC 2010, GAO 2003).

Declining sea ice may also aid fuel deliveries for some communities as the ice-free season grows longer. For coastal villages that are ice-bound for some portion of the year, declining sea ice may allow more flexible or more frequent fuel deliveries. Communities along Alaska’s southern coast and in the Aleutian Islands experience powerful winter storms, but these villages are not typically vulnerable to the enhanced erosion associated with declining sea ice and thawing permafrost, as the region is ice-free year-round and permafrost is uncommon (ACIA 2005, ISER 2008a).

River flooding and riverbank erosion, enhanced by thawing permafrost along riverbanks, threaten fuel supply infrastructure in ANVs along Alaska’s rivers (ACIA 2005, McNamara 2010, USGCRP 2014)**.** Spring flooding along Alaska’s river banks, typically due to ice jam floods, is a seasonal hazard for many ANVs and often leads to increased rates of erosion along riverbanks, which can damage or destroy fuel transportation and storage infrastructure. Riverbank erosion results from a number of causes, including natural processes (such as flooding) and riverbank disturbances. In regions with permafrost, increased active layer depth due to permafrost thaw can accelerate riverbank erosion, as soils are weakened. For example, the native village of Huslia is located on the northern bank of the Koyukuk River in central Alaska. For a number of reasons, including permafrost loss, the bank of the Koyukuk is eroding at an average of 10 to 30 feet per year (USACE 2007a). In response to the erosion threat, AVEC has already moved the village power plant, including its bulk gas and oil storage tanks, inland. Currently, the village’s boat landing and additional fuel tanks are threatened by encroaching erosion (USACE 2007a).

River flooding can also affect fuel delivered by road. In the North Slope, much of the region’s fuel production activities rely on fuel delivered via the Dalton Highway. In May of 2015, the Sagavanirktok River experienced unprecedented spring flooding that inundated approximately 80 miles of the gravel highway and closed the road for more than two weeks (DeMarban 2015, Edge 2015, Klint 2015). Earlier in the year, ice had covered sections of the road, rendering it impassible for days (Wood 2015). The flooding was a result of heavy summer rains, which were trapped in place by the winter freeze, followed by a spring thaw that rapidly melted the accumulated water (DeMarban 2015).

Wildfires in Alaska are growing in frequency and size and may threaten the TAPS and lead to rapid permafrost thaw. Increasing incidence of forest fires may affect the TAPS as well as ANRC subsidiaries with operations related to TAPS maintenance, repair, and emergency response. The pipeline is designed to resist forest fires and is protected by an aluminum jacket and insulation, as well as its placement within a 64-foot-wide right-of-way clear-cut of vegetation. Past fires have not affected the pipeline's operations; however, the costs associated with protecting the pipeline may increase, as climate change is projected to increase the risk of forest fires in Alaska (BLM 2007, D'Oro 2003, News-Miner 2014). For example, in response to a fire that approached the TAPS in 2014 near the Yukon River Crossing, pipeline operators mobilized sprinkler systems, water trucks, and bulldozers in case the fire threatened the pipeline or support structures (News-Miner 2014).

FUEL PRODUCTION

Potential climate change impacts:

- Increased risk in disruption of fuel supply and increase in costs due to warming temperatures and diminished snow cover that reduce the number of tundra travel days
- Increased risk of damage to structures due to permafrost thaw and differential soil settling

Oil and gas production in Alaska are important sources of both fuel and income for some Native communities. Several ANRCs own land or mineral rights to land with oil and gas resources, and these entities receive royalties from oil and gas production. Through the revenue-sharing structure of ANCSA, all twelve land-holding regional corporations share revenue derived from resource extraction. Most of the land-holding regional corporations are also engaged in energy production or supporting services (oilfield services) that can include operations management, drilling, construction, logistics, engineering, maintenance, environmental remediation, and other services (Alaska Journal of Commerce 2015). Table 2-3 summarizes the assets and activities of the regional corporations with land holdings in Alaska related to fuel production.

Figure 2-11. A Rolligon (a type of low ground pressure vehicles) prepares the surface of an ice road in the North Slope.
Source: BLM 2005

Warming temperatures have contributed to a reduction in the number of days of allowable road travel on frozen tundra, while dependence on ice roads for oil and gas production in the North Slope is increasing (ADNR 2004, DOE 2013a). Oil and gas exploration and production on Alaska's tundra requires off-road transportation to remote well sites. But off-road travel is limited to the winter season to protect the sensitive tundra ecosystems. The Alaska Department of Natural Resources (ADNR) determines the annual opening and closing dates for off-road travel on tundra, basing its decisions on the thickness and hardness of the ground frost (ADNR 2004). Higher temperatures and thawing permafrost can shorten the winter operating season, decreasing productivity and increasing costs (DOE 2013a, NOAA 2014). Since the 1970s, both warmer conditions and changes in regulatory criteria have shortened the tundra travel season by an average of 100 days (ADNR 2004, DOE 2013a, NOAA 2014). Although the long-term trend is toward warmer temperatures and fewer tundra travel days, recent changes to management and new technologies and techniques may help ameliorate this effect. For example, the winter of 2014–2015 saw a large increase in tundra travel season, in part due to ADNR's opening of different areas in the North Slope individually (rather than as a single region), and also due to new snow prepacking techniques that accelerate soil freezing underneath new snow (Rosen 2015). The challenges of shorter winter working seasons are compounded by record demand for tundra travel as the extent of active North Slope oil and gas wells grows and becomes less geographically concentrated. In the winter of 2013–2014, a record-high number of miles of ice roads were approved for construction (DeMarban 2014).

Management standards for tundra travel are stricter in the Foothills sections of the North Slope, requiring 50% more snow for off-road travel than in the coastal regions (ADNR 2004, Head 2010). This may indicate that future oil and gas exploration on the Arctic Slope Regional Corporation's (ASRC's) holdings in the foothills of the Brooks Range could be more difficult than North Slope activity in general as temperatures warm and the tundra travel season shortens (Alaska Journal of Commerce 2015, DOE 2013a). In the winter of 2014–2015, the Lower Foothills region stayed closed fully two months later than the coastal regions, and the Upper Foothills region was never opened for tundra travel (Rosen 2015).

In addition to a shorter season, the area of tundra that is expected to be sufficiently frozen to support ice roads is projected to fall. The Intergovernmental Panel on Climate Change (IPCC) projects that, by mid-century (2045–2059), the average land area accessible by winter season ice roads in Alaska will fall by 29% compared to 2000–2014 (IPCC 2014a).

Permafrost thaw causing differential settling may affect fuel production infrastructure, including drilling pads, pump stations, camp structures, and other structures supporting oil production (ACIA 2005, USARC 2003)**.** Warming temperatures in the North Slope are expected to reduce the thickness of the permafrost layer and increase the depth of the active soil layer (the layer that freezes and thaws annually). North Slope drilling occurs on the tundra north of the Brooks Range that is underlain by colder, thicker permafrost and may not be as susceptible to thawing as the warm permafrost in Alaska's interior (USARC 2003). Nonetheless, loss of permafrost thickness can increase the depth of the active layer, reduce the load-bearing capacity of soils and lead to differential settling, and undermine the foundations of structures, including drilling pads, production installations, and supporting structures (ACIA 2005, DOE 2013a, USARC 2003). For structures that rely on slab foundations that use active or passive cooling systems to prevent permafrost thaw (these foundations are used for buildings that must support heavy loads, including heavy equipment shops and other industrial buildings), warmer temperatures may also mean these systems are insufficient, and an increasing failure rate is likely (ACIA 2005, PTF 2000).

Offshore oil and gas in the Arctic Ocean

Royal Dutch Shell has been pursuing offshore oil exploration in the Arctic Ocean, including the Chukchi and Beaufort Seas, for several years. An earlier attempt in 2012 was disrupted by severe winter storms and resulted in the drilling rig Kulluk running aground off of Sitkalidak Island, east of Kodiak (Figure 2-12) (Funk 2014, NOAA 2013i).

Figure 2-12. The drilling rig Kulluk aground on the shore of Sitkalidak Island in 2013. In this picture, the rig is weathering 40 mph winds and 20-foot seas as it waits to be recovered.
Source: NOAA 2013i

Warming oceans and reduced sea ice may extend the open-ocean season and enable greater drilling opportunities and more flexible operations (DOE 2013a). Current exploration plans call for drilling wells in the Chukchi Sea off the coast of Wainwright in summer and autumn of 2015 (Shell 2015). In 2014, six North Slope village corporations and ASRC joined together to form Arctic Iñupiat Offshore, LLC, and to acquire an equity share in Shell Oil's offshore development in the Arctic Outer Continental Shelf (ASRC 2014).

Table 2-3. Alaska Native Regional Corporations business relating to fuel production and supporting activities.

Corporation	Fuel Production and Related Activities
Ahtna, Inc.	Ahtna Construction and Primary Products provides construction, pipeline maintenance, and oil spill emergency preparedness services, and Alyeska Pipeline Service Co. (operator of the TAPS) has been a major Ahtna customer. Ahtna, Inc. has also recently engaged in oil and gas exploration on its own lands and adjacent state lands in the Copper River sedimentary basin. The company and its partners have drilled one exploratory well with plans to drill a second (Alaska Journal of Commerce 2015).
Aleut Corp.	Aleut Corp. provides fuel services for Adak, including the airport and port (Alaska Journal of Commerce 2015).
Arctic Slope Regional Corp. (ASRC)	ASRC owns the mineral rights to substantial resources in the Arctic Slope region, including the Alpine Oil Field in the Colville River Delta 50 miles west of Prudhoe Bay (on land owned by the Kuukpik Native Village Corporation) and the largest untapped coal resource in the United States (Alaska Journal of Commerce 2015, ASRC 2013, Kuukpik Corp. 2015). ASRC also owns ASRC Energy Services which engages in oil and gas exploration, drilling, geosciences services, oilfield operations and maintenance, and pipeline construction in the North Slope, as well as offshore drill rig construction and servicing in New Iberia, Louisiana, and logistical and oilfield support in the Bakken Shale in North Dakota. ASRC's subsidiaries also provide other oilfield support such as drill pad and ice road construction and offshore spill response (ASRC Energy 2013). Another ASRC subsidiary, Petro Star, Inc., owns and operates two of Alaska's five active oil refineries, located in Valdez and North Pole (Petro Star 2015).
Bering Straits Native Corp.	Bering Straits Native Corp. does not engage in any significant business lines related to fuel production. Among other activities, Bering Straits Native Corp. subsidiaries provide fuel delivery as part of their logistics business line (Bering Straits 2015).
Bristol Bay Native Corp. (BBNC)	BBNC's subsidiaries provide a wide range of fuel production services. Peak Oilfield Service Co. provides logistical services including ice road construction and rig transport in the North Slope; construction, fabrication, and trucking support to the petrochemical industry in the Cook Inlet region; tank cleaning services at the TAPS marine terminal in Valdez; and construction and maintenance services in the Bakken Shale in North Dakota (Peak 2015). CCI Industrial Services provides services relating to pipeline and storage tank maintenance, oil spill response, and others, and Kakivik Asset Management provides inspections and testing services for pipelines (CCI 2015, Kakivik Asset Management 2015). In the Bristol Bay region, oil and gas exploration has occurred sporadically over the previous century—including on BBNC lands—without discovering any economic quantities for production (BBNC 2015). Outside of Alaska, BBNC's subsidiary PetroCard distributes fuel in the Northwest and provides fleet fuel payment services nationwide (PetroCard 2013).
Calista Corp.	Calista Corp. subsidiaries work in many sectors across Alaska and the nation. Some Calista subsidiaries perform a wide variety of services for the oil and gas sector. These include logistics and transportation, facility support, communications, permitting and environmental impact assessments, construction and engineering, and others (Calista 2014). Calista subsidiaries are also involved in other energy sectors. For example, STG Inc. provides wind turbine installation services.
Chugach Alaska Corp.	Chugach Alaska Corporation's many subsidiaries include several companies that provide oilfield services and fuel production-related activities. Chugach Professional Oilfield Services and a recent acquisition, All American Oilfield Associates LLC, provide a complete array of services to drilling operations in both the North Slope and Cook Inlet regions, including staffing, engineering, logistics, well planning, and rig design (Chugach Alaska 2014). Chugach Alaska Services Inc. provides additional services such as maintenance and oil spill response (Chugach Alaska 2014).

Cook Inlet Region, Inc. (CIRI)	CIRI subsidiaries are involved in a variety of energy activities in Alaska and in the lower 48. CIRI's oilfield services subsidiary, Cruz Energy Services, serves the Bakken Shale play and is based in North Dakota. Cruz Marine provides navigation and construction support in Alaska. CIRI also holds an interest in Cook Inlet Natural Gas Storage Alaska (CINGSA). CINGSA is Alaska's first underground gas storage facility. Other subsidiaries include wind farms in Alaska, Nebraska, Texas, Wyoming, and Washington (CIRI 2015a). The Cook Inlet region is home to both natural gas and oil resources, and CIRI has leased production rights on both sides of the Inlet. CIRI expects exploration to increase in the future and is seeking to encourage new Cook Inlet gas development (CIRI 2015b).
Doyon, Ltd.	Doyon, Ltd. provides a wide range of oilfield services through its many subsidiaries. Doyon Drilling, Inc. is Doyon, Ltd.'s largest subsidiary and one of two major drilling contractors in the North Slope, with contracts serving both BP and ConocoPhillips (Alaska Journal of Commerce 2015, Doyon 2015). Other subsidiaries include a pipeline construction company, Doyon Associated, LLC, and Doyon Anvil, LLC, which provides engineering, program management, and other support services (Doyon 2015). Doyon, Ltd. is the largest private landowner in Alaska and has land and mineral rights holdings in two undeveloped potential oil plays: Nenana Basin and Yukon Flats Basin. Doyon, Ltd. has drilled exploration wells in the Nenana Basin and is encouraging exploration by providing online data from historical drilling (Alaska Journal of Commerce 2015, Doyon 2014).
Koniag Inc.	Koniag, Inc.'s subsidiary Dowland-Bach provides engineering and design support to oilfield operators (Koniag 2011).
NANA Regional Corp.	NANA Regional Corp. (NANA) has engaged in oilfield services since shortly after its founding, and its subsidiary NANA Oilfield Services, Inc., provides fuel and camp services in the North Slope. GIS Oilfield Services provides onshore and offshore fabrication services in Louisiana, and NANA Australia provides drilling and other support in Perth, Australia. NANA subsidiaries provide engineering and logistics support across the lower 48 and in nine other countries (Alaska Journal of Commerce 2015, NANA 2015, NANA Australia 2015). The NANA region does not currently host any producing oil wells, but NANA is pursuing development of potential natural gas in the Selawik Basin (Alaska Journal of Commerce 2015).
Sealaska Corp.	Sealaska Corp. does not does not engage in any significant business lines related to fuel production.

Source: U.S. Census Bureau 1995

Chapter 3: NORTHWEST TRIBAL LANDS

Key Climate Change and Extreme Weather Hazards Affecting Tribal Trust Land Energy Systems in the Northwest

- **Increasing wildfire:** Increasing temperatures and more frequent summer drought are factors contributing to projected increases in the size and frequency of wildfire, which may threaten the electric grid and lead to power outages and increased direct costs of repair and maintenance for tribes that own and operate grid infrastructure.
- **Changing water availability:** Reduced mountain snowpack and earlier seasonal snowmelt could decrease summer hydropower generation, a key source of power for utilities serving tribal trust lands (TTLs) in the Northwest.
- **Rising temperatures:** Projected higher temperatures are expected to increase demand for air conditioning in the summer and may increase summer electricity bills.

OVERVIEW OF NORTHWEST REGION

There are 41 federally recognized tribal trust lands (TTLs) in the Northwest (U.S. Census Bureau 2010b). They are home to about 163,000 residents and are spread throughout the region, as shown in Figure 3-1 (U.S. Census Bureau 2010a). Two TTLs in the region are served by tribal utility authorities (EIA 2014c, WAPA 2010), and there are several major elements of energy infrastructure owned and operated by TTLs in the Northwest.[7]

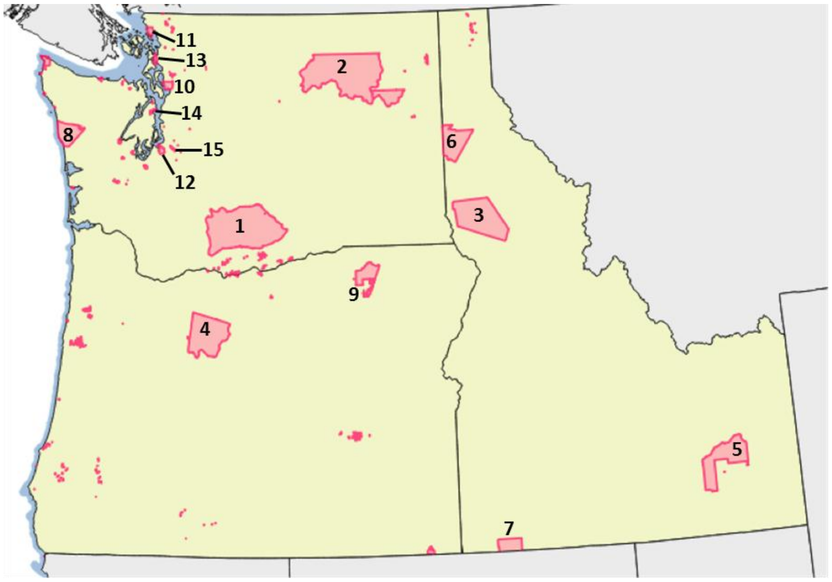

Figure 3-1. TTLs located in the Northwest.
Large reservations have been numbered in the figure above; see Table 3-1 for the corresponding trust land name.
Graphic source: Energetics 2015; Data source: U.S. Census Bureau 2015

Electricity Supply

Most TTLs do not own major power plants or have them onsite (EIA 2014c) and instead rely on offsite power producers for reliable electricity. Power is generated by major power plants and transmitted

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[7] "Major energy infrastructure" includes the following: high-voltage (> 345 kV) transmission lines; large (> 1 MW) electric generation plants; oil, natural gas, or coal production areas; oil refineries; natural gas processing plants; and crude oil, petroleum product, or natural gas pipelines.

over long distances to users via a high-voltage transmission network. Substations connect high-voltage transmission networks to low-voltage distribution networks and use large power transformers to reduce the voltage. Distribution lines deliver power to customers over short distances. Most of the electric grid infrastructure used to transmit electricity to tribal residents and businesses is not owned by tribes, but two TTLs, the Yakama Reservation and Cow Creek Reservation, own and operate their own electric utilities (EIA 2014c, WAPA 2010).

Two reservations in the region own hydroelectric plants: the Warm Springs Reservation in Oregon shares joint ownership of the Pelton Round Butte hydroelectric project (Portland General Electric 2006), and the Colville Confederated Tribes on the Colville Reservation hold an ownership stake in the Grand Coulee and Wells Dams.

Fuel Supply

Residents of the Northwest region rely on pipeline, rail, truck, and marine transport for fuel supply. There is a small natural gas field in Oregon, but most natural gas used for residential heating in the region is transported into the region by pipeline from producing areas in Canada, Colorado, New Mexico, and Wyoming. Petroleum products, including gasoline and diesel used by residents and businesses on TTLs, are likely refined at refineries in Washington or transported into the region by pipeline, tanker, and barge from Canada and Utah (EIA 2014c). Petroleum products are then trucked throughout the region.

Table 3-1. TTLs in the Northwest.

States with TTLs:	Idaho, Oregon, Washington
Number of TTLs:	41
Total population:	163,000
Total area (square miles):	9,600

Large TTLs

	Trust Land Name	Population**	Total Area (sq. miles)
1)	Yakama Nation Reservation (WA)	31,272	2,188
2)	Colville Reservation (WA)	7,687	2,185
3)	Nez Perce Reservation (ID)	18,437	1,204
4)	Warm Springs Reservation (OR)	4,012	1,023
5)	Fort Hall Reservation (ID)	5,767	856
6)	Coeur d'Alene Reservation (ID)	6,760	537
7)	Duck Valley Reservation (ID/NV)	1,309	453
8)	Quinault Reservation (WA)	1,408	324
9)	Umatilla Reservation (OR)	3,031	270
10)	Tulalip Reservation (WA)	10,631	52
11)	Lummi Reservation (WA)	4,706	37
12)	Puyallup Reservation (WA)	46,816	29
13)	Swinomish Reservation (WA)	3,010	21
14)	Port Madison Reservation (WA)	7,640	12
15)	Muckleshoot Reservation (WA)	3,870	6

*Note: "Large" tribal trust lands are those lands greater than 300 square miles in area or with >3,000 residents.
**Note: The population of TTLs refers to the number of residents on each TTL according to the 2010 Census, not the number of enrolled members of each tribe.
Sources: U.S. Census Bureau 2010a, U.S. Census Bureau 2010b

IMPLICATIONS FOR ENERGY SECTOR

Increasing air and water temperatures, changing water availability, and increasing wildfire due to climate change are likely to affect energy demand and electricity and fuel supply to TTLs in the Northwest. Additionally, severe storms may continue to affect tribal energy systems (see Table 3-2).[8]

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[8] This report describes vulnerabilities of tribal energy systems related to both climate change and extreme weather. "Potential climate change impacts" refer to threats to tribal energy systems that are projected to change (increase, in most instances)

Table 3-2. Examples of extreme weather and climate change impacts that could adversely affect the energy infrastructure serving TTLs in the Northwest.

Extreme weather event or climate change trend affecting energy infrastructure	Potential implications for tribes
Severe storms, including convective storms, winter storms, and increasing heavy rainfall events	
• Risk of flooding and damage to low-lying power generation, transmission, and distribution infrastructure	• Power outages and damage to energy infrastructure on TTLs
• Risk of damage and disruption to fuel transportation infrastructure on both land and critical waterways	• Potential disruption in fuel supply
Rising air and water temperatures	
• Increased electricity demand for air conditioning	• Higher electricity bills for cooling in the summer
• Reduced power line transmission capacity and efficiency, increased risk of deformation and damage to power lines, and reduced service life of some electrical equipment	• Greater likelihood of power outages and potential for higher electricity costs
• Decreased efficiency and available generation capacity of thermoelectric power plants	• Potential for higher electricity costs
Changing water patterns, including a shift in the timing of streamflow	
• Decreased available hydropower capacity during the summer	• Potential for higher electricity costs
Increasing risk of wildfire and duration of wildfire season	
• Increased risk of damage to power transmission and distribution infrastructure	• Greater likelihood of power outages and damage to energy infrastructure serving TTLs

Energy End-Use

Potential climate change impacts:

- Increased electricity demand for cooling in the summer
- Decreased energy demand for propane, fuel oil, wood, electricity, and natural gas for space heating in the winter

Residents of the Northwest use electricity for air conditioning, although regional summers are relatively mild, so air conditioning use is below the national average (EIA 2013c). Many households in the Northwest, including tribal residents, also rely on electricity for heat during cold winters (see Table 3-3). TTLs such as the Yakama Nation and Coeur d'Alene Reservations located in the Cascade region and interior portions of the Northwest currently experience severe cold during the winter; temperatures can drop well below 0°F (NOAA 2013b). Wood and tank gas (such as propane) are also commonly used heating fuels among regional tribes (U.S. Census Bureau 2003). As temperatures increase, energy demand for cooling is projected to increase while demand for heating decreases (NOAA 2013b), which may result in an increase in summer electricity bills and a decrease in winter heating bills.

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compared to historical norms. Climate change impacts in the Northwest include increasing heavy rainfall events, warmer air and water temperatures, changing precipitation and snowmelt patterns, and increasing wildfire. "Potential extreme weather impacts" refer to weather events that threaten tribal energy systems, but quantifying the effects of climate change on the frequency, duration, or severity of these events is still an area of active research. Such extreme weather impacts include convective storms and winter storms. In this report, potential extreme weather impacts are not associated with a trend but rather as a continued threat to tribal energy systems.

Table 3-3. Primary household heating fuel for selected Native American communities in the Northwest.

TTL	Primary Heating Fuel (Percentage of Households Using Fuel)
Colville Reservation, WA	Wood (56%)
Fort Hall Reservation, ID	Electricity (51%)
Nez Perce Reservation, ID	Wood (48%), electricity (45%)
Warm Springs Reservation, OR	Electricity (58%)
Yakama Reservation, WA	Electricity (73%)

Source: U.S. Census Bureau 1995

Hotter summer temperatures are likely to increase the demand for cooling energy, such as air conditioning and refrigeration (DOE 2013a, NOAA 2013b). Increases in summer temperatures are likely to be modest for TTLs near the coast, such as the Quinault and Makah Reservations, while TTLs located further inland, including the Duck Valley and Fort Hall Reservations, may experience average summer temperatures as much as 6°F higher by mid-century (NOAA 2013b). As a result, the annual average number of cooling degree days (CDDs), which is used to measure cooling energy demand, is projected to increase by 89% on average in the Northwest by mid-century (2041–2070, compared to 1971–2000) (USGCRP 2014). Across the region, TTLs are projected to see 100–400 more CDDs per year, and the largest changes in CDDs (300–400 CDDs) occur near TTLs in the western portions of Washington and Oregon and on the Duck Valley Reservation in southern Idaho (Figure 3-2) (NOAA 2013b).[9]

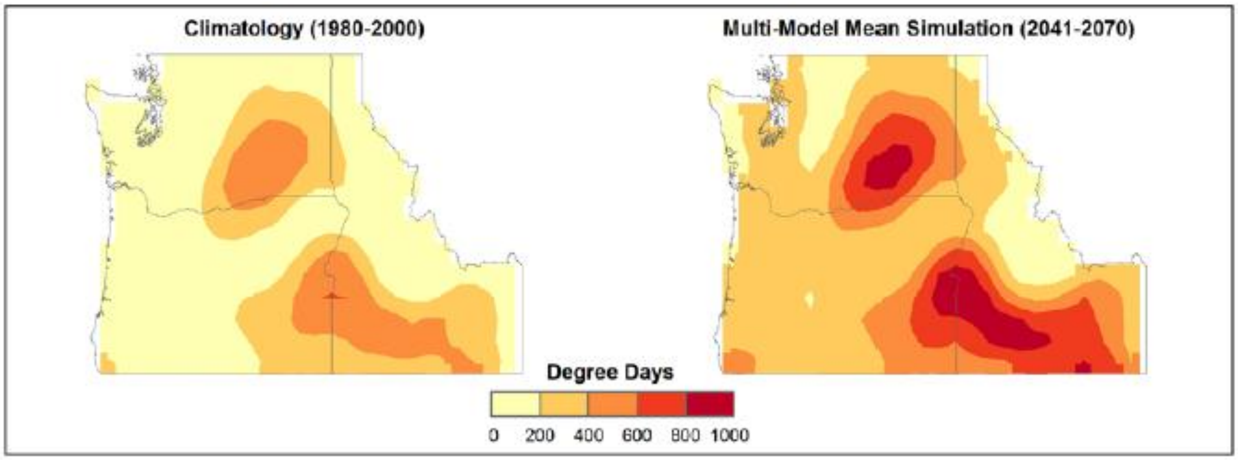

Figure 3-2. Climate change is projected to increase the number of CDDs in the Northwest under a high emissions scenario, increasing the demand for cooling energy.
Source: NOAA 2013b

For many TTLs, an increase in CDDs may result in higher air conditioning use, higher electricity bills, and an increase in peak demand for electric power (Auffhammer 2011, DOE 2013a). Increasing temperatures can also drive the installation of air conditioner units in buildings where they were previously absent (Auffhammer 2011), a trend that could further increase costs and peak electricity demand.

In most of the Northwest, the greatest demand for electricity occurs during the winter season, in part because of the widespread use of electricity for space heating (EIA 2013a, NPCC 2010). However, increasing summer electricity use for air conditioning is expected to contribute to a narrowing of the gap between summer and winter peak electricity demand, with the two peaks expected to be equal by 2030 (NPCC 2010). Beyond that time period, as

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[9] A CDD is calculated from the sum of the daily variation of temperature above a baseline temperature, typically 65°F. This calculation is a proxy for the energy needed to cool a space.

temperatures continue to rise, further increases in cooling demand could result in a shift of peak demand from winter to summer. Such a shift may create additional stress on electric power infrastructure, as it will coincide with the region's reduced hydropower generation capacity and heightened wildfire risks to transmission and distribution infrastructure (USGCRP 2014).

Warmer winter temperatures are likely to reduce demand for heating (DOE 2013a, NOAA 2013b). Average winter temperatures are projected to increase by 3.0°F–5.0°F by mid-century under a high emissions scenario, and the average number of heating degree days (HDDs) per year is projected to decrease by 15% (NOAA 2013b, USGCRP 2014). The number of HDDs may decrease by 1,000–1,400 HDDs in the areas of the Northwest where TTLs are located.[10] TTLs in the eastern portion of the region, such as the Fort Hall and Coeur d'Alene Reservations, are expected to experience the largest decrease in HDDs, while TTLs such as the Yakama Nation and Quinault Reservations may experience more modest decreases (NOAA 2013b). The change in HDDs corresponds to a proportional reduction in demand for heating energy. Warmer temperatures will mean that tribal residents and businesses may see lower heating energy bills for heating fuels, depending in part on the cost of fuel.

Electricity Supply

ELECTRIC GRID

Potential extreme weather impacts:

- Storm damage to grid infrastructure located on or connected to TTLs

Potential climate change impacts:

- Increased risk of wildfire or heat damage to the grid infrastructure located on or connected to TTLs
- Decreased capacity and efficiency of transmission lines from increasing temperatures

The Yakama Reservation and Cow Creek Reservation own and operate tribal utility authorities—Yakama Power and the Umpqua Indian Utility Cooperative (WAPA 2010)—but all TTLs in the region rely on the efficient operation of transmission and distribution infrastructure to receive electricity. This infrastructure is increasingly vulnerable to damage and disruption as temperatures and wildfires in the region increase (DOE 2013a, USGCRP 2014), and as a result, customers on TTLs may experience more power outages. Tribal residents and businesses may also face an increase in the cost of electricity as utilities face increasing climate change-related hazards and may need to invest in additional capacity, maintenance, and repairs to ensure reliable service.

More wildfires increase the risk of power outages (DOE 2013a). Changes in precipitation and temperature projected for the Northwest are expected to contribute to a much higher incidence of wildfire in the Northwest, possibly increasing the burn area by more than 400% in some locations (USGCRP 2014) (see Figure A-9 in Appendix A). TTLs may become more vulnerable to power outages that result when fire destroys utility poles and power lines; this is especially true of those TTLs located near forested areas, such as the Umatilla and Spokane Reservations. For example, the Duck Valley Indian Reservation lost power for eight days in 2007 when wildfires destroyed grid infrastructure that supplies the reservation with electricity; transmission lines were damaged, and utilities estimated that as many as 200 power poles were destroyed (AP 2007). The Colville Reservation in northeastern Washington, which contains six major transmission lines, has been threatened by wildfires several times in the past decade. (For more information, see the sidebar titled "Increased Wildfire Risk to Electricity Infrastructure on TTLs: Colville Reservation.") Based on projections for wildfire damage in the Northwest, the area within and surrounding the Colville Reservation will face a three-fold increase in the extent of wildfire damage as a

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[10] An HDD is calculated from the sum of the daily variation of temperature below a baseline temperature, typically 65°F. This calculation is a proxy for the energy needed to heat a space.

Tribal utility authorities in the Northwest

Umpqua Indian Utility Cooperative

The Cow Creek Band of Umpqua Tribe of Indians became the first tribe in the Northwest to own and operate an electric utility with the formation of the Umpqua Indian Utility Cooperative in 2001 (WAPA 2010). The cooperative purchases about 2.5 MW of power from the Bonneville Power Administration and supplies electricity to the Truck and Travel Center and the Seven Feathers Casino and Hotel complex on the Cow Creek Reservation (WAPA 2010).

Yakama Power

The Confederated Tribes and Bands of the Yakama Indian Nation created Yakama Power as a way to purchase low-cost power from the Bonneville Power Administration and reduce electricity costs on the Yakama Reservation (WAPA 2010). The utility began serving retail customers in 2006, and served a peak load of 12.1 MW in 2013 (BPA 2014). The Wapato Irrigation Project, also owned by Yakama Power, is a system of 1,100 miles of canals, control systems, and transformers with a 34.5 kV transmission line (WAPA 2010). This project includes three hydroelectric generators with a combined capacity of 4.2 MW: Drop 2 and Drop 3 (Yakama Power 2015); Yakama Power has invested in repairs to these generators and hopes to reinvest revenues from selling power generated using Drop 2 and Drop 3 in the Wapato Irrigation Project (Yakama Power 2015).

result of climate change (USGCRP 2014). By 2080, wildfires in the Umatilla National Forest, located near the Umatilla Reservation in northeastern Oregon, are projected to see a six-fold increase in the area burned (USGCRP 2014). Even outside the immediate area of a wildfire, the associated soot, heat, and smoke can reduce transmission line capacity and foul equipment, causing disruptions to service or even outages (DOE 2013a).

Hotter temperatures may reduce transmission capacity and efficiency and increase the risk of damage to grid equipment (Bérubé et al. 2007, DOE 2013a). Increasing temperatures in the Northwest will affect power lines in several ways. High temperatures increase the risk of physical damage to some electric grid infrastructure (DOE 2013a), and operators may reduce electricity transmission on hot days to protect infrastructure from heat-related damage such as excessive conductor sag and to prevent possible wildfire ignition (Sathaye et al. 2012, USBR 2000). Transformers can reach destructive temperatures during emergency overloading, and higher ambient temperatures increase this risk. As heated power lines expand and sag, they risk damage from contact with trees and other objects or other power lines (DOE 2013a, Hashmi et al. 2013).

Average annual temperatures in the region are projected to increase by up to 8.5°F by the end of the century, and a recent study in California found that a projected 9°F increase in temperature could reduce transmission line capacity 7%–8% (NOAA 2013b, Sathaye et al. 2012). Increasing temperature also decreases efficiency of transmission and distribution infrastructure; the same study found that a 9°F increase in temperature could increase total loss factors for transmission and distribution grids by 1.5%–2.5% (Sathaye et al. 2012). Transmission and distribution losses, which increase as efficiency falls, are typically greatest during peak demand periods (Sathaye et al. 2012), and the maximum power available to customers on TTLs may be reduced during extreme heat waves, when demand for cooling is highest. A recent study found that Yakama Power, the electric utility owned by the Yakama Nation, has more than 60 miles of power lines that may require upgrades as increasing temperatures significantly reduce transmission capacity and efficiency (Wiseman 2011).

Increased wildfire risk to electricity infrastructure on TTLs: Colville Reservation

The Colville Reservation contains two 230 kV transmission lines and four 115 kV transmission lines that deliver power from nearby hydroelectric generators, an important source of power to the Colville Confederation of Tribes. An extensive network of distribution lines delivers power to residents on the reservation (Figure 3-3).

In 2008, wildfires burned more than 34 square miles of the Colville Reservation in northeastern Washington (DOE 2011, KHQ 2008). In 2014, the Devil's Elbow Complex Fire burned more than 28 square miles on the reservation, threatened infrastructure, and forced evacuations (KHQ 2014). This area of the Northwest is projected to see a threefold increase in the area burned by wildfire by 2080 under a 2.2°F global temperature increase (USGCRP 2014).

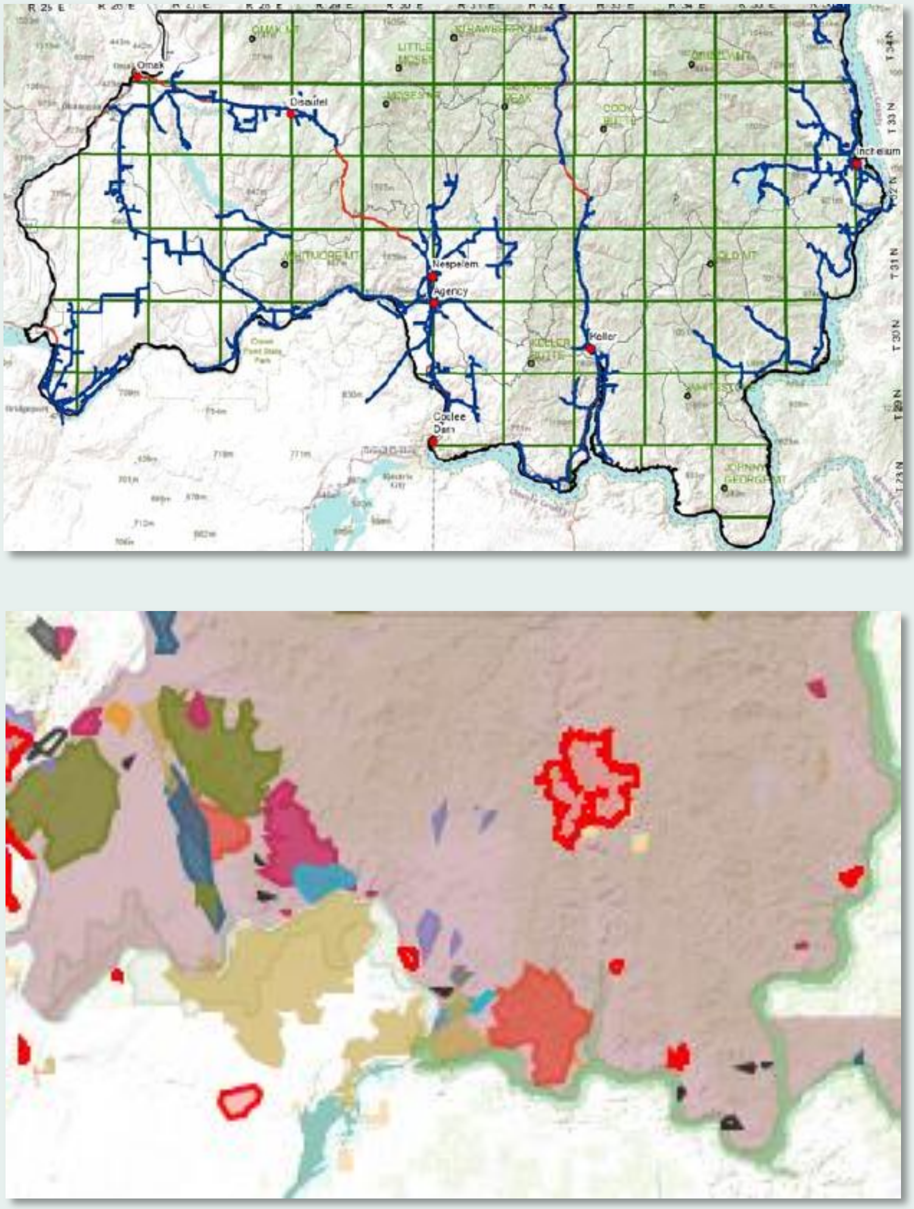

Figure 3-3. Above: Power transmission and distribution lines on the Colville Reservation (indicated in dark blue). Below: Locations of 2008 and 2014 wildfires on the Colville Reservation (indicated by pink and red borders, respectively).
Sources: DOE 2011, NWCC 2015

Severe storms can damage electric grid infrastructure (DOE 2015a). High winds, lightning, and tornadoes associated with severe convective storms and heavy snowfall, high winds, and ice during winter storms can cripple electric grid infrastructure. Although the Northwest has the lowest frequency of convective storm activity in the lower 48 states, such storms do occur, and associated high winds and tornadoes can blow trees or tree branches into power lines, causing the lines to break and wooden poles to snap (NOAA 2013b). High winds can also blow power lines into branches, towers, or other power lines, which can short out lines, and lightning can damage electric grid infrastructure if it strikes lines or adjacent trees. During winter storms, ice accretion on power lines can cause lines to sag and snap wooden poles; even if transmission lines are not coated in thick ice, they may be damaged if they begin to gallop[11] as a result if high winds (USACE 2014). Alternatively, heavy snow can cause tree branches to break and fall on power lines, which may overload poles and cause them to break (Abi-Samra et al. 2014, USACE 2014). This may cause significant damage if failure of a single pole initiates a line of pole failures (USACE 2014).

Storm damage to electric grid infrastructure on the Colville Indian Reservation

The Colville Indian Reservation was hit with a severe wind storm on July 20, 2012, when two storm cells collided on the south end of the reservation. The storm produced microbursts up to 100 mph and caused pockets of intense damage in the area. Power was knocked out when the storm knocked down more than 900 miles of power lines and broke 250 power poles (USDA 2015).

Figure 3-4. A wind storm on July 20, 2012, caused severe damage at the Colville Indian Reservation.
Source: USDA 2015

ELECTRIC POWER GENERATION

Potential extreme weather impacts:

- Storm damage to power plants

Potential climate change impacts:

- Decreased summer hydropower capacity due to earlier snowmelt and reduced streamflow in the summer
- Decreased efficiency and available generation capacity from thermoelectric power plants due to higher air and water temperatures
- Increased risk of flood damage to power plants due to increasing extreme precipitation events and sea level rise

Climate change may have a significant impact on the Northwest power generation infrastructure that provides electricity to TTLs. During the summer, the energy sector may experience reduced power production; hydroelectric plants are challenged by lower streamflow, and high temperatures reduce the efficiency of thermoelectric plants (DOE 2013a). If changing water availability limits hydroelectric power generation, tribal residents and businesses may see an increase in the cost of electricity, as utilities may need to rely on more expensive thermoelectric power generation to meet demand for power. For example, a previous study on the 2005 drought in the Pacific Northwest

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[11] Power lines "gallop" when ice builds up on the power line, causing it to sway and buck in the wind. In high winds, or with sufficient ice buildup, galloping power lines can be very dangerous, as they may eventually fail, snapping power poles or causing lines to fall.

found that decreasing hydropower production during a drought could result in a short-term 4%–7% increase in electricity costs for consumers (CTED 2005). If climate change leads to an increase in demand for electricity and reduced production from hydroelectric and thermoelectric power plants during the summer, utilities may need to invest in equipment upgrades and additional generation capacity to ensure reliable service, which may also lead to rate increases for consumers.

Tribal governments are invested in hydropower

The Confederated Tribes of the Warm Springs Reservation of Oregon (CTWS) and Portland General Electric jointly own the 338 MW Round Butte Dam and 108 MW Pelton Hydroelectric Dam on the Deschutes River, shown in Figure 3-5 (PGE 2006). Through Warm Springs Power and Water Enterprises, CTWS also retains full ownership of the 19 MW Reregulating Dam (Figure 3-5), which is used to meet peak power demands by balancing river flows (DOE 2011). Another TTL in the Northwest, the Colville Reservation, holds an ownership stake in the Wells Dam and Grand Coulee Dam, which are located on reservation lands (DOE 2011). The Chief Joseph Dam is also located on Colville Reservation lands.

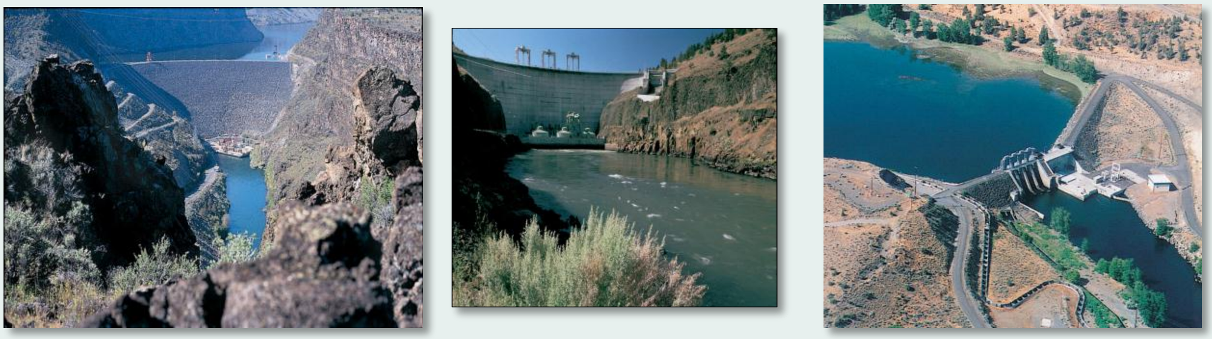

Figure 3-5. CTWS has ownership stake in the Round Butte (left) and Pelton Hydroelectric (center) Dams and retains full ownership over the Reregulating Dam (right).
Source: PGE 2015

In addition to providing electricity to tribal residents and businesses living on the Yakama Reservation, Yakama Power owns and operates three small hydropower generators as part of its operation of the Wapato Irrigation Project, producing 4.2 MW (Yakama Power 2015).

Changes in the timing of streamflow resulting from earlier snowmelt may reduce hydropower generation capacity in the summer (BPA 2011, USGCRP 2014). Hydropower is an abundant resource in the Northwest, producing 72% of the region's power output (Figure 3-6) (EIA 2013b). The Northwest is currently an exporter of power during the summer, typically sending power south to meet peak demand in California and southwestern markets (EIA 2011a).

Increasing temperatures due to climate change are projected to result in a significant shift in the timing of peak streamflow, with higher water flows occurring earlier in the year and lower flows in the summertime. Without changes to the capacity of

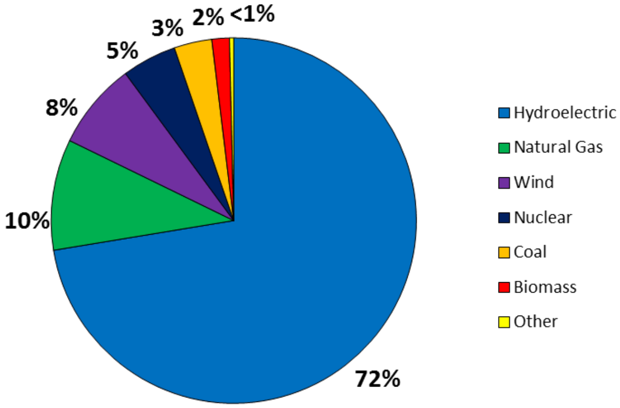

Figure 3-6. Generation in the Northwest is dominated by hydroelectric power.
Source: EIA 2013b

hydroelectric dams and reservoirs to store excess water available earlier in the year, the reduction in summer flows may reduce the capacity of the region's network of hydropower generators to produce electricity during high demand periods. One study indicates that summer runoff in the region may decrease by 20% or more by the 2080s, decreasing generation even as demand for electricity is projected to increase in response to increasing air temperatures (DOE 2013b, NOAA 2013b, USGCRP 2014). Reductions in hydropower generation may lead to increases in the cost of electricity for tribal residents and businesses as utilities may need to rely increasingly on thermoelectric power generation. Additionally, hydropower operators that generate revenue by selling surplus power to the market may see a reduction in this revenue source with increasing streamflow volatility (CTED 2005, DOE 2013b). This could have a significant impact on the several tribal governments in the region that have ownership stakes in hydropower dams, including the Grand Coulee Dam, the largest hydroelectric facility in the United States (see sidebar "Tribal governments are invested in hydropower").

Increasing air and water temperatures reduce the efficiency and available capacity of thermoelectric power plants (DOE 2013a). The Northwest produces 20% of net electricity generation from power plants using natural gas, nuclear fuel, coal, biomass, or geothermal energy ("thermoelectric" power plants), with approximately half of that power provided by power plants burning natural gas (EIA 2013b). Higher air temperatures and surface water temperatures reduce the thermal efficiency of power generation and therefore reduce the amount of power that can be generated from power plants on hot days (DOE 2013a).

As both temperatures and the number of extremely hot days increase throughout the Northwest, power plants serving TTLs may face a decrease in available generating capacity (DOE 2013a, NOAA 2013b). In the summer, this reduction in available capacity may place additional stress on a regional power system that may already be facing summertime capacity limitations from reduced hydropower resources, grid disruptions from wildfires, and increasing energy demand for air conditioning.

Storms—including convective storms and increasing heavy precipitation events—and sea level rise threaten flooding of low-lying power plants (DOE 2013a). The Northwest is projected to experience an increase in the frequency of extreme precipitation events as a result of climate change (NOAA 2013b). Because inland power plants tend to be located in low-lying areas near rivers and floodplains (DOE 2013a), power plants serving TTLs in the Northwest may become more vulnerable to critical disruptions in power production and operation as a result of inundation from flooding. Most coastal power plants in the Northwest are sufficiently elevated not to be at risk from sea level rise, but four power plants in the Puget Sound—where many TTLs, including the Tulalip Reservation, are located—are less than four feet above sea level. These plants may be increasingly vulnerable to damage from wave action or storm surge due to sea level rise (Climate Central 2014, USGCRP 2014).

Vulnerabilities of biomass-powered thermoelectric generation to climate change

The Yakama Nation and Coeur d'Alene Reservations are among the top reservations in the United States in terms of potential for biomass-powered electric generation, and the Yakama Nation is currently investigating the development of woody biomass power generation in partnership with Yakama Forest Products (Yakama Power 2015). However, TTLs currently generating electricity from biomass (particularly from wood) may experience shortfalls in supply of fuel from local biomass resources as increasing air and water temperatures and potential drought stress and insect outbreaks may affect biomass production (USGCRP 2014). Increasing temperatures may have an impact on the feasibility of future biomass development on TTLs interested in developing renewable energy generation potential. The impact on forests from wildfire could further reduce the availability of wood to the lumber industry, a major contributor to the wood waste used for biomass electricity generation in the region (EIA 2014c, USGCRP 2014).

Fuel Supply

FUEL TRANSPORT

Potential extreme weather impacts:

- Storm damage to transportation infrastructure and possible disruptions in fuel supply

Potential climate change impacts:

- Increased risk of disruption of fuel supply, including gasoline, diesel, fuel oil, and propane, as a result of flooding caused by extremely heavy precipitation and sea level rise

Since TTLs in the Northwest do not produce oil and gas (EIA 2014c), their populations depend on transport of fuels by modes such as rail, barge, pipeline, and truck. Most petroleum is imported into the region by the Olympic, Yellowstone, or Chevron pipelines (EIA 2014c), but a large share of the region’s gasoline is also transported by truck and by barge (Figure 3-7) (WDOC 2013). Coal used to fuel electric power plants is typically brought into the region by rail from the Powder River Basin (EIA 2014c). Residents of the region receive natural gas by pipeline, primarily from Canada, the Southwest, or the Great Plains (EIA 2014c).

Storms, including convective storms, winter storms, and increasing heavy precipitation events, may damage and disrupt fuel supply infrastructure (DOE 2013a). The greatest changes in precipitation in the Northwest are projected to occur to the east of the Cascade Range. For TTLs in this area, such as the Duck Valley Reservation in Idaho and the Umatilla Reservation in eastern Oregon, extreme precipitation events are projected to increase by 20%–40% by mid-century under a high emissions scenario (NOAA 2013b). As climate change increases the potential for flooding and inundation of low-lying infrastructure, there is a correlated increase in the threat to the network of infrastructure used to supply TTLs with fuels such as gasoline, diesel, natural gas, and propane. Because water flow is heavily managed in some river basins through the use of dams for hydropower, flood control, and environmental management (USACE 2015, USGCRP 2014), the degree to which increasing precipitation and extreme precipitation will cause increased flooding to infrastructure serving TTLs may vary.

Without increased flood control measures, increasing extreme precipitation in the Northwest could have the potential to affect multiple transport modes supplying fuels to TTLs. The supply lines of gasoline and other important fuels such as diesel and propane could be disrupted by increased flooding. When highways and roads are flooded, delivery to TTLs of critical fuel supplies such as gasoline, diesel, propane, and fuel oil may be delayed (DOT 2006). Flooding can also impede the safe navigation of barges, a situation that can result in disruption to the motor fuel supply at inland locations in the Northwest.

Severe convective storms can further damage energy infrastructure through heavy winds and tornadoes, which can damage railcars, rail stations, roadways, and, in case of strong tornadoes, pipelines (CCSP 2008, NOAA 2015b, Rossetti 2007). Lightning during these storms can interfere with rail and road signaling equipment, disrupting transport of fuels (CCSP 2008, Rossetti 2007).

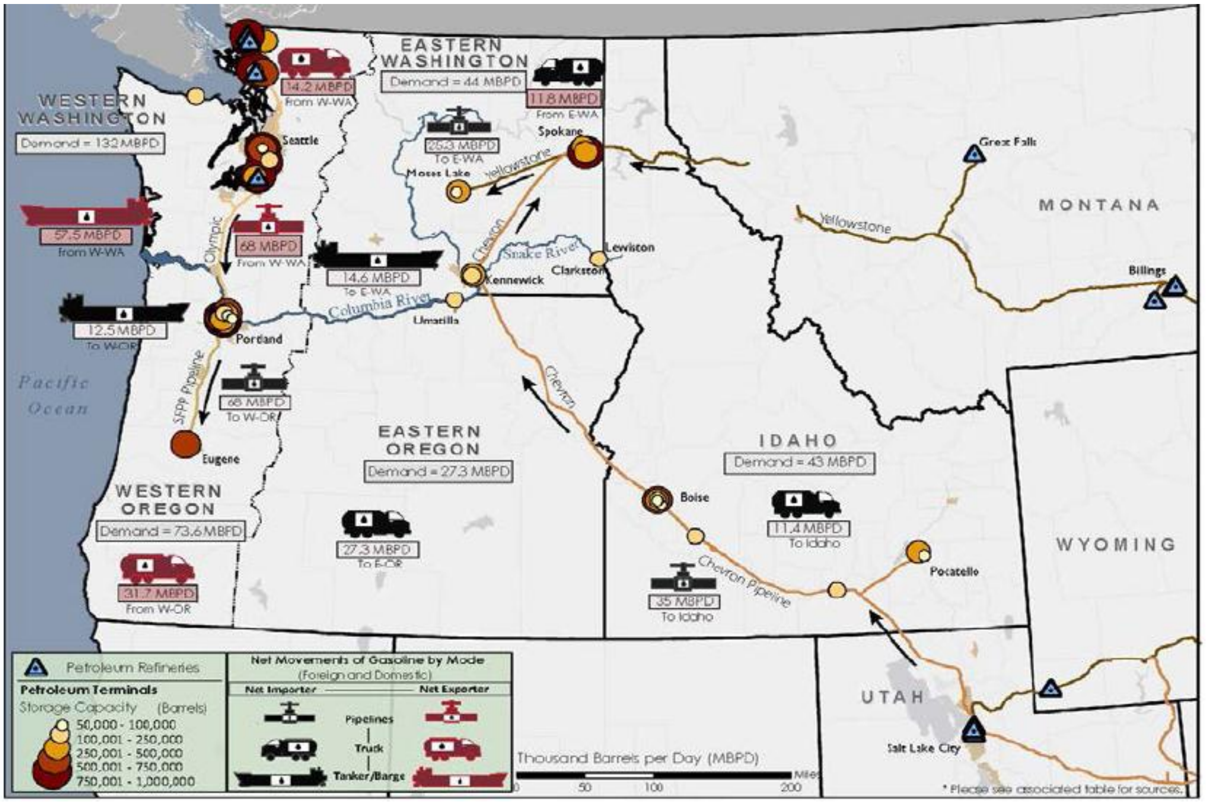

Figure 3-7. Gasoline in the Northwest is principally transported by pipeline, truck, and waterway.
Source: WDOC 2013

Transportation of fuels to TTLs may also be disrupted by heavy snowfall and extreme cold during winter storms. Blizzard conditions can cause roads to close, and trucks may reduce speeds on roads that remain open. Rail transport may be disrupted if snow blows onto rail switches. Extreme cold can cause port infrastructure and vessel superstructures to freeze over and may cause ice formation on waterways, disrupting marine and inland transport of fuels (DHS 2014).

Flood damage to roads on the Quinault Reservation

In January 2015, two days of heavy rain caused severe damage to road infrastructure on the Quinault Reservation in Washington. During the storm, parts of the southwest Olympic Mountains, where the Quinault Reservation is located, got up to 13 inches of rain, and 12 rivers in western Washington flooded. The storm caused flooding, landslides, culvert failures, and washouts, closing major roads leading into the Reservation. A main access road, the Moclips Highway 109 Bridge, was washed out when the Moclips River flooded (ICTMN 2015). State route 109 was closed because of standing water and debris, and U.S. Highway 101 was closed because of flooding and washouts (ICTMN 2015, Walker 2015).

Chapter 4: SOUTHWEST TRIBAL LANDS

Key Climate Change and Extreme Weather Hazards Affecting Tribal Trust Land Energy Systems in the Southwest

- **Rising temperatures:** Higher temperatures and increasing heat waves are expected to increase electricity demand for cooling and may increase electricity bills. High temperatures may also disrupt electric grid and generation infrastructure and lead to brownouts or blackouts during extreme heat events.
- **Decreasing water availability:** Decreasing water availability could reduce available generation capacity which, if not offset by additional capacity or demand reduction measures, may result in power outages.
- **Increasing wildfire:** Hotter and drier conditions are expected to contribute to increasing frequency, severity, and duration of wildfires that may damage electric grid infrastructure serving TTLs, leading to power outages and increased direct costs of repair and maintenance for tribes that own and operate electric grid infrastructure.

OVERVIEW OF SOUTHWEST REGION

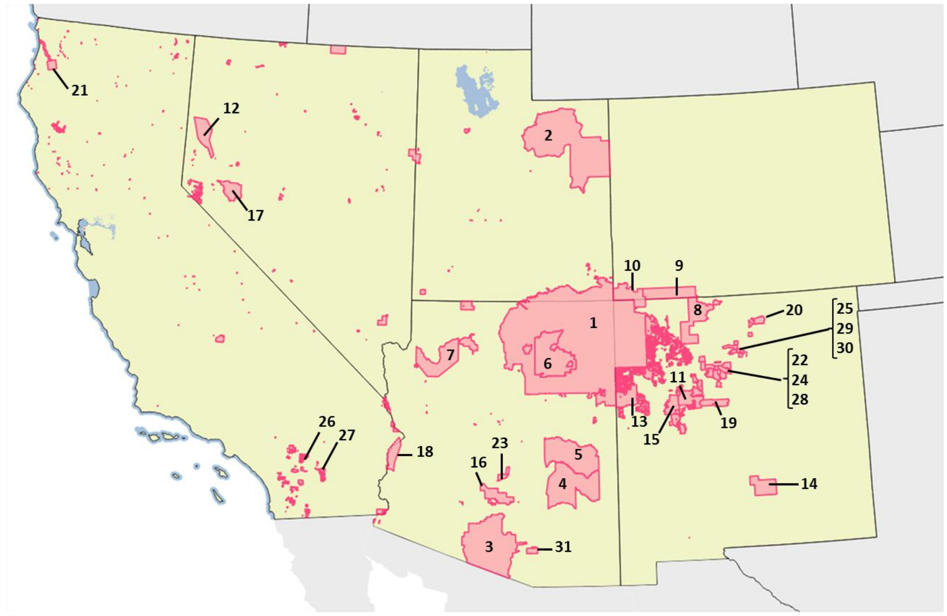

Figure 4-1. TTLs located in the Southwest region.
Large reservations have been numbered in the figure above; see Table 4-1 for the corresponding trust land name.
Graphic source: Energetics 2015; Data source: U.S. Census Bureau 2015

There are 174 tribal trust lands (TTLs) spread throughout the Southwest region that are home to more than 350,000 residents (See Figure 4-1 and Table 4-1) (U.S. Census Bureau 2010a). This includes the largest TTL in the United States, both by size and population: the Navajo Nation in Arizona, New Mexico, and Utah with 173,667 residents living on 24,156 square miles (U.S. Census Bureau 2010a, U.S. Census Bureau 2010b). TTLs in the Southwest contain extensive energy infrastructure, including two major electric generating stations and two operating coal mines on leased land on the Navajo Nation (Table 4-2), six tribal utility authorities, oil and gas production areas, and significant renewable energy resources (EIA 2014c).

Table 4-1. TTLs in the Southwest.

States with TTLs:	Arizona, California, Colorado, Nevada, New Mexico, Utah
Number of TTLs:	174
Population:	352,000
Area (square miles):	56,600

Large TTLs*

Trust Land Name	Population**	Total Area (sq. miles)
1) Navajo Nation Reservation (AZ/NM/UT)	173,667	24,156
2) Uintah and Ouray Reservation (UT)	24,369	6,825
3) Tohono O'odham Nation Reservation (AZ)	10,201	4,454
4) San Carlos Reservation (AZ)	10,068	2,927
5) Fort Apache Reservation (AZ)	13,409	2,631
6) Hopi Reservation (AZ)	7,185	2,533
7) Hualapai Indian Reservation (AZ)	1,335	1,605
8) Jicarilla Apache Nation Reservation (NM)	3,254	1,374
9) Southern Ute Reservation (CO)	12,153	1,063
10) Ute Mountain Reservation (CO/NM/UT)	1,742	901
11) Laguna Pueblo (NM)	4,043	785
12) Pyramid Lake Paiute Reservation (NV)	1,660	730
13) Zuni Reservation (AZ/NM)	7,891	726
14) Mescalero Reservation (NM)	3,613	719
15) Acoma Pueblo (NM)	3,011	596
16) Gila River Indian Reservation (AZ)	11,712	585
17) Walker River Reservation (NV)	746	531
18) Colorado River Indian Reservation (AZ/CA)	8,764	464
19) Isleta Pueblo (NM)	3,400	331
20) Taos Pueblo (NM)	4,384	156
21) Hoopa Valley Reservation (CA)	3,041	142
22) Santo Domingo Pueblo (NM)	3,255	106
23) Salt River Reservation (AZ)	6,289	85
24) San Felipe Pueblo (NM)	3,563	80
25) Santa Clara Pueblo (NM)	11,021	77
26) Agua Caliente Indian Reservation (CA)	24,781	54
27) Torres-Martinez Reservation (CA)	5,594	49
28) Sandia Pueblo (NM)	4,965	39
29) Ohkay Owingeh (NM)	6,309	27
30) Pueblo of Pojoaque (NM)	3,316	21
31) Pascua Pueblo Yaqui Reservation (AZ)	3,484	2

*Note: "Large" tribal trust lands are those lands >300 square miles in area and/or with >3,000 Native American residents

**Note: The population of TTLs refers to the number of residents on each TTL according to the 2010 Census, not the number of enrolled members of each tribe.
Sources: U.S. Census Bureau 2010a, U.S. Census Bureau 2010b

Electricity Supply

Six TTLs in the Southwest own and operate their own electric power utilities: the Navajo Nation, Fort Mojave Reservation, Maricopa (Ak Chin) Indian Reservation, Tohono O'odham Nation, Gila River Indian Reservation, and Jicarilla Apache Nation. There are almost 4,500 MW of electric generation capacity on TTLs in the region (EIA 2014c, WAPA 2010). However, aside from small renewable projects, TTLs are dependent on power that is generated by major power plants offsite or on lands leased to non-tribally affiliated power companies. Power is transmitted long distances to users by high-voltage transmission networks to low-voltage distribution networks, some of which are owned and operated by tribal utility authorities. Large power transformers reduce the voltage, and distribution lines deliver power to tribal residents and businesses.

Fuel Supply

There are several tribes on TTLs in the Southwest that own and operate energy companies as well as tribes that lease lands to energy companies to produce oil, natural gas, and coal resources. The Navajo Nation has coal, natural gas, and oil interests in the region, and the Southern Ute Indian Tribe on the Southern Ute Reservation has vast onshore and offshore energy holdings throughout the United States (Minard et al. 2014, Red Willow Production Company 2015).[12] As of 2014, TTLs in the Southwest contained about 415 oil wells, over 700 gas wells, and 2 coal mines (EIA 2014c).

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[12] For more information on TTL energy holdings, see sidebar: "Vulnerability of Southwestern TTL energy holdings to climate change."

Tribal residents and energy companies operating on TTLs, including those owned by TTLs, rely on several modes of transport for the efficient delivery of fuels. Crude oil is transported throughout the region by rail and pipeline, including the Navajo Nation's Running Horse Pipeline (EIA 2014c, NNOGC 2015). Petroleum products such as motor gasoline and fuel oil are distributed primarily by pipeline (EIA 2014c) and truck to residents. Coal extracted on Navajo Nation lands and brought into the region for electricity generation is transported by rail and truck (EIA 2014c).

Table 4-2. Major Energy Infrastructure on the Navajo Nation.

Kayenta Mine	The Kayenta Mine, operated by Peabody Energy, is the only operating coal mine in Arizona (EIA 2014c, Nania et al. 2014). The mine produces over 8 million short tons of coal annually, placing it among the 30 largest coal mines in the United States (EIA 2014c). It supplies coal to the Navajo Generating Station (Nania et al. 2014).
Navajo Mine	The Navajo Mine in New Mexico is owned and operated by the Navajo Nation (Nania et al. 2014). It produces almost 8 million short tons of coal annually and supplies coal to the Four Corners Generating Station (EIA 2014c, Nania et al. 2014).
Navajo Generating Station (NGS)	The NGS is the second largest power plant in Arizona, with a nameplate capacity of 2,250 MW (EIA 2014c, Nania et al. 2014). The Navajo Nation receives roughly $25 million in royalties and lease fees from NGS annually (Nania et al. 2014). The coal-fired plant provides power to the Central Arizona Project, a major irrigation system in the Southwest (Nania et al. 2014).
Four Corners Generating Station	The Four Corners Generating Station is one of the largest power plants in New Mexico, with a nameplate capacity of 2,040 MW (EIA 2014c). The coal-fired plant is located on lands leased from the Navajo Nation and is the major consumer of coal from the Navajo Mine (EIA 2014c, Nania et al. 2014).
Running Horse Pipeline	The Navajo Nation-owned Navajo Nation Oil and Gas Company owns and operates Running Horse Pipeline, which transports crude oil through Utah, Colorado, and New Mexico (NNOGC 2015).

Sources: EIA 2014c, Nania et al. 2014, NNOCG 2015

IMPLICATIONS FOR ENERGY SECTOR

Electric grid and electricity generation infrastructure and fuel production and transportation serving TTLs in the Southwest may be vulnerable to severe storms as well as increasing temperatures, decreasing water availability, and increasing wildfire due to climate change, as shown in Table 4-3.[13] TTLs in the region are also projected to experience significant increases in cooling energy demand with increasing temperatures due to climate change.

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[13] This report describes vulnerabilities of tribal energy systems related to both climate change and extreme weather. "Potential climate change impacts" refer to threats to tribal energy systems that are projected to change (increase, in most instances) compared to historical norms. Climate change impacts in the Southwest include increasing heavy rainfall events, warmer air and water temperatures, changing water availability, and increasing wildfire. "Potential extreme weather impacts" refer to weather events that threaten tribal energy systems, but quantifying the effects of climate change on the frequency, duration, or severity of these events is still an area of active research. Such extreme weather impacts include convective and winter storms. In this report, potential extreme weather impacts are not associated with a trend but rather as a continued threat to tribal energy systems.

Table 4-3. Examples of extreme weather and climate change impacts that could adversely affect the energy infrastructure serving TTLs in the Southwest.

Extreme weather event or climate change trend affecting energy infrastructure	Potential implications for tribes
Severe storms, including convective and winter storms and increasing frequency of heavy precipitation events	
• Risk of damage to power generation, transmission, and distribution infrastructure	• Power outages and damage to energy infrastructure on TTLs
• Risk of damage and disruption to fuel transportation infrastructure on both land and critical waterways	• Potential disruption in fuel supply
Rising air and water temperatures	
• Increased demand for average and peak cooling energy	• Greater likelihood of power outages and higher electricity bills
• Reduced transmission capacity and efficiency and reduce service life of some electrical equipment	• Greater likelihood of power outages and potential for higher electricity costs
• Decreased available generation capacity of thermoelectric power plants	• Greater likelihood of power outages and potential for higher electricity costs
• Increased risk of damage or disruption to rail transport of fuels	• Greater likelihood of disruption in fuel supply
Changing water availability	
• Decreased efficiency and available generation capacity at thermoelectric power plants	• Potentially higher electricity costs and greater likelihood of power outages
• Seasonal shifts in available hydropower capacity	• Potentially higher electricity costs and potential loss in revenue for TTLs that own hydropower facilities
• Stress on water supplies for energy production on TTLs	• Greater likelihood of increased costs of production
Increasing wildfire	
• Increased risk of damage to electric grid infrastructure	• Greater likelihood of power outages and damage to energy infrastructure on TTLs

Energy End-Use

Potential climate change impacts:

- Increased electricity demand for cooling in the summer
- Decreased energy demand for propane, fuel oil, wood, electricity, and natural gas for space heating in the winter

Residents and businesses in the Southwest region rely on electricity for cooling during hot, dry summers, and some TTLs in the region use electricity as the primary heating fuel during cool winters (Table 4-4). Many households on TTLs in the Southwest, including the Navajo Nation, relied on wood as their primary heating fuel in 1995, but tribal residents also employed tank gas, including propane, and utility gas (U.S. Census Bureau 1995). Increasing air temperatures are projected to decrease demand for heating energy and increase demand for cooling energy (DOE 2013a).

Table 4-4. Primary household heating fuel in selected Native American communities in the Southwest.

TTL	Primary heating fuel (percentage of households using fuel)
Acoma Pueblo, NM	Wood (39%), tank gas, including propane (31%)
Colorado River Reservation, AZ/CA	Electricity (53%)
Fort Apache Reservation	Tank gas, including propane (43%), wood (38%)
Gila River Reservation, AZ	Electricity (31%), tank gas, including propane (28%)
Hoopa Valley Reservation, CA	Wood (82%)
Hopi Reservation, AZ	Coal (37%), wood (33%)
Isleta Pueblo, NM	Utility gas (47%)
Jicarilla Apache Reservation, NM	Utility gas (79%)
Laguna Pueblo, NM	Utility gas (41%), tank gas, including propane (29%)
Mescalero Apache Reservation, NM	Tank gas, including propane (62%)
Navajo Reservation, AZ/NM/UT	Wood (57%)
Papago Reservation, AZ	Wood (38%), electricity (34%)
Pascua Yaqui Reservation, AZ	Utility gas (93%)
Salt River Reservation, AZ	Electricity (64%)
San Carlos Reservation, AZ	Utility gas (34%)
Uintah and Ouray Reservation, UT	Electricity (32%), tank gas, including propane (30%)
Zuni Pueblo, AZ/NM	Wood (72%)

Source: U.S. Census Bureau 1995

Increasing air temperatures, including hotter summers and increasing frequency and duration of heat waves, are likely to increase demand for cooling energy (DOE 2013a, NOAA 2013c). As air temperatures in the Southwest increase, TTLs in the region are projected to experience an average 44% increase in cooling degree days (CDDs), a proxy for cooling energy demand, per year by mid-century (2041–2070, compared to 1971–2000) (NOAA 2013c, USGCRP 2014).[14] Under a high emissions scenario, TTLs throughout the region, including the Hopi Reservation and Agua Caliente Indian Reservation, are projected to see CDDs increase by 200–800 degree days by mid-century as shown in Figure 4-2. CDDs may increase by up to 1,000 degree days per year in the same time period on TTLs in the southwestern sector of the region, including the many TTLs in southern California and the Tohono O’odham Nation in Arizona (NOAA 2013c).

The increase in CDDs and increase in frequency and duration of heat waves is projected to increase both peak and average energy demand (DOE 2013a). A study in California found that increasing temperatures due to climate change could increase average per capita peak energy demand in the state by 12%–24% by the end of the century under a high emissions scenario (compared to 2003–2009) (Sathaye et al. 2012). Air conditioning use in portions of the Southwest is historically high; however, the number of air conditioned residences in portions of the Southwest such as coastal California and Colorado is low relative to the national average. Increased demand for air conditioning with increasing CDDs in these regions may exacerbate increasing demand for cooling. As a result, tribal residents and businesses could experience increases in electricity costs (DOE 2012a).

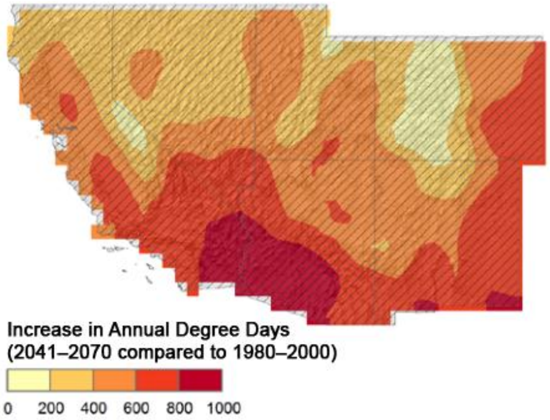

Figure 4-2. The number of CDDs in areas of the Southwest region containing TTLs is projected to increase significantly under a high emissions scenario by mid-century.
Source: NOAA 2013c

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[14] A CDD is calculated from the sum of the daily variation of temperature above a baseline temperature, typically 65°F. This calculation is a proxy for the energy needed to cool a space.

Increasing winter air temperatures are likely to decrease demand for heating energy (DOE 2013a, NOAA 2013c). TTLs in the Southwest are projected to experience a 20% decrease in heating degree days (HDDs) per year by mid-century (2041–2070, compared to 1971–2000) as air temperatures increase due to climate change, leading to a subsequent decrease in demand for heating energy and a decrease in annual winter heating bills (USGCRP 2014).[15] Projections indicate that throughout most of the Southwest, the annual number of HDDs may decrease by at least 900 HDDs by mid-century under a high emissions scenario. TTLs in high elevation areas, such as the Uintah and Ouray Reservation in northeast Utah, may experience 1300–1700 fewer HDDs per year in the same time frame under a high emissions scenario (NOAA 2013c).

Electricity Supply

ELECTRIC GRID

Potential extreme weather impacts:

- Storm damage to grid infrastructure located on or connected to TTLs

Potential climate change impacts:

- Increased risk of wildfire or heat damage to the grid infrastructure located on or connected to TTLs
- Decreased capacity and efficiency of transmission lines from increasing temperatures

Figure 4-3. The Navajo Tribal Utility Authority provides electricity to more than 30,000 customers across the Navajo Nation.
Source: NTIA 2014

Several TTLs in the Southwest own and operate tribal utility authorities that provide electrical service to tribal residents and businesses (Table 4-5). The largest of these utility authorities, the Navajo Tribal Utility Authority, provides electrical services to almost 40,000 customers in the Navajo Nation spanning three states (Figure 4-3) (EIA 2013b). In addition to the Navajo Nation-owned Navajo Tribal Utility Authority, tribal utility authorities in the Southwest include the Aha Macav Power Service on the Fort Mojave Reservation, the Ak-Chin Electric Utility Authority on the Maricopa (Ak Chin) Indian Reservation, the Tohono O’odham Utility Authority on the Tohono O’odham Nation Reservation, the Gila River Indian Community Utility Authority on the Gila River Indian Reservation, and the Jicarilla Power Authority on the Jicarilla Apache Nation Reservation (WAPA 2010). Transmission and distribution infrastructure owned and operated by these tribal utility authorities may be at increased risk of physical damage and disruptions in service due to increased wildfires and extreme heat events due to climate change. Additionally, tribal residents and businesses may face increased risk of power outages due to damage and disruption of onsite and offsite electric grid infrastructure that serves TTLs and may experience an

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[15] An HDD is calculated from the sum of the daily variation of temperature below a baseline temperature, typically 65°F. This calculation is a proxy for the energy needed to heat a space.

increase in the cost of electricity as utilities may need to invest in additional capacity, maintenance, and repairs to ensure reliable service.

Table 4-5. Tribal utility authorities in the Southwest.

Utility Name	Residential Customer Count	Total Customer Count	Summer Peak Demand (MW)	Winter Peak Demand (MW)
Navajo Tribal Utility Authority	36,217	40,544	122	137
Navajo Tribal Utility Authority (AZ)	27,548	30,862	--	--
Navajo Tribal Utility Authority (NM)	8,031	8,958	--	--
Navajo Tribal Utility Authority (UT)	638	724	--	--
Aha Macav Power Service	687	964	11.0	6.0
Ak-Chin Electric Utility Authority	293	429	7.0	4.5

Note: Data are not available for the Jicarilla Power Authority, whose agreement was finalized in April 2014. Data are also not available for the Tohono O'odham Utility Authority or Gila River Indian Community Utility Authority.

Source: EIA 2013b

Increasing frequency of wildfires may increase the risk of physical damage and disruption to electric grid infrastructure (DOE 2013a, Sathaye et al. 2012). Wildfires may directly damage the physical electric grid infrastructure by destroying small overhead lines with wooden poles (Figure 4-4). However, even if wildfires do not directly damage lines, transmission line capacity may be decreased by heat, smoke, and particulate matter. Lines may need to be shut down by operators during a wildfire to prevent leakage currents and arcing between lines or between lines and the ground (Sathaye et al. 2012). For example, during a 1999 wildfire on the Fort Apache Indian Reservation in Arizona, utilities had to cut off power to the TTL when the fire began to burn below power lines (AP 1999).

Figure 4-4. A 2009 wildfire on the Tohono O'odham Nation Reservation in Arizona burned close to power lines on the reservation.
Source: BIA 2012

Hotter temperatures could increase the risk of damage to grid equipment and reduce transmission capacity and efficiency (Bérubé et al. 2007, DOE 2013a). Increasing air temperatures, including longer and hotter heat waves in the summer, can increase the risk of damage to electric grid infrastructure and reduce transmission capacity (Bérubé et al. 2007, DOE 2013a). High temperatures can cause thermal expansion of power lines, and increasing sag in lines increases the risk of outages when lines arc to trees, the ground, or other power lines (DOE 2013a). High temperatures also shorten the lifetime of power transformers by increasing the rate of breakdown of materials (Bérubé et al. 2007).

Figure 4-5. A wildfire burns near power lines on the La Jolla Reservation in California.
Source: EPA 2013b

Increasing temperatures typically cause operators to reduce the current-carrying capacity of transmission lines and capacity of substations to prevent permanent damage to infrastructure (Sathaye et al. 2012). Summer air temperatures in the region are projected to increase by 5.0°F–6.5°F throughout most of the region, and according to a study conducted in California, a 9°F increase in ambient temperature could result in a 7%–8% decrease in transmission line capacity and a 1.5%–2.5% decrease in transmission and distribution grid efficiency (DOE 2013a, Sathaye et al. 2012). Additionally, every 1.8°F increase in ambient temperature results in a 0.7% reduction in transformer capacity (Sathaye et al. 2012). Projections indicate that substation capacity in California could decline 1.0%–3.5% depending on the emissions scenario, and under a high emissions scenario, increasing summer air temperatures could decrease transformer capacity by up to 3.5%–4.6% in some portions of the Southwest by mid-century (NOAA 2013c, Sathaye et al. 2012).

Severe storms may damage electric grid infrastructure (DOE 2015a). Severe convective storms can damage electric grid infrastructure through high winds, lightning, and tornadoes. Lightning can cause power outages if it strikes electric grid equipment or strikes trees and causes branches to fall on power lines. Tornadoes can severely damage and down transmission and distribution lines, and high winds can cause power lines to come into contact with branches, other power lines, or towers and cause lines to short.

Winter storms can also damage electric grid infrastructure through high winds and heavy snow and ice and cause cascading failures throughout transmission systems. During high wind conditions, transmission lines can gallop, which will damage the lines and support structures (USACE 2014). [16] Branches can snap and fall on power lines during heavy snowfall, which can cause poles to snap (Abi-Samra et al. 2014, USACE 2014). During ice storms, ice can coat lines, causing power lines to sag and breaking support poles (USACE 2014).

ELECTRIC POWER GENERATION

Potential climate change impacts:

- Decreased summer hydropower production due to increasing temperatures, evaporation, and decreasing water availability in the summer
- Decreased efficiency and available generation capacity from thermoelectric power plants due to higher air and water temperatures and increased water scarcity

Several TTLs in the Southwest contain major power generation facilities onsite, including the Navajo Generating Station and Four Corners Generating Station on the Navajo Nation Reservation (Figure 4-6), but do not own or operate these facilities (EIA 2014c). These facilities serve as major employers for tribal residents and supply power to the grid that ultimately serves these TTLs (Nania et al. 2014). Thermoelectric power generators are vulnerable to increasing temperatures and decreasing water availability; disruptions in service at these facilities may increase the likelihood of power outages on TTLs, and electricity bills on TTLs may increase if utilities invest in upgrading or building additional infrastructure to increase reliability. Hydroelectric power generators are also vulnerable to decreasing water availability, which may result in a decrease in hydropower generation. Reductions in hydropower generation may result in increasing electricity bills for tribal residents and businesses, as utilities may need to purchase power or rely on more expensive sources of electricity such as natural gas-fired generation to ensure that demand for electricity is met (CEC 2015, Gleick 2015).

TTLs in the Southwest such as the Campo Kumeyaay Nation and Moapa River Indian Reservation have invested in onsite renewable generation to supplement the electricity supplied by the grid. Wind and solar photovoltaics are

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[16] Power lines “gallop” when ice builds up on the power line, causing it to sway and buck in the wind. In high winds, or with sufficient ice buildup, galloping power lines can be very dangerous, as they may eventually fail, snapping power poles or causing lines to fall.

typically less vulnerable to the impacts of climate change, although limited information has been published on the subject (DOE 2013a).[17]

Higher air temperatures and decreasing water availability in summer, along with changing snowmelt runoff timing, may decrease hydropower generation (AEG & Cubed 2005, DOE 2013a). In the Southwest region, seasonal hydropower production is expected to shift as a result of declining snowpack and earlier spring snowmelt, and total hydropower production may decline as average precipitation in the region and stream flow on major rivers decline (NOAA 2013c).

Figure 4-6. The Four Corners Generating Station is located on Navajo Nation lands in New Mexico.
Source: EPA 2013a

About 70% of all hydroelectric generating capacity in the region is located in California and is made up of high-elevation dams that are dependent on seasonal melting snowpack from the Sierra Nevada during the spring and summer (AEG & Cubed 2005, EIA 2013d, EIA 2013e). In the Southwest, winter precipitation is projected to increase, but snowpack may decrease as more precipitation is projected to fall as rain owing to increasing temperatures, particularly in the Sierra Nevada. By the end of the century, California snowpack is projected to fall significantly under a high emissions scenario. Snowmelt is also projected to occur earlier as temperatures increase, which may further reduce summer hydropower generation (USGCRP 2014).

Several large dams in the region, including the Hoover Dam, are located in the Colorado Basin, which is projected to experience increasing frequency, length, and intensity of drought due to climate change (USGCRP 2014). Recent studies estimate that Colorado River flows may decrease by 5%–20% by mid-century because of changing precipitation patterns and increasing temperature. A water-budget analysis in the region found that there is a 50% chance that Lake Mead and Lake Powell will reach minimum power pool levels by 2017 under the current operating status of the reservoir system as a result of climate change. This would affect more than 3,700 MW of generating capacity on the lower Colorado River (Garfin et al. 2013).

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[17] For more information on the vulnerability of renewable generation to climate change impacts, see box "Renewable Generation on TTLs in the Southwest."

Renewable generation on TTLs in the Southwest

Climate change may alter wind patterns, which could have an impact on wind resource potential on TTLs such as the Campo Kumeyaay Reservation. The reservation has developed a large-scale wind project with the ability to power 30,000 homes (Campo Kumeyaay Reservation 2015). However, there is no consensus on how climate change will affect wind resources as projections vary across emissions scenarios and models (DOE 2013a).

Increasing temperatures may reduce generation capacity of solar photovoltaic (PV) systems such as the 250 MW Moapa Southern Paiute Solar Project that is under construction on the Moapa River Indian Reservation (EIA 2014c). This project will deliver energy to Los Angeles and provide enough power to supply more than 93,000 residences (DOE 2014a). For every 1.8°F increase in air temperatures above 77°F, the efficiency of crystalline silicon PV cells decreases by about 0.08% (DOE 2013a). However, new technologies employed in these systems are likely less vulnerable to increasing temperatures (DOE 2013a).

Figure 4-7. Left: The Campo Kumeyaay Nation is developing a large-scale wind project on the Campo Kumeyaay Reservation. Right: The Moapa Southern Paiute Solar Project is a 250 MW on-site, off-grid solar project currently under construction on the Moapa River Indian Reservation in Nevada.

Sources: DOE 2012b (left); DOE 2014a (right)

Hotter air and water temperatures and decreasing surface and groundwater availability in the Southwest decrease thermoelectric power generation capacity and efficiency. The efficiency and capacity of thermoelectric power plants decreases as temperatures increase, and available generation capacity in the region could be severely affected by the combined effects of increasing water temperatures and seasonal drought. According to one study, every 1.8°F increase in temperature above the temperature at which natural gas fired combined capacity plants are designed to operate optimally (typically 15°C or 59°F) can reduce the capacity of the plant by 0.3%–0.5%. As a result, depending on the emissions scenario, natural gas-fired power plants in California could lose 1.7%–4.5% peak capacity by the end of the century as a result of climate change (Sathaye et al. 2012).

Less than one percent of the installed thermoelectric generation capacity uses freshwater sources for water-intensive once-through cooling systems, but those plants that do may be vulnerable to decreasing water availability (UCS 2012). A recent study found that five power plants totaling about 3,300 MW of thermoelectric power generation may be vulnerable to decreasing water availability due to low water intake structures (Garfin et al. 2013). For example, while the water intake structure for the Navajo Generating Station is 220 feet below the surface of Lake Powell, the water intake structure for the Four Corners Generating Station on the Navajo Nation lands is only 5 feet below the surface of the San Juan River (Nania et al. 2014). While many of the power plants in the region use surface water sources, power plants in the region that rely on groundwater for cooling systems may be vulnerable to decreasing water availability as climate change may lead to an increase in water demand from competing users and a decrease in recharge rates for groundwater aquifers (USGCRP 2014).

Energy-water nexus on Navajo Nation lands

Thermoelectric power generation and water delivery on Navajo Nation lands have a highly interdependent relationship that is expected to be affected by climate change. The two major coal-fired power plants on Navajo Nation lands serve as major sources of employment for residents and are vulnerable to increased stress on water supplies due to climate change; these plants also provide power for the Central Arizona Project (CAP) and Salt River Project (SRP), two large water delivery systems in the Southwest (Nania et al. 2014). Once completed, the CAP is expected to provide water from the Colorado River to almost 137,000 acres of tribal lands and 700,000 acres of agricultural land not on TTLs (USBR 2015a). The SRP delivers roughly one million acre-feet of water a year across a 240,000 acre service area (USBR 2015b). The SRP is also a major electricity provider for more than 980,000 retail customers, including residents and businesses on TTLs in Arizona such as the Salt River Pima-Maricopa Indian Community and the Fort McDowell Yavapai Nation Reservation (SRP 2015, WAPA 2012).

As air temperatures and water temperatures increase, these plants would also require more cooling water, which would require even more power for cooling water pumps. Higher water temperatures may also force thermoelectric power plants to curtail operations to avoid exceeding thermal discharge limits in place to protect aquatic systems (DOE 2013a). According to a recent study, twenty power plants in the Southwest that potentially supply electricity to TTLs in the region already discharge water at maximum temperatures over 90°F (Garfin et al. 2013).

Fuel Supply

FUEL TRANSPORT

Potential extreme weather impacts:

- Storm damage to transportation infrastructure and possible disruptions in fuel supply

Potential climate change impacts:

- Increased risk of damage to rail infrastructure and disruptions in service due to increasing temperatures

Residents in the Southwest depend on fuel transportation infrastructure for efficient delivery of fuels, including coal, natural gas, motor gasoline, fuel oil, and propane. Additionally, energy producers in the region, including the Navajo Nation and Southern Ute Reservation, which produce oil and gas (and coal, in the case of the Navajo Nation) in the San Juan Basin, depend on fuel transportation infrastructure to move their product to processing facilities or refineries and eventually to end users. Most of the coal mined and used in the region, including coal from the Navajo Nation, is transported by rail and truck to power plants, and natural gas is transported throughout the region by pipelines (EIA 2014c). Crude oil and petroleum products are typically transported throughout the region by pipelines, including the Running Horse Pipeline, owned and operated by the Navajo Nation, that transports crude oil from Utah to New Mexico (EIA 2014c). Producers in the Southwest are also increasingly turning to transport of crude to refineries by rail (EIA 2014c). Petroleum products may also be distributed locally by truck. Fuel transportation infrastructure in the Southwest, specifically rail transport, may be vulnerable to increasing temperatures, and damage or disruption may result in disruption of service to TTLs.

Increasing temperatures, including more frequent and longer heat waves, could damage fuel transportation infrastructure and result in service disruptions (CCSP 2008, NOAA 2013c). High temperatures can damage and disrupt rail infrastructure, such as the private railroad that carries coal from the Kayenta Mine on the Navajo Nation directly to the Navajo Generating Station (EIA 2014c). Above the temperature design limits, tracks can buckle under heat stress, and railroad operators may issue blanket slow orders to prevent derailments (CCSP 2008, DOT 2011).

Sustained high temperatures, which are expected to occur more frequently with increasing heat waves in the region, can damage roads through softening asphalt concrete pavement, resulting in rutting (DOT 2014). Concrete pavement can heave at joints during heat waves and roads may be damaged if temperatures exceed the typical 108°F design threshold for asphalt binder (DOT 2014). Asphalt pavement is particularly susceptible to cracking due to the combined effects of high heat and drought, which may occur more frequently because of climate change (DOT 2014).

Severe storms can cause extensive damage to fuel transportation infrastructure and disrupt transport of fuels (CCSP 2008, NOAA 2015b, Rossetti 2007)**.** Tornadoes, high winds, and lightning associated with severe convective storms can damage rail, road, and pipeline infrastructure. Strong tornadoes can lift cars and knock over railcars, and high winds can cause rollovers and derailments of railcars. Additionally, winds and lightning can damage highway signs and signaling equipment (CCSP 2008, Rossetti 2007). During winter storms, snow and ice can close or slow traffic on roadways and disrupt rail transport (DHS 2014).

FUEL PRODUCTION

Potential climate change impacts:

- Increased cost of production due to declining summer water availability

Tribes in the Southwest own and operate energy interests and generate revenue from royalties from oil and gas production and coal mining areas on tribal lands. For example, in addition to owning and operating the Navajo Mine, the Navajo Nation holds oil and gas interests in the San Juan Basin through the Navajo Nation Oil and Gas Company (see “Vulnerability of Southwestern TTL energy holdings to climate change”) (Minard et al. 2014). The Southern Ute Tribe owns and operates extensive oil and gas operations throughout the country (see “Vulnerability of Southwestern TTL energy holdings to climate change”) (Red Willow Production Company 2015). Other TTLs such as the Uintah and Ouray Reservation in Utah rely on royalties from production on lands leased to energy companies. Fuel production operations on TTLs are vulnerable to decreasing water availability due to climate change, and as a result, production costs on TTLs may increase (DOE 2013a, USGCRP 2014).

Decreasing water availability may affect production operations (DOE 2013a, USGCRP 2014)**.** TTLs throughout the Southwest are projected to experience significant decreases in surface water availability as well as decreasing groundwater storage (NOAA 2013c, USGCRP 2014), and fuel production can be a water-intensive process depending on the play and the drilling technique. For example, producers in the Piceance Basin under the Uintah and Ouray Reservation use hydraulic fracturing operations, which require about 1.2 million gallons of water per well in the region (Encana 2011). In New Mexico, water use ranges from 500,000–8,000,000 gallons per well and has increased with increasing use of hydraulic fracturing in the state (EMNRD 2015). As a result of increasing water use and localized strain on water supply in production areas, water has become increasingly scarce (EMNRD 2015). Increasing water use, competing water uses, and decreasing water availability may affect the cost of production on TTLs in the region.

Vulnerability of Southwestern TTL energy holdings to climate change

Navajo Nation energy holdings and decreasing water availability

The Navajo Nation owns and operates a coalmine and relies on royalties and lease fees for coal, oil, and natural gas extraction on reservation lands for a large portion of their annual revenue. In addition to providing the Navajo Nation with a large portion of their general funds, fuel production centers on Navajo Nation lands are a major source of employment for residents (Nania et al. 2014). The Kayenta Mine, operated by Peabody Energy, employs Navajo tribal members, and Peabody Energy pays the Navajo Nation more than $37.2 million a year and the Navajo Tribal Utility Authority about $9.9 million a year in electrical fees (Nania et al. 2014). The other large coal mine on Navajo Nation land, the Navajo Mine, was recently purchased by the Navajo Nation for $85 million (Nania et al. 2014) and brings the Navajo Nation at least $42 million a year (Minard 2014).

The Navajo Nation also owns and operates the Navajo Nation Oil and Gas Company (NNOGC), which generates revenue for the tribe. NNOGC contributed $49.6 million to the Navajo Nation in 2013, and in 2014, NNOGC owned $450 million in assets (NNOGC 2015). The company generated $155 million in revenue in 2014 from operations including oil and gas production in the San Juan Basin, transport of crude through the Running Horse Pipeline, and operation of gas stations in the Navajo Nation (NNOGC 2015).

Energy production operations on the Navajo Nation require water for continued operations and may be vulnerable to decreasing water availability in the region. Many oil companies operating on the Navajo Nation lands use non-potable groundwater, and the Kayenta Mine uses 1.1 million gallons of groundwater a day from the N-Aquifer for dust suppression and for washing coal (Minard 2014). Prior to 2006, the Kayenta Mine used slurry operations, which consumed about 44 billion gallons of groundwater from this aquifer, and studies indicate that the aquifer has not recovered from this drawdown (Minard 2014).

Decreasing water availability and increased stress on groundwater storage due to drought and increased demand for water may affect the ability of energy companies to operate on the TTL. The Navajo Nation has experienced severe drought in recent years, and projections indicate that precipitation is going to decrease in this region and drought will be more frequent and intense (NOAA 2013c, USGCRP 2014). TTLs on the Colorado Plateau, including the Navajo Nation, have been in a drought for over 10 years and this trend is projected to continue (USGCRP 2014).

Vulnerability of Southern Ute Indian Tribe energy holdings to climate change

The Southern Ute Indian Tribe, located on the Southern Ute Reservation in Colorado, has substantial energy holdings throughout the United States through the Southern Ute Indian Tribe Growth Fund, which includes Red Willow Production Company, Red Cedar Gathering Company, Aka Energy Group, and Southern Ute Alternative Energy. Southern Ute Alternative Energy focuses on renewable energy sources such as biomass and biofuels, solar, and wind power (SUAE 2015), and the Aka Energy Group and Red Cedar Gathering Company are natural gas gathering and treating companies. Red Cedar Gathering Company operates on reservation lands in the San Juan Basin (Southern Ute Indian Tribe Growth Fund 2015), but Aka Energy produces almost 700,000 gallons of natural gas liquids (NGLs) from 12 processing and treatment plants in Colorado, Kansas, New Mexico, Oklahoma, and Texas (Aka Energy LLC 2015). The Red Willow Production Company is an oil and natural gas production company with interests in more than 1,800 wells through operations in the western United States and the Gulf of Mexico (Red Willow Production Company 2015).

Like other oil and gas production areas in the Southwest, the Southern Ute Indian Tribe's energy production interests may be vulnerable to decreasing water availability, but Red Willow Production Company's offshore oil and gas production may also be vulnerable to the increasing frequency of intense hurricanes (Categories 4 and 5) expected in the North Atlantic Basin. Red Willow Production Company produces more than 39,000 BOE (barrel of oil equivalent) per day from two wells in the Mississippi Canyon in the Gulf of Mexico (Red Willow Production Company 2015). Increasing frequency of intense hurricanes in the Gulf of Mexico increases the risk of damage or disruption to these operations, as offshore oil and gas platforms are vulnerable to high winds and surf during hurricanes. Offshore platforms are built to withstand stresses such as wind speeds and wave heights for a 100-year storm, but these threshold limits have been surpassed in recent years (Cruz and Krausmann 2008), and a recent study found that 3%–6% of offshore platforms exposed to hurricane force winds are expected to experience damage and 2%–4% of offshore platforms could be expected to be destroyed (Kaiser & Yu 2009). Intense hurricanes could further disrupt offshore production by damaging the offshore pipelines that carry offshore oil and gas to facilities along the Gulf Coast. Pipelines may be damaged when large surface waves and strong near-bottom currents create underwater mudslides (Burkett 2011).

Chapter 5: Great Plains Tribal Lands

Key Climate Change and Extreme Weather Hazards Affecting Tribal Trust Land Energy Systems in the Great Plains

- **Severe storms**: High winds, ice storms, and tornadoes may result in power outages due to damaged electric infrastructure, including the electric grid and generation plants, and disrupt fuel supply lines.
- **Rising temperatures:** Increasing temperatures and heat waves are likely to increase electricity demand for cooling and increase electricity bills. High temperatures may also disrupt electric grid and generation operations and increase the likelihood of brownouts and blackouts.
- **Increasing drought:** Increasing frequency of drought in some areas may decrease available thermoelectric and hydropower generation, which, if not offset by additional capacity or demand reduction measures, may result in power outages.
- **Increasing extreme precipitation:** Increasing frequency of heavy rainfall events and resultant flooding may damage fuel transport and electric infrastructure and may disrupt fuel and electricity supply.

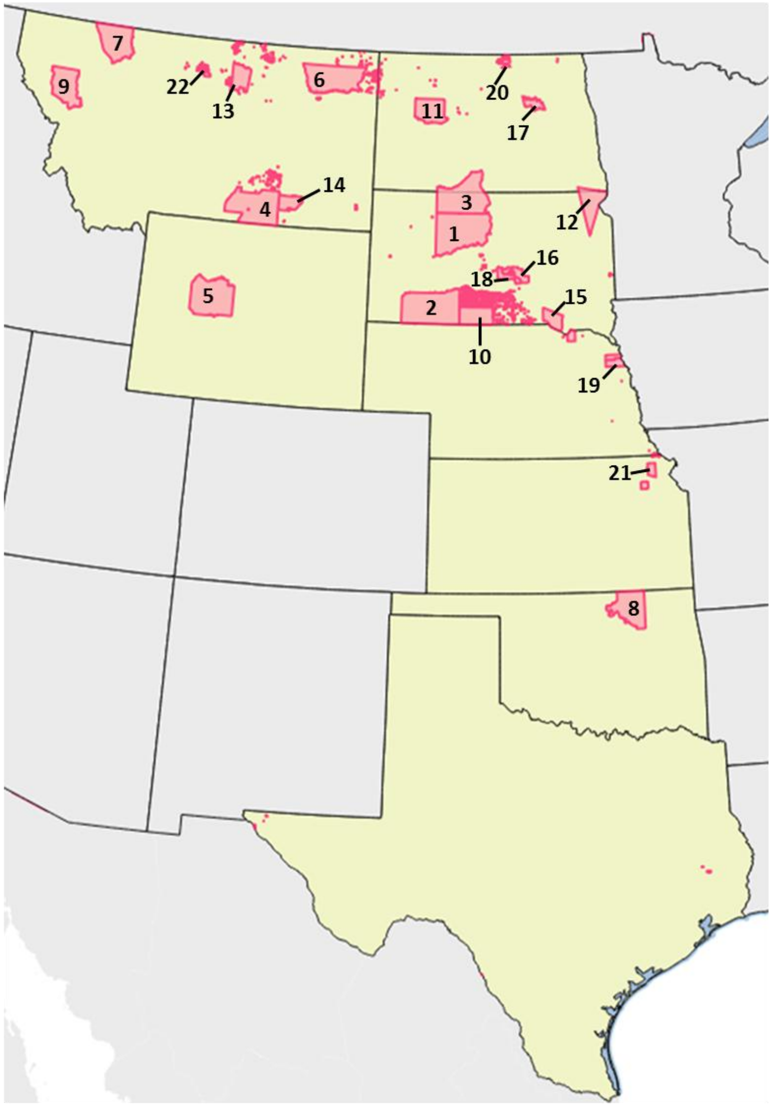

Figure 5-1. TTLs located in the Great Plains region.
Large reservations have been numbered in the figure above; see Table 5-1 for the corresponding trust land name.
Graphics source: Energetics 2015; Data source: U.S. Census Bureau 2015

OVERVIEW OF GREAT PLAINS REGION

There are 243,236 residents living on 33 federally recognized tribal trust lands (TTLs) in the Great Plains region (see Table 5-1) (U.S. Census Bureau 2010a). There are TTLs in every state in the region, as shown in Figure 5-1 (U.S. Census Bureau 2010b). TTLs in the Great Plains have energy resources including oil, natural gas, and coal reserves, as well as significant potential for development of renewable energy. However, most TTLs do not have major energy infrastructure on their properties.[18]

Table 5-1. TTLs in the Great Plains.

States with TTLs:	Kansas, Montana, Nebraska, North Dakota, Oklahoma, South Dakota, Texas, and Wyoming
Number of TTLs:	33
Total population:	243,000
Total area (square miles):	40,100

Large TTLs*

Trust Land Name	Population**	Total Area (sq. miles)
1) Cheyenne River Reservation (SD)	8,090	4,419
2) Pine Ridge Reservation (SD/NE)	18,834	4,354
3) Standing Rock Reservation (SD/ND)	8.217	3,663
4) Crow Reservation (MT)	6,863	3,607
5) Wind River Reservation (WY)	26,490	3,533
6) Fort Peck Indian Reservation (MT)	10,008	3,302
7) Blackfeet Indian Reservation (MT)	10,405	2,400
8) Osage Reservation (OK)	47,472	2,304
9) Flathead Reservation (MT)	28,359	2,058
10) Rosebud Indian Reservation (SD)	10,869	1,975
11) Fort Berthold Reservation (ND)	6,341	1,583
12) Lake Traverse Reservation (ND/SD)	10,922	1,509
13) Fort Belknap Reservation (MT)	2,851	1,018
14) Northern Cheyenne Indian Reservation (MT/SD)	4,789	707
15) Yankton Reservation (SD)	6,465	685
16) Crow Creek Reservation (SD)	2,010	461
17) Spirit Lake Reservation (ND)	4,238	399
18) Lower Brule Reservation (SD)	1,505	390
19) Omaha Reservation (NE/IA)	4,773	310
20) Turtle Mountain Reservation (ND)	8,669	237
21) Kickapoo (KS) Reservation (KS)	4,134	237
22) Rocky Boy's Reservation (MT)	3,323	171

*Note: "Large" TTLs are those lands > 300 square miles in area and/or with >3,000 Native American residents.
**Note: The population of TTLs refers to the number of residents on each TTL according to the 2010 Census, not the number of enrolled members of each tribe.
Sources: U.S. Census Bureau 2010a, U.S. Census Bureau 2010b

Electricity Supply

TTLs in the region are connected to the wider high-voltage transmission grids and bulk power markets in the region and rely fully or partially on offsite commercial power plants. On-site generation in the region's TTLs includes the 206 MW Kerr hydroelectric facility located on the Flathead Reservation and recently purchased by the Confederated Salish and Kootenai Tribes, as well as several small onsite power generators burning oil, natural gas, and landfill gas (LFG) (EIA 2013e, EIA 2014c, Ingram 2014). The Flathead, Blackfeet, and Wind River Reservations have significant potential for renewable generation resources (EIA 2014c).

Fuel Supply

Several tribes in the Great Plains region have leased lands to energy companies to produce the major oil, natural gas, and coal resources within regional TTLs. In Wyoming, the Crow Nation sits on the Absaloka coal mine, an estimated 9-billion-ton coal reserve, and currently derives about half of its annual budget from revenues from the mine (Hansen 2013). As of 2014, there were approximately 2,200 oil wells and 130 natural gas wells on lands leased by TTLs in the Great Plains (EIA 2014c). This includes about 1,000 oil wells on the Fort Berthold Reservation, 100 oil wells on the Blackfeet Reservation, and 50 oil wells on the Fort Peck

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[18] "Major energy infrastructure" includes the following: high-voltage (> 345 kV) transmission lines; large (> 1 MW) electric generation plants; oil, natural gas, or coal production areas; oil refineries; natural gas processing plants; and crude oil, petroleum product, or natural gas pipelines.

Reservation, all of which sit above the Bakken shale formation (EIA 2014c). The Osage Reservation owns mineral rights on land containing 1,000 oil wells (EIA 2014c). There are also seven natural gas processing plants on TTLs in the Great Plains, with a combined processing capacity of almost 200 MMcf/d (million cubic feet per day) (EIA 2014c). The production and processing areas on TTLs in the region are not tribally owned, but tribes and individual residents of TTLs receive royalty incomes from fuel production, and production areas employ residents of TTLs. For example, the Three Affiliated Tribes and residents of Fort Berthold received over $183 million in oil and gas royalties in 2012 (BIA 2013).

No TTLs in the region have petroleum refining capacity, and residents of TTLs in the region rely on national fuel transport infrastructure for fuel products. Fuels including motor gasoline, residual fuel oil, and propane are shipped from refineries and terminals by pipeline or rail, and are further distributed throughout the region by barge and truck (EIA 2014c). Several TTLs in the region are transited by pipelines for crude and refined petroleum, as well as natural gas. The Blackfeet, Forth Berthold, Osage, and Wind River Reservations have on-reservation natural gas processing plants, and several others are crossed by natural gas pipelines (EIA 2014c). Natural gas is also transmitted by pipelines to TTL consumers. Coal used to generate electricity that is consumed by TTLs is transported primarily by rail, as well as by barge and truck (EIA 2014c).

Table 5-2. Primary examples of extreme weather and climate change impacts that could adversely affect the energy infrastructure serving TTLs in the Great Plains

Extreme weather event or climate change trend affecting energy infrastructure	Potential implications for tribes
Severe storms, including severe convective storms and winter storms, and increasing frequency of heavy precipitation events	
• Damage to electric grid infrastructure and power plants	• Power outages and damage to power lines on and supplying TTLs
• Damage to roads and rail lines, potentially rendering them impassable for energy transport	• Disruption in fuel supply
Rising air and water temperatures	
• Increased average and peak demand for cooling energy	• Higher electricity bills for cooling in the summer
• Reduced transmission capacity and efficiency and reduced service life of some electrical equipment	• Greater likelihood of power outages and potential for higher electricity costs
• Decreased available generation capacity of thermoelectric power plants	• Greater likelihood of power outages and potential for higher electricity costs
Changing water availability	
• Shifts in available hydropower capacity	• Reduced hydropower generation, potential for higher electricity costs, and potential loss in revenue for tribal agencies that own hydropower facilities
Increasing wildfire	
• Increased risk of damage to electric grid infrastructure	• Greater likelihood of power outages and damage to energy infrastructure on TTLs

IMPLICATIONS FOR ENERGY SECTOR

Electric grid and fuel supply infrastructure serving TTLs in the Great Plains are vulnerable to damage from severe storms, and may be increasingly vulnerable, as climate change may result in increasing heavy precipitation events, warmer temperatures, changing water availability, and increasing wildfire in the region (Table 5-2).[19]

Energy End-Use

Potential climate change impacts:

- Increased electricity demand for cooling in the summer
- Decreased energy demand for propane, fuel oil, wood, electricity, and natural gas for space heating in the winter

Because of the large latitudinal range in the Great Plains, climate on TTLs throughout the region varies from bitterly cold winters in the northern Great Plains to extremely hot summers in the southern Great Plains (NOAA 2013d). Electricity is used for cooling during the hot summers, particularly in the southern states. Most households in the Great Plains region use natural gas for heating (EIA 2013c), but the majority of residents living on TTLs rely on tank gas, including propane (Table 5-3) (U.S. Census Bureau 1995). As climate change leads to increased temperatures in the region, including not only warmer weather but also increased frequency and length of heat waves, demand for cooling energy is projected to increase while demand for heating is projected to decrease (NOAA 2013d).

Table 5-3. Primary household heating fuel in selected Native American communities in the Great Plains

TTL	Primary heating fuel (percentage of households using fuel)
Blackfeet Reservation, MT	Utility gas (42%)
Cheyenne River Reservation, SD	Tank gas, including propane (57%)
Crow Reservation, MT	Tank gas, including propane (35%), utility gas (26%), electricity (25%)
Devils Lake Sioux Reservation, ND	Electricity (46%)
Flathead Reservation, MT	Electricity (42%)
Fort Belknap Reservation, MT	Utility gas (34%), tank gas, including propane (30%)
Fort Berthold Reservation, ND	Tank gas, including propane (48%)
Fort Peck Reservation, MT	Utility gas (64%)
Lake Traverse Reservation, ND/SD	Electricity (52%)
Northern Cheyenne Reservation, MT/SD	Electricity (65%)
Osage Reservation, OK	Utility gas (64%)
Pine Ridge Reservation, NE/SD	Tank gas, including propane (60%)
Rosebud Reservation, SD	Tank gas, including propane (51%)
Standing Rock Reservation, ND/SD	Tank gas, including propane (69%)
Turtle Mountain Reservation, ND/SD	Tank gas, including propane (39%), electricity (33%)
Wind River Reservation, WY	Tank gas, including propane (42%)

Source: U.S. Census Bureau 1995

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[19] This report describes vulnerabilities of tribal energy systems related to both climate change and extreme weather. "Potential climate change impacts" refer to threats to tribal energy systems that are projected to change (increase, in most instances) compared to historical norms. Climate change impacts in the Great Plains include increasing heavy rainfall events, warmer temperatures, changing water availability, and increasing wildfire. "Potential extreme weather impacts" refer to weather events that threaten tribal energy systems, but quantifying the effects of climate change on the frequency, duration, or severity of these events is still an area of active research. Such extreme weather impacts include convective and winter storms. In this report, potential extreme weather impacts are not associated with a trend but rather as a continued threat to tribal energy systems.

Increasing temperatures, including warmer summers and increasing frequency and duration of heat waves, are likely to increase demand for cooling energy (DOE 2013a, NOAA 2013d)**.** Cooling energy demand, measured through the increase in cooling degree days (CDDs) per year, is projected to increase by 37% in the Great Plains as a whole by mid-century (2041–2070, compared to 1971–2000) (USGCRP 2014). The number of cooling degree days (CDDs) in the southern Great Plains is projected to significantly increase as summer air temperatures increase by up to 6.5°F and the number of extremely hot days (>95°F) increases by up to 28 days per year by mid-century (2041–2070, compared to 1980–2000) (NOAA 2013d).[20] The number of CDDs in Oklahoma, where the Osage Reservation is located, is projected to increase by 600–1,000 degree days by mid-century under a high emissions scenario; and portions of Texas, including the Kickapoo (TX) and the Alabama–Coushatta Reservations, may experience 3,000–4,500 CDDs per year (NOAA 2013d). Increasing CDDs may increase air conditioning use on TTLs, and increased penetration of air conditioning could amplify increasing demand for electricity and possibly increase energy bills in summer (Auffhammer 2011, DOE 2013a, EIA 2013c).

Warming winter temperatures are likely to decrease demand for heating energy (DOE 2013a, NOAA 2013d)**.** As winter air temperatures increase, the number of heating degree days (HDDs) is projected to decrease significantly, particularly in the northern Great Plains, which is projected to see up to 30 fewer extremely cold days each year and a 6.5°F increase in winter air temperatures by mid-century (2041–2070, compared to 1971–2000) (NOAA 2013d).[21] Throughout the region, heating energy demand, measured through HDDs per year, is projected to decrease by 18% by mid-century (USGCRP 2014). Under a high emissions scenario, the number of HDDs in the portions of the Great Plains containing the Wind River, Flathead, and Blackfeet Reservations is projected to decrease by 1,250–1,650 degree days by mid-century (NOAA 2013d). This may lead to a decrease in demand for heating fuel, including natural gas and propane, on TTLs during the winter and, depending on the cost of fuel and type of fuel used, could translate to a reduction in winter heating bills on TTLs.

Tribal utility authorities in the Great Plains

Mission Valley Power is owned by the Bureau of Indian Affairs (BIA) but operated by the Confederated Salish and Kootenai Tribes and provides electricity to the Flathead Indian Reservation (WAPA 2010). In 2014, the utility reported revenues of over $28 million (Mission Valley Power 2014). Mission Valley Power purchased almost 80% of its power from the Bonneville Power Authority and received the remaining power from the Kerr Dam (Azure 2011).

Another tribal utility authority, the Oceti Sakowin Power Authority, is currently in development. This power authority was developed by six Sioux tribes—the Cheyenne River Sioux, Crow Creek Sioux, Yankton Sioux, Rosebud Sioux, Oglala Sioux, and Sisseton Wahpeton Oyate Sioux Tribes—from reservations in the Great Plains to develop and operate a utility-scale wind power and transmission system in South Dakota (CGI America 2015).

Figure 5-2. Employees of Mission Valley Power perform maintenance on power lines in the service area.
Source: BIA 2015a

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[20] A CDD is calculated from the sum of the daily variation of temperature above a baseline temperature, typically 65°F. This calculation is a proxy for the energy needed to cool a space.

[21] An HDD is calculated from the sum of the daily variation of temperature below a baseline temperature, typically 65°F. This calculation is a proxy for the energy needed to heat a space.

Electricity Supply

ELECTRIC GRID

Potential extreme weather impacts:

- Storm damage to grid infrastructure that serves TTL residents and businesses

Potential climate change impacts:

- Increased risk of wildfire or heat damage to the grid infrastructure located on or connected to TTLs
- Decreased efficiency and capacity of transmission lines from increasing temperatures

Transmission and distribution infrastructure serving TTLs in the Great Plains is susceptible to severe convective storms as well as increasing temperatures and increasing frequency and intensity of wildfires. TTLs in the region, with the exception of the Flathead Indian Reservation which operates Mission Valley Power (Table 5-4), rely on efficient electric service from utilities that are not owned or operated by the tribes. Additionally, since there is only one tribally owned or operated major electric generation facility on tribal lands—the Kerr Dam on the Flathead Reservation—TTLs primarily rely on electricity generated offsite at major power plants, and power lines that deliver this electricity to TTLs must be considered when assessing potential vulnerabilities. Disruption or damage to electric grid infrastructure in the Great Plains could lead to widespread or localized power outages, including on TTLs. As utilities invest in additional capacity, maintenance, and repairs to ensure reliable service, tribal residents and businesses may also see an increase in the cost of electricity.

Table 5-4. Mission Valley Power, operated by the Flathead Reservation

Utility Name	Residential Customer Count	Total Customer Count	Summer Peak Demand (MW)	Winter Peak Demand (MW)
Mission Valley Power	14,512	20,893	56.1	79.5

Source: EIA 2013e

Severe storms damage electric grid infrastructure (DOE 2015a). Severe convective storms can cause extreme damage to electric grid infrastructure (Figure 5-3). Nationally, severe storms—including thunderstorms, high winds, and tornadoes—caused 479 grid disruptions during the period 1999–2013, more than half of all weather-related outages (DOE 2015a). Tornadoes can down power lines, poles, and transmission structures, and high winds can break tree branches and blow trees or branches onto power lines, breaking the lines and poles. Winds can also cause power lines to come into contact with branches, towers, or other power lines, shorting the line and leading to the automatic closure of the circuit, which may require additional work before it can be brought back online. Lightning during severe convective storms can also damage electric grid infrastructure if it strikes the equipment or strikes trees and causes them to fall on power lines. For example, a strong convective storm on the Rosebud Indian Reservation in South Dakota in 2012 produced a tornado, hail, and strong winds that damaged power poles and lines, resulting in power outages on the reservation (AP 2012).

Figure 5-3. A tornado snapped utility poles when it hit the Pine Ridge Reservation in South Dakota in 1999.
Source: NOAA 2010

Winter storm damage on the Cheyenne River Reservation

An ice storm in the northern Great Plains in 2010 caused significant damage to energy infrastructure on the Cheyenne River Reservation. The January 22 ice storm knocked down about 3,000 power lines that supply electricity to the reservation, leaving residents without power for almost a week (Yocha Dehe Wintun Nation 2010). Wind chills dipped well below zero, but residents were unable to heat their homes. Without power, the water system failed, and the Cheyenne Reservation went without running water (Yocha Dehe Wintun Nation 2010).

Winter storms can severely damage electric grid infrastructure. High winds and heavy snow associated with blizzard conditions that typically occur in the northern Great Plains can cause branches to snap and fall on power lines, which can weigh down poles and cause them to collapse (Abi-Samra et al. 2014, USACE 2014). During high wind conditions, transmission lines and support structures can suffer damage if lines gallop.[22] If a single pole fails, this can initiate a cascading failure of transmission support structure that can sometimes stretch over tens of miles. In addition, ice storms can significantly damage transmission and distribution lines and poles (USACE 2014).

Rising temperatures, including increased frequency and duration of heat waves, increase the risk of damage to electric grid infrastructure and reduce transmission capacity and efficiency (DOE 2013a)**.** Hotter temperatures lead to thermal expansion of transmission line materials, causing lines to sag and increasing the risk that energized lines will come into contact with trees and the ground (DOE 2013a). High temperatures also increase the rate of material breakdown in power transformers, and operators are forced to reduce loadings on transformers on hot days to prevent extensive damage (Bérubé et al. 2007, Hashmi et al. 2013, USBR 2000). As temperature increases, operators may reduce transmission capacity to prevent permanent damage to grid infrastructure (Sathaye et al. 2012). According to one study, a 9°F increase in average temperatures could result in a 7%–8% decrease in transmission capacity and a 1.5%–2.5% decrease in transmission and distribution grid efficiency (Sathaye et al. 2012); summer air temperatures in the region are projected to increase 4.0°F–6.5°F by mid-century (NOAA 2013d). Transmission and distribution system losses are typically largest during peak demand periods, and rising demand could increase with increasing temperatures (Sathaye et al. 2012), which could affect electricity supply and costs to tribal residents and businesses.

Increased frequency and intensity of wildfires increase the risk of damage to grid infrastructure (DOE 2013a, NRC 2011)**.** Transmission and distribution infrastructure in the Great Plains region is vulnerable to damage from wildfires. Increasing wildfires may lead to damaged infrastructure on TTLs, such as the Wind River Reservation, as well as power outages on TTLs if lines serving TTLs are damaged. The fire itself can destroy wood poles and steel towers, and soot and fire retardant can foul transmission lines. During wildfires, operators may shut down or reduce loading on transmission lines to prevent damage from smoke and soot, which can cause arcing between lines (DOE 2013a).

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[22] Power lines “gallop” when ice builds up on the power line, causing it to sway and buck in the wind. In high winds, or with sufficient ice buildup, galloping power lines can be very dangerous, as they may eventually fail, snapping power poles or causing lines to fall.

ELECTRIC POWER GENERATION

Potential extreme weather impacts:

- Storm damage to power plants

Potential climate change impacts:

- Decreased efficiency and available generation capacity from thermoelectric power plants due to higher air and water temperatures and water scarcity
- Shifts in hydropower production in the Missouri River Basin due to changing streamflow
- Increased risk of flood damage to power plants due to increasing extreme precipitation events

The Flathead Reservation in Montana will soon own and operate a major hydroelectric facility (EIA 2014c, Ingram 2014), but other TTLs in the Great Plains do not own major electric power generating plants (>1 MW), and tribal residents and businesses instead typically rely on offsite generation. The hydropower facility soon to be operated by the Flathead Reservation may be affected by changing seasonal water availability, and offsite power generators in the region are at risk from severe convective storms and may be increasingly vulnerable to increasing temperatures, decreasing water availability, and flooding during extreme precipitation events (DOE 2013a). Climate change may increase the frequency of events that damage or disrupt power generators, potentially resulting in higher electricity prices on TTLs and increasing the risk of power outages.

The majority of electricity generation in the Great Plains region is from thermoelectric power plants, which use fossil fuels, nuclear energy, biomass, and solid waste to heat water that will then produce steam and drive turbines. Coal-fired power plants and nuclear power plants generate 43% and 36% of all electricity generated in the Great Plains, respectively. Hydropower accounts for only 3% of all electricity generated in the region, but is a major source of electricity generation in states with large TTLs, including Montana (41%) and South Dakota (50%) (EIA 2013b).

Hydropower production on the Flathead Reservation

The Confederated Salish and Kootenai Tribes on the Flathead Reservation are expected to become the first tribes in the United States to own a major hydroelectric power plant when they acquire the Kerr Dam, which is located in the Columbia River Basin (EIA 2014c). The plant may be affected by changes in seasonal water availability due to climate change (BPA 2011, DOE 2013a, USGCRP 2014). The tribe will officially purchase the Kerr Dam on the Flathead River in September 2015 for about $18 million (McNeel 2014). The Dam generates about 1.1 million MWh electricity a year, and the market price when the tribe takes ownership is expected to fall around $32 per MWh, so in addition to providing power for more than 145,000 households, the Dam could be a source of revenue for the Flathead Reservation (McNeel 2014).

Figure 5-4. The Confederated Salish and Kootenai Tribes will officially acquire the Kerr Dam in September 2015.
Source: BPA 2012

Severe convective storms can damage power plants in the region, and increasing frequency of extreme precipitation events and associated flooding increases the risk of damage to power plants (AP 2010a, DOE 2013a, NOAA 2013d)**.** The northeastern Great Plains is expected to continue to see an increase in the frequency of heavy precipitation events and an associated increase in the likelihood of flooding, increasing the risk to low-lying power plants located along rivers (DOE 2013a). During severe convective storms, tornadoes and high winds can also damage power plant facilities (AP 2010a).

Shifting streamflow in the Columbia and Missouri River basins may affect seasonal hydropower production (BPA 2011, DOE 2013a, USGCRP 2014). Hydroelectric power produced in the northern Great Plains is generated from the Missouri and Columbia River basins. The Missouri River watershed supplies water for hydroelectric generators in Montana and South Dakota, collecting runoff and snowmelt from an expansive watershed that covers most of the northern plains states. This watershed is projected to experience changes to precipitation that vary depending on the emissions scenario, season, and location. These changes include both increases and decreases. For example, the southwestern portion of the basin that borders the continental divide in Wyoming's mountains draws from an area that is projected to experience decreases in average precipitation and specifically in spring and summer precipitation. The decreases in seasonal precipitation could affect streamflow and hydropower production. The northern portion of the basin is projected to see an increase in precipitation in all seasons (NOAA 2013d).

In the Columbia River Basin, which includes far western portions of Montana and Wyoming, hydropower production may be affected by seasonal changes in precipitation and snowmelt patterns. Winter precipitation and early spring snowmelt are projected to increase, and this earlier snowmelt, along with reduced summer precipitation, may decrease summer streamflow (BPA 2011, DOE 2013a, USGCRP 2014). Reductions in hydropower generation could lead to an increase in the cost of electricity for tribal residents and businesses if utilities rely on more expensive thermoelectric power generation to meet demand. If tribal hydropower operators generate revenue by selling surplus power to the market, increasing streamflow volatility may result in a reduction in this source of revenue (CTED 2005, DOE 2013b).

Increasing air and water temperatures decrease the efficiency and available generation capacity of thermoelectric power plants (DOE 2013a, NOAA 2013d)**.** Thermoelectric power plant efficiency decreases as air and water temperatures increase, and high water temperatures may force thermoelectric and nuclear power plants to curtail operations, particularly in the southern Great Plains. Thermoelectric power plants require water for cooling, and they may be forced to shut down operations if water temperatures go above a certain temperature, as regulations establish thermal discharge limits to protect aquatic ecosystems (DOE 2013a). According to one study of Texas power plants, curtailments due to increasing water temperatures and limits on thermal discharge could reduce peak load capacity by 5,500 MW in 2030 under a high emissions scenario (Cook 2013).

Decreasing water availability may force thermoelectric power plants to curtail production or shut down during shortages (DOE 2013a, NOAA 2013d)**.** Portions of the southern and western Great Plains, including Texas, Oklahoma, and western Montana and Wyoming, are expected to experience an increase in the number of consecutive dry days and a reduction in total average summer precipitation, which may reduce the amount of water available for cooling (DOE 2013a, NOAA 2013d). Power plants that rely on surface freshwater sources such as rivers and lakes for cooling water may be forced to reduce or stop operations if water levels are too low to support production (DOE 2013a, UCS 2012). Additionally, plants that rely on groundwater sources for cooling may be vulnerable to decreasing water availability as climate change may result in decreasing recharge rates and increased demand from competing users for water from groundwater aquifers (USGCRP 2014).

Fuel Supply

FUEL TRANSPORT

Potential extreme weather impacts:

- Storm damage to transportation infrastructure and possible disruptions in fuel supply

Potential climate change impacts:

- Increased risk of disruption of fuel supply, including gasoline, diesel, fuel oil, and propane, as a result of flooding caused by extremely heavy precipitation
- Increased risk of damage to rail infrastructure and disruptions in service due to increasing temperatures

Although there are production areas on TTLs in the Great Plains, production and processing facilities are on leased lands or are located off-site. As a result, TTLs are dependent on fuel transportation infrastructure for efficient delivery of fuels, including natural gas, motor gasoline, fuel oil, and propane. Many TTLs also likely rely on offsite power generation, as there are no major electric generation facilities on TTLs. Therefore, residents and businesses are vulnerable to disruptions of coal and natural gas transport to major offsite electricity generation facilities for power generation. Many natural gas and petroleum product pipelines transect the Great Plains region (EIA 2014c). Petroleum products and coal are also transported throughout the region by rail and barge and may be distributed locally by truck (EIA 2014c). These modes of transport are at risk of damage by severe convective storms and are also increasingly vulnerable to increasing precipitation, including extreme precipitation events, and increasing temperatures. Damage or disruption in fuels transport may lead to disruption of service to TTLs.

Severe storms can cause extensive damage to fuel transportation infrastructure (CCSP 2008, NOAA 2015b, Rossetti 2007)**.** During severe convective storms, tornadoes can damage railroad, road, and pipeline infrastructure, including railcars and stations, sections of pipe, and compressor stations (Kinder Morgan 2008, Unger 2013). Tornadoes that rate F2 and higher on the Fujita Scale can knock over boxcars and lift cars (NOAA 2015b). Convective storms can also damage railroads and roads, as high winds during convective storms can cause rollovers and derailments of both stationary and moving railcars and damage highway signs, signaling equipment, and lights (CCSP 2008, Rossetti 2007). Lightning during convective storms can interfere with rail and road signaling equipment (CCSP 2008, Rossetti 2007).

Snow and ice during severe winter storms can close roadways and delay fuel shipments, and heavy snowfall such as that associated with blizzard conditions can result in road closures and reduce speeds on roads that remain open (DHS 2014). Snow can also blow onto rail switches and disrupt rail transport of fuels (DHS 2014). Extreme cold can disrupt marine and inland waterway transport of fuels; port infrastructure and vessel superstructures may ice over if air temperatures fall below freezing (DHS 2014). Barge transportation can be further disrupted by ice formation on waterways, and ice formation on a ship can reduce the vessel's stability by changing its center of gravity (DHS 2014).

Increasing average precipitation and more frequent extreme precipitation events and associated flooding increase the risk of damage to fuel transportation infrastructure and may increase disruptions in service (CCSP 2008)**.** Both annual precipitation and extreme precipitation events are projected to increase in the northeastern Great Plains, leading to potentially damaging regional flooding events (NOAA 2013d). During heavy precipitation events, runoff and flooding can damage roads and rail tracks and, if rail lines and roads are submerged, disrupt service (CCSP 2008). Increases in peak streamflow, such as that seen in the Red River Valley of North Dakota due to both increasing rainfall and rapid spring snowmelt, can further erode track beds (DOE 2013a, Hirsch and Ryberg 2011, CCSP 2008, USGCRP 2014).

Extreme precipitation and associated flooding can also damage pipelines that transport fuels used on TTLs. During extreme precipitation events, flooding can erode soil cover and expose buried pipelines to damage from flood-borne debris (CCSP 2008). Flooding can also cause the soil underneath pipelines to sink, increasing stress on pipelines (NRC 2008).

Increasing temperatures, including more frequent, severe, and longer-lasting heat waves, may damage fuel transportation infrastructure and increase disruptions in service (CCSP 2008)**.** High temperatures are projected to occur more frequently on TTLs, including the Osage and Kickapoo (KS) Reservations, and can damage rails and force operators to slow service (CCSP 2008). If temperatures exceed railroad design limits, tracks can buckle under heat stress (CCSP 2008). To reduce the risk of buckling, derailments, and further track damage, railroad operators will reduce railcar loads and issue blanket “slow orders” under high-temperature conditions (DOT 2011).

Infrastructure damage on Rocky Boy’s Indian Reservation due to flooding during extreme precipitation events

In June 2010, 4–5 inches of rain fell in portions of eastern Montana over four days, causing extensive flood damage on Rocky Boy’s Indian Reservation (Claymore 2010). In addition to damaging more than 25% of the homes on the reservation and destroying water lines, flooding from the storm washed out roads and resulted in an estimated $32 million in damages (Figure 5-5) (AP 2010b). In 2013, Rocky Boy’s Indian Reservation was again hit by a heavy rainfall event leading to extensive flooding (AP 2013). In early June, more than a foot of rain fell in two weeks, again causing extensive damage to homes and leading to closures of six roads on the reservation (AP 2013).

Under a high emissions scenario, Rocky Boy’s Indian Reservation is projected to experience an up to 30% increase in the average number of days each year with extreme precipitation.

Figure 5-5. Heavy rainfall washed out roads on Rocky Boy’s Reservation in June 2010.
Source: FEMA 2010

TTLs in southern portions of the region, particularly those in Texas and Oklahoma, may see sustained high periods of extreme heat, which can damage roads through softening asphalt concrete pavement, resulting in rutting (DOT 2014). If temperatures exceed 108°F, asphalt binder can be severely damaged. Additionally, concrete pavement can heave at joints during heat waves, and asphalt pavement is particularly susceptible to cracking due to the combined effects of high heat and drought, which may occur more frequently because of climate change (DOT 2014).

FUEL PRODUCTION

Potential climate change impacts:

- Increased cost of oil and gas production due to declining summer water availability

Several TTLs in the Great Plains region, including the Fort Berthold and Osage Reservations, rely on royalties from oil and gas production areas located on tribal lands. The oil and gas producers operating on TTLs may face decreasing water availability due to climate change (USGCRP 2014). This could in turn increase costs for production operations in the region (DOE 2013a, USGCRP 2014) and affect production operations and costs on TTLs.

Decreasing summer precipitation and increasing seasonal drought may affect oil and gas production (DOE 2013a, USGCRP 2014). Oil and gas operations on regional TTLs are producing resources from unconventional plays, including coalbed methane in the Cherokee Platform on the Osage Nation and shale oil in the Bakken Shale formation underlying Fort Berthold (EIA 2014c). Under a high emissions scenario, the Osage Reservation may see a 10%–15% decrease in summer precipitation and 3–6 day increase in the annual maximum number of consecutive dry days (<0.1 inches of precipitation) by mid-century (NOAA 2013d). Similarly, the area of North Dakota where Fort Berthold is located may see up to a 2-day increase in the number of consecutive dry days (<0.01 inches) by mid-century under a high emissions scenario (USGCRP 2014). Some extraction techniques require large volumes of water and may be affected by the projected decrease in water availability in the region (DOE 2013a). For example, producers in the Bakken, such as those operating on Fort Berthold lands, typically use

Figure 5-6. An oil rig on the Fort Berthold Reservation.
Source: BIA 2015a

Hurricane and sea level rise impacts on the Alabama–Coushatta Reservation

Energy infrastructure serving the Alabama–Coushatta Reservation in Texas may be affected by hurricanes and sea level rise. Climate change projections indicate that the frequency of intense Atlantic hurricanes (Categories 4 and 5) and the rainfall rates within 60 miles of tropical storm centers are projected to increase (USGCRP 2014). Because of a combination of land subsidence along the Gulf Coast and global sea level rise, relative sea levels along the Texas coastline have increased 0.05–0.27 inches a year from the middle of the 20th century to 2006 and are projected to rise at an average rate of 0.06–0.48 inches per year between 1992 and 2050, depending on future ice sheet melt (USGCRP 2014). An accelerating rate of relative sea level rise in the region will enhance storm surge associated with hurricanes. The projected increase in frequency of intense hurricanes, combined with accelerating relative sea level rise, increases the risk of damage to electric grid and fuel transport infrastructure that serves the Alabama–Coushatta Reservation (DOE 2013a). During hurricanes, high winds may damage power lines, and sea level rise-enhanced storm surge and heavy rainfall may expose low-lying substations to flooding (DOE 2013a). Hurricanes and sea level rise-enhanced storm surge also increase the risk of damage to road and rail infrastructure used to transport fuels to residents and businesses, and increase the risk of disruption to barge transport of fuels in the area (DOE 2013a). As a result, residents and businesses on the Alabama–Coushatta Reservation may be at higher risk of power outages and face fuel supply disruptions (DOE 2013a, USGCRP 2014).

hydraulic fracturing, a technique that can use as much as 60,000 barrels or 3 million gallons of water. In the Bakken, this water currently can cost between $2.00/bbl and $16.80/bbl,[23] as it has to be trucked from Lake Sakakawea, the only reliable source of water in the region (NDIC 2010). Lake Sakakawea is a main water supply source for the surrounding area, and competing water uses combined with decreasing water availability could affect the cost of oil and gas production on this TTL.

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[23] Total costs for water reflect acquisition costs, including the purchase of raw water and the cost of transporting water to the fracture location, and disposal costs, including the cost of transportation from the fracture location to a well for disposal and the cost of deep-well injection. Transportation costs introduce the highest level of variability in total cost as they depend on trucking charges, haul distance, and wait time (NDIC 2010).

Chapter 6: MIDWEST TRIBAL LANDS

Key Climate Change and Extreme Weather Hazards Affecting Tribal Trust Land Energy Systems in the Midwest

- **Severe storms:** High winds, ice storms, and tornadoes may damage critical energy infrastructure and disrupt fuel supply and electric power service.
- **Rising temperatures:** Warming temperatures are expected to increase electricity demand and may lead to higher energy bills in the summer and increase the likelihood of power outages.
- **Increasing extreme precipitation:** Increasing frequency and intensity of heavy precipitation events and resultant flooding may damage electric grid and generation infrastructure and disrupt fuel supply lines.

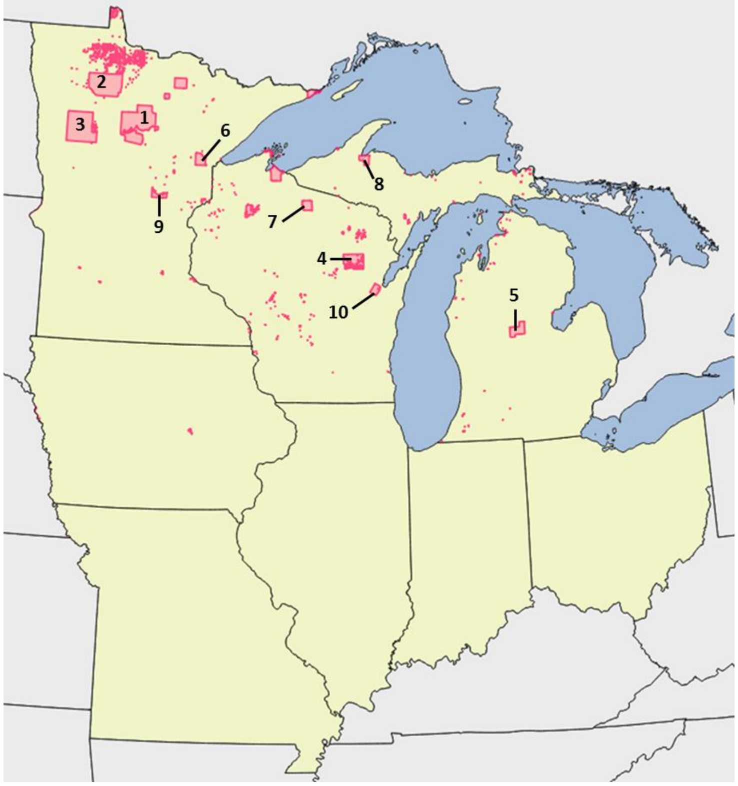

Figure 6-1. TTLs located in the Midwest region. *Numbers associated with large reservations correspond to numbering in Table 6-1.*

Graphics source: Energetics 2015; Data source: U.S. Census Bureau 2015

OVERVIEW OF MIDWEST REGION

The Midwest region contains 37 federally recognized tribal trust lands (TTLs) that are home to over 112,000 residents (U.S. Census Bureau 2010a) (Table 6-1). TTLs in Iowa, Michigan, Minnesota, and Wisconsin are concentrated in the Great Lakes region (Figure 6-1). There is no major energy infrastructure on TTLs in the Midwest (EIA 2014c), and residents and businesses are dependent on offsite fuel and electricity production.[24]

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[24] "Major energy infrastructure" includes the following: high-voltage (>345 kV) transmission lines; large (>1 MW) electric generation plants; oil, natural gas, or coal production areas; oil refineries; natural gas processing plants; and crude oil, petroleum product, or natural gas pipelines

Electricity Supply

TTLs depend on large offsite power plants to generate electricity as they do not own or operate any large generation facilities (EAI 2014c, Hallenbeck 2010). The electricity is transmitted from power plants through a high-voltage transmission network, and large transformers reduce the voltage before routing the electricity to low-voltage distribution networks that deliver power a short distance to tribal residents and businesses.

Fuel Supply

TTLs in the Midwest region do not produce fuel and are dependent on pipeline and truck transport for their supply of fuels, including motor gasoline, propane, and natural gas (EIA 2014c). Natural gas is transported to residents and businesses in the Midwest region by pipeline (EIA 2014c). Petroleum products are transported by pipeline and then from pipeline terminals to TTLs likely by truck (EIA 2014c). Petroleum product pipelines enter into Iowa, Minnesota, Wisconsin, and the Lower Peninsula of Michigan from Canada and western states; and petroleum is also delivered to the Upper Peninsula of Michigan by tanker and barge (EIA 2014c). Coal is transported throughout the region by rail, barge, and truck (EIA 2014c).

Table 6-1. TTLs in the Midwest.

States with TTLs:	Iowa, Michigan, Minnesota, Wisconsin
Number of TTLs:	37
Total population:	112,000
Total area (square miles):	5,700

Large TTLs*

Trust Land Name	Population**	Total Area (sq miles)
1) Leech Lake Reservation (MN)	10,660	1,311
2) Red Lake Reservation (MN)	5,896	1,258
3) White Earth Reservation (MN)	9,562	1,167
4) Menominee Reservation (WI)	3,141	363
5) Isabella Reservation (MI)	26,274	218
6) Fond du Lac Reservation (MN/WI)	4,250	159
7) Lac du Flambeau Reservation (WI)	3,442	135
8) L'Anse Reservation (MI)	3,703	110
9) Mille Lacs Reservation (MN)	4,907	103
10) Oneida (WI) Reservation	22,776	102

*Note: "Large" tribal trust lands are those lands > 300 square miles in area and/or with >3,000 Native American residents

**Note: The population of TTLs refers to the number of residents on each TTL according to the 2010 Census, not the number of enrolled members of each tribe.

Sources: U.S. Census Bureau 2010a, U.S. Census Bureau 2010b

IMPLICATIONS FOR ENERGY SECTOR

Climate change is expected to affect many elements of the critical energy infrastructure serving TTLs in the Midwest, including power plants, fuel supply networks, and electric power transmission and distribution systems (see Table 6-2). Energy infrastructure is already vulnerable to damage and disruption from severe storms and may be at increased risk from increasing heavy rainfall and warmer air and water temperatures.[25]

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[25] This report describes vulnerabilities of tribal energy systems related to both climate change and extreme weather. "Potential climate change impacts" refer to threats to tribal energy systems that are projected to change (increase, in most instances) compared to historical norms. Climate change impacts in the Midwest include increasing heavy rainfall events and warmer air and water temperatures. "Potential extreme weather impacts" refer to weather events that threaten tribal energy systems, but quantifying the effects of climate change on the frequency, duration, or severity of these events is still an area of active research. Such extreme weather impacts include convective and winter storms. In this report, potential extreme weather impacts are not associated with a trend but rather as a continued threat to tribal energy systems.

Table 6-2. Examples of extreme weather and climate change impacts that could adversely affect the energy infrastructure serving TTLs in the Midwest.

Extreme weather event or climate change trend affecting energy infrastructure	Potential implications for tribes
Severe storms, including convective and winter storms and increasing heavy precipitation events	
• Risk of flooding and damage to low-lying power generation, transmission, and distribution infrastructure	• Power outages and damage to energy infrastructure on TTLs
• Risk of damage and disruption to fuel transportation infrastructure both on land and on critical waterways	• Potential disruption in fuel supply
Rising air and water temperatures	
• Increased electricity demand for air conditioning	• Higher electricity bills for cooling in the summer
• Reduced power line transmission capacity and efficiency, increased risk of deformation and damage to power lines, and reduced service life of some electrical equipment	• Greater likelihood of power outages and potential for higher electricity costs
• Decreased efficiency and available generation capacity of thermoelectric power plants	• Greater likelihood of power outages and potential for higher electricity costs

Energy End-Use

Potential climate change impacts:

- Increased electricity demand for cooling in the summer
- Decreased energy demand for propane, fuel oil, wood, electricity, and natural gas for space heating in the winter

The Midwest region is characterized by warm, humid summers and cold winters, and energy demand for winter heating is five to seven times greater than energy demand for cooling (USGCRP 2014). However, the majority of households in the Midwest use natural gas and heating oil for heating in the winter (EIA 2013f), so peak demand for electricity is on average 14% higher in summer than winter (EIA 2013a). Although propane is the third most common fuel for space heating in the Midwest region (after natural gas and electricity), it is an especially important fuel for Native American communities, which tend to have a much higher rate of propane use than average U.S. households (EIA 2013f, U.S. Census Bureau 1995). Fifty-four percent of the households on the Menominee Reservation in Wisconsin, for example, use propane or other containerized gas as the primary heating fuel (Table 6-3). Energy use in the summer is primarily for electricity to meet cooling demand, and more than 20% of all households in the Midwest region have air conditioning (EIA 2013f).

Table 6-3. Primary household heating fuel in selected Native American communities in the Midwest.

TTL	Primary heating fuel (percentage of households using fuel)
Leech Lake Reservation, MN	Fuel oil (37%)
Menominee Reservation, WI	Tank gas including propane (54%)
Oneida (West) Reservation, WI	Utility gas (39%)
Red Lake Reservation, MN	Electricity (44%), wood (33%)

Source: U.S. Census Bureau 1995

Higher temperatures are likely to increase the demand for average and peak cooling energy (DOE 2013a, NOAA 2013e, USGCRP 2014). The number of cooling degree days (CDDs) in the Midwest, used to measure cooling energy demand in a given year, is projected to increase by 64% by mid-century (2041–2070, compared to 1971–2000) as a result of climate change (NOAA 2013e, USGCRP 2014). As summer temperatures in the region increase by 4.5°F–6.0°F and the number of extremely hot days increases by up to 15 days, TTLs in the region may see 400–800 additional CDDs a year by mid-century (2041–2070, compared to 1980–2000) (Figure 6-2) (NOAA 2013e, USGCRP 2014).[26] Projections show that the Sac and Fox/Meskwaki Settlement in Iowa will experience the highest number of CDDs of the TTLs in the region, with 800–1,200 CDDs by mid-century under a high emissions scenario. Although the total number of projected CDDs is highest towards the southern portion of the region, for the TTLs in the northern areas such as L'Anse Reservation in Michigan, the relative change is most dramatic. For this and other far northern TTLs, the change projected by mid-century represents a doubling of cooling energy demand compared to historical climatology.

Increases in temperature can drive the adoption of air conditioners in buildings that previously did not have air conditioning (Auffhammer 2011). Although air conditioners are common in the Midwest, an increase in the market penetration of air conditioners could magnify demand for electricity beyond expected increases from temperature alone, further contributing to increases in peak demand on hot days. In extreme cases, significant increases in energy demand during extremely hot days may lead to brownouts or blackouts (USGCRP 2014). As energy use increases with increasing temperatures, tribal residents may see higher electricity bills during the summer months.

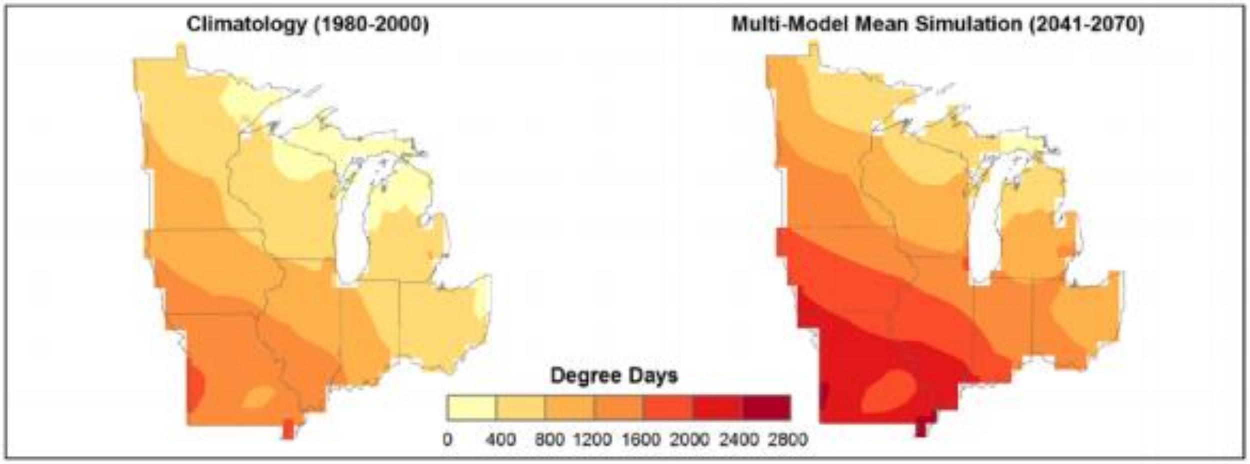

Figure 6-2. The mean annual number of cooling degree days for the Midwest region is projected to increase significantly from 1980–2000 (left) to 2041–2070 (right).
Source: NOAA 2013e

Higher winter temperatures and fewer days below freezing are likely to reduce demand for heating energy (DOE 2013a, NOAA 2013e, USGCRP 2014). An up to 6.0°F increase in winter air temperatures and 20–25 day decrease in extremely cold days may lead to a projected 15% decrease in heating energy demand, expressed through the number of heating degree days (HDDs) per year, by mid-century (2041–2070, compared to 1980–2000) (NOAA 2013e, USGCRP 2014). TTLs are projected to experience a large decrease in HDDs, ranging from 1,100–1,400 fewer HDDs in most of the region by mid-century (2041–2070, compared to 1980–2000) (NOAA 2013e).[27] TTLs such as the Sault Sainte Marie Reservation and Hannahville Indian Community on the Upper Peninsula in Michigan may experience as many as 1,500 fewer HDDs by mid-century under a high emissions scenario. Because of warmer winters and lower heating energy needs, residents and businesses on TTLs are likely to save money on their heating energy bills.

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[26] A CDD is calculated from the sum of the daily variation of temperature above a baseline temperature, typically 65°F. This calculation is a proxy for the energy needed to cool a space.

[27] An HDD is calculated from the sum of the daily variation of temperature below a baseline temperature, typically 65°F. This calculation is a proxy for the energy needed to heat a space.

Electricity Supply

ELECTRIC GRID

Potential extreme weather impacts:

- Storm damage to grid infrastructure located on or connected to TTL

Potential climate change impacts:

- Increased risk of flood or heat damage to the grid infrastructure located on or connected to TTLs
- Decreased efficiency and capacity of transmission lines from increasing temperatures

At least eight different electric utilities, including three electric cooperatives, serve the largest TTLs in the Midwest (EIA 2013a). Electric grid infrastructure, including transmission lines, substations, distribution lines, and utility poles, are all vulnerable to damage and disruption from severe weather as well as projected changes in temperature and precipitation in the Midwest.

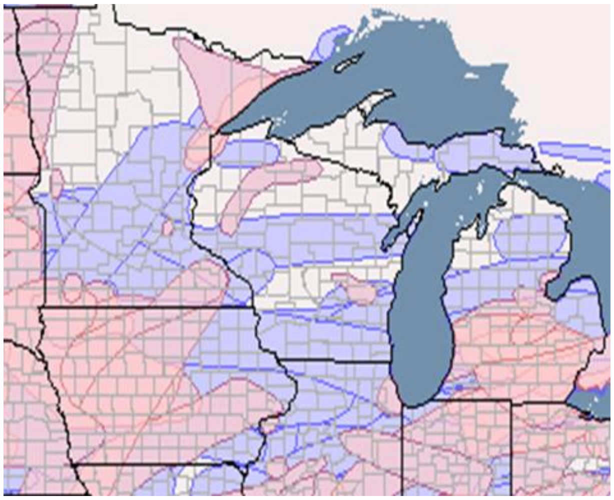

Figure 6-3. Areas near Midwest TTLs suffering utility infrastructure damage from ice storms. Damaged areas from storms since 1940 are shown in blue, and more recent (since 1990) in pink.
Source: USACE 2014

Winter storms, ice, and heavy snowfall can damage electric grid infrastructure (USACE 2014). Winter storms can damage power transmission and distribution lines, potentially interrupting service to electric power customers on TTLs in the Midwest (Figure 6-3). Ice accumulation can cause tree branches to fall onto distribution lines, or cause the lines to sag, making them vulnerable to damage from passing vehicles or contact with the ground as well as increasingly vulnerable to tree damage (USACE 2014). Ice accumulation can also increase the impact of high winds on high-voltage transmission lines, heightening the stress on system components that can lead to cascading equipment failure (USACE 2014).

Since 1990, ice storms have caused damage to utility infrastructure surrounding several TTLs, including regions containing the Lac du Flambeau Reservation in Wisconsin, the Huron Potawatomi Reservation in southern Michigan, and the Sac and Fox/Meskwaki Settlement in Iowa. Historically, the northern areas of Wisconsin and the Upper Peninsula of Michigan have seen a lower frequency of damaging ice storms than areas located further south, indicating that TTLs in the northern regions may be less vulnerable to damage from winter storms (USACE 2014).

Convective storms can damage electric grid infrastructure (DOE 2015a). Severe convective storms, which can include lightning, high winds, and tornadoes, can severely damage electric grid infrastructure and are the largest source of weather-related outages in the United States (DOE 2015a). All elements of grid infrastructure may be damaged by tornadoes and extremely high winds, and tornadoes can damage infrastructure by striking equipment or striking trees, causing branches to fall on lines. For example, in 2013, a severe storm with straight-line winds that reached 100 mph knocked out power to hundreds of residents of the Menominee Indian Reservation in Wisconsin (The Shawano Leader 2013).

Extremely hot days increase vulnerability of electric power supply

TTLs such as the L'Anse Reservation in the Upper Peninsula of Michigan are projected to experience significant changes in temperature. TTLs may see an average temperature increase of more than 5°F by mid-century (NOAA 2013e).

High temperatures affect both demand for electric power and the capacity of infrastructure to supply it (DOE 2013a). System failures can occur when extreme temperatures increase peak demand for air conditioning while simultaneously reducing the capacity to generate, transmit, and distribute power (DOE 2013a). Consequently, TTLs in the Midwest including the L'Anse Reservation may become more vulnerable to power outages or brownouts as a result of climate change (USCGRP 2014).

Increasing air temperatures and higher nighttime temperatures reduce transmission capacity and increase the risk of damage to transformer equipment (DOE 2013a, Bérubé et al. 2007). Higher temperatures projected for the Midwest may affect power transmission and distribution lines by increasing the risk of temperature-related physical damage to transmission lines and decreasing the capacity of grid infrastructures (DOE 2013a). High temperatures increase the risk of physical damage to electric grid infrastructure. For example, transformers can reach critical temperatures during emergency overloading, and power lines are more vulnerable to physical damage from interference with trees and other objects as high temperatures cause lines to sag as they expand (Hashmi et al. 2013, DOE 2013a).

To protect infrastructure from permanent heat-related damage, electric grid operators may reduce capacity on hot days (Sathaye et al. 2012, USBR 2000). A study found that a 9°F temperature increase could cause transmission capacity to decrease by 7%–8% and distribution and transmission grid efficiency to decrease 1.5%–2.5% (Sathaye et al. 2012); summer temperatures in the Midwest are projected to increase 4.5°F–6.0°F (NOAA 2013e). System losses are highest during peak demand periods (Sathaye et al. 2012), and without upgrades to the aging electric grid infrastructure serving TTLs in the Midwest (USGCRP 2014), residential and commercial customers may experience a decrease in the total power available to them during extreme heat waves, when demand for cooling is highest (DOE 2013a). As utilities face increasing hazards they may need to invest in additional capacity, maintenance, and repairs to ensure reliable service, and tribal residents and businesses may experience an increase in the cost of electricity.

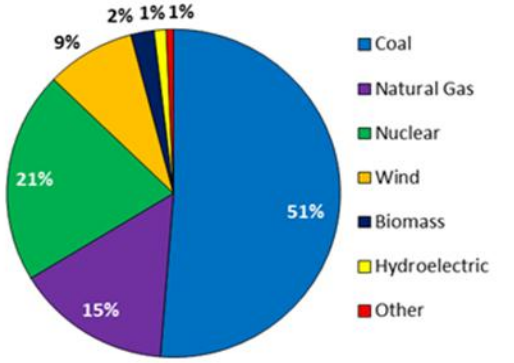

Figure 6-4. Coal dominates the fuels used for electricity generation in Midwestern states with TTLs (Iowa, Michigan, Minnesota, and Wisconsin).
Source: EIA 2013b

Increasing frequency of extreme precipitation events put transmission and distribution infrastructure at greater risk of inundation from flooding (DOE 2013a, USGCRP 2014). Climate change is projected to increase the number of heavy rainfall events in the Midwest region, and flooding may present a threat to low-lying electric grid infrastructure, such as substations. The Hannahville Reservation in the Upper Peninsula of Michigan and the Red Lake and White Earth Reservations in Minnesota may all experience more than a 40% increase in the number of days per year with extreme precipitation events (days with >1 inch of precipitation). Flooding can be especially severe in the Midwest when heavy precipitation combines with melting snow (USGCRP 2014).

ELECTRIC POWER GENERATION

Potential extreme weather impacts:

- Storm damage to power plants

Potential climate change impacts:

- Decreased efficiency and available generation capacity from thermoelectric power plants due to higher air and water temperatures
- Increased risk of flood damage to power plants due to increasing extreme precipitation events

TTLs in the Midwest have few onsite power generation resources (EIA 2014c), and therefore rely on power that is produced offsite to serve the electricity demands of tribal businesses and residents. There are several ways that climate change and severe weather can negatively affect the power generation infrastructure that serves TTLs in the Midwest, and impacts on power generation will likely be felt on TTLs through increasing power outages or increased prices, if utilities increase or upgrade generation capacity to ensure reliable service to customers.

Rising air and water temperatures decrease the efficiency of thermoelectric power plants and could decrease available electricity generation capacity (DOE 2013a). Increasing temperatures projected for the Midwest will decrease the efficiency of power generation from power plants using natural gas, coal, biomass, and nuclear fuels to generate electricity ("thermoelectric" power plants). Thermoelectric power plants produce 90% of power in states with TTLs (see Figure 6-4), with coal supplying over half of total electricity production (EIA 2013f). As temperatures increase, power plants require more water for cooling, operating less efficiently (DOE 2013a, UCS 2011).

If water temperatures increase above a certain threshold, power plants may be at risk of exceeding the mandated limits on the temperature of water discharged back to the environment. When this occurs, power plants can be forced to curtail production (DOE 2013a). All of these temperature-related impacts may increase the risk that power plants providing electricity to TTLs will experience reduced power output and higher costs for capacity additions, environmental measures, or efficiency improvements that may be passed on to customers including residents and businesses on TTLs.

Decreasing efficiency of biomass power generation

The Midwest's agricultural industry and abundant forests provide agricultural byproducts and wood to power biomass power plants, which provide 2% of the net power produced in states with TTLs (EIA 2013b). These thermoelectric power plants require water for cooling, and may be affected by increasing air and water temperatures. For tribal communities invested in biomass power generation enterprises, such as the Koda Energy power plant jointly owned by the Shakopee Mdewakanton Sioux Community in Minnesota (Figure 6-5) (Koda Energy 2015), increasing temperatures due to climate change may reduce future power output capacity and revenue from retail sales of power.

Figure 6-5. The Koda Energy Power Plant jointly owned by the Shakopee Mdewakanton Sioux Community generates enough energy to power 30,000 homes in Shakopee, Minnesota (DOE 2010).
Source: DOE 2014b

Flooding associated with severe convective storms and increasingly frequent extreme precipitation events can damage power plants (DOE 2013a). Inland power plants tend to be located in low-lying areas near rivers and floodplains (DOE 2013a), and may be at risk because of the projected increase in not only total precipitation in the Midwest region but also the frequency of heavy precipitation events (days with more than one inch of precipitation) (NOAA 2013e). Especially when combined with melting snow, heavy precipitation can cause severe flooding in the region (USGCRP 2014). As a result, power plants serving TTLs in the Midwest may become more vulnerable to critical disruptions in power production and operation as a result of inundation from flooding. Power plants serving TTLs in the Midwest are also at risk of flood and wind damage during severe convective storms.

Fuel Supply

FUEL TRANSPORT

Potential extreme weather impacts:

- Storm damage to transportation infrastructure and possible disruptions in fuel supply

Potential climate change impacts:

- Increased risk of disruption of fuel supply, including gasoline, diesel, fuel oil, and propane, as a result of flooding caused by extremely heavy precipitation

The network of infrastructure supplying solid, liquid, and gaseous fuels to customers in the Midwest is diverse, and includes interstate pipelines carrying petroleum products and natural gas, railways transporting crude oil and coal, and waterways delivering fuels by tanker and barge (EIA 2014c). Many of the TTLs in the region are located near the Great Lakes, which contain important ports in the regional petroleum supply chain, including the port of Escanaba serving Michigan's Upper Peninsula, and the ports of Detroit, Port Huron, and Chicago to the south (EIA 2014c). Petroleum products and coal are also delivered via the Upper Mississippi waterway (EIA 2014c). Both natural gas and petroleum product pipelines move fuel into the Midwest from both Canada and domestic points in the western and southern United States (EIA 2014c). Finally, roadways likely represent critical infrastructure for TTLs receiving fuels such as gasoline, diesel, and propane that are often delivered by truck to their final destinations.

Thirty-six percent of households using propane are located in the Midwest, and Michigan has the highest residential propane consumption of any state in the nation (EIA 2014c, EIA 2014d). Propane deliveries to TTLs in the northern Midwest may be vulnerable to disruptions in supply as a result of winter storms or flooding from the projected increase in precipitation and extreme precipitation caused by climate change. Propane enters the upper Midwest via pipelines (Mid-American and ONEOK) flowing north from Kansas and, the Cochin Pipeline originating in Canada, and is increasingly brought into the region by rail and long-range trucking (EIA 2014e, EIA 2015b). Propane tanks are then distributed by truck to retail outlets or customers on TTLs.

Severe winter weather may disrupt fuel transport (DHS 2014)**.** Snow, ice, and high winds associated with winter storms can cause major disruption to the transport of fuels in several ways. Road closures, as well as slower speeds on highways and secondary roads, can cause delays in the supply of critical liquid fuels such as gasoline, fuel oil, and propane to TTLs (DOT 2006, DHS 2014). Furthermore, because natural gas pipelines and fuel storage facilities often require electricity to operate equipment (NERC 2011), power outages caused by downed transmission and distribution lines can also cause disruptions in fuel supplies when, for example, pipeline pumps become inoperable (DOE 2013a). Winter storms can cancel or delay fuel shipments by rail when snow accumulation interferes with rail switches (DHS 2014). Ice accumulation on vessels can create hazards for vessels transporting fuels on critical waterways serving markets in the Midwest. Extreme cold associated with winter storms can also create disruptions in fuel transport when heavy ice interferes with the function of port facilities and inland waterway infrastructure (DHS 2014).

Extreme precipitation and regional propane supply

Because the agricultural processing industry in the Midwest uses propane for drying grain, wet weather can significantly affect the demand for propane and has been a contributing factor to regional supply constraints (EIA 2014e). Climate change is projected to increase average precipitation in the Midwest is by 6%-12% by mid-century (NOAA 2013e). Absent new propane transport and storage capacity, a higher industrial demand for agricultural drying could translate into an increased risk of future propane shortages for residential heating on TTLs.

Severe convective storms can damage fuel transportation infrastructure and disrupt fuel supply lines (CCSP 2008, NOAA 2015b). Lightning and tornadoes associated with severe convective storms can damage aboveground elements of fuel transportation infrastructure. Tornadoes can damage sections of pipeline and compressor stations (Kinder Morgan 2008, Unger 2013), and have the ability to lift cars and knock over railcars (NOAA 2015b). High winds can cause rollovers, derailment of stationary and moving cars, and damage to highway signs (CCSP 2008, Rossetti 2007). Additionally, lightning and high winds can damage road and rail signaling equipment (CCSP 2008, Rossetti 2007).

Flooding impacts on roadways

In December 2014, severe flooding shut down a key road serving the Menominee Tribe of Indians located on the Menominee Reservation near Keshena, Wisconsin. The road was closed for four days after floodwaters from the Wolf River and an ice jam created a backup of water that required imported generators and pumps to remove (Phelps 2014).

More frequent extreme precipitation events may increase the risk of damage and disruption to fuel transportation infrastructure (DOE 2013a, USGCRP 2014). Flooding and inundation caused by heavy rainfall can cause major damage and disruption to critical fuel transport infrastructure including roads, bridges, pipelines, and railways (DOE 2013a). In addition to temporary disruptions in service, prolonged flooding can result in structural damage including weakened roadbeds and railway beds (USGCRP 2014). Especially in the Midwest, heavy rainfall and rapid snowmelt (quickened by rising temperatures) can contribute to extreme flooding when these events are combined (USGCRP 2014).

The Midwest contains a dense network of railways that are important components of fuel transport in the region (EIA 2014c). Railways supply propane and other petroleum products to markets serving TTLs. Both railways and waterways are important to the supply of coal to Midwest power plants (EIA 2014c). Railways often follow low-lying terrain along riverbeds (DOE 2013a), and extreme flooding has the potential to disrupt rail transport of these fuels, with the potential to impact several energy sectors at the same time. Similarly, flooding in waterways can disrupt barge traffic carrying fuels destined for Midwest power plants or communities on Midwest TTLs (EIA 2011b).

Chapter 7: NORTHEAST TRIBAL LANDS

Key Climate Change and Extreme Weather Hazards Affecting Tribal Trust Land Energy Systems in the Northeast

- **Severe storms:** Powerful winter storms and strong convective storms may disrupt fuel supply lines and damage electric grid infrastructure, leading to power outages.
- **Rising temperatures:** Higher temperatures and increasing heat waves may make power outages more likely, and associated increases in electricity demand may increase energy bills.
- **Increasing frequency of intense hurricanes and extreme precipitation:** Increasing frequency of intense hurricanes, extreme precipitation events, and resultant flooding and storm surge may damage and disrupt electricity and fuel supply to tribal trust lands.

OVERVIEW OF NORTHEAST REGION

The 18 federally recognized tribal trust lands (TTLs) in the Northeast region are home to approximately 17,000 residents (U.S. Census Bureau 2010a) (Table 7-1). These TTLs are located in Connecticut, Maine, Massachusetts, New York, and Rhode Island, as shown in Figure 7-1 (U.S. Census Bureau 2010b). Most of these lands do not contain major energy infrastructure on the property; instead, residents and businesses rely heavily on energy imported from elsewhere in the region and on critical infrastructure located outside the boundaries of the TTLs.[28]

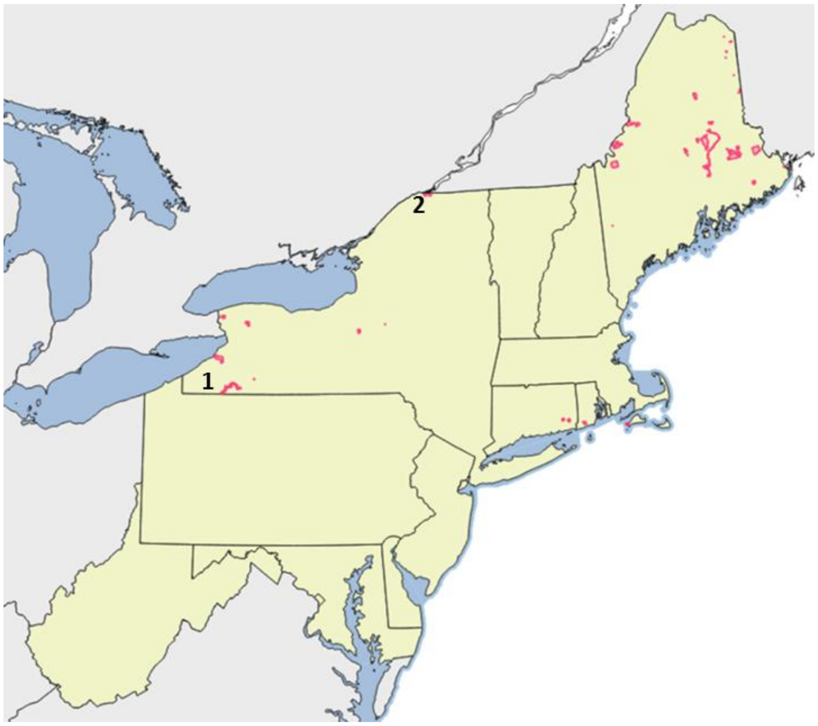

Figure 7-1. TTLs are located in five states of the Northeast region. *Numbers associated with large reservations correspond to numbering in Table 7-1.* Graphics source: Energetics 2015; Data source: U.S. Census Bureau 2015

Electricity Supply

With the exception of the Mashantucket Pequot Nation, which gets some of its

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[28] "Major energy infrastructure" includes the following: high-voltage (>345 kV) transmission lines; large (>1 MW) electric generation plants; oil, natural gas, or coal production areas; oil refineries; natural gas processing plants; and crude oil, petroleum product, or natural gas pipelines.

electricity from an on-site natural gas-fired generator, tribal residents and businesses in the region depend on large offsite power plants to generate their electricity as there are no major power plants on TTLS (EIA 2014c, Hallenbeck 2010). Electricity is typically generated at major power plants before being transmitted long distances by high-voltage transmission lines to large transformers that reduce the voltage. Power is then delivered to tribal residents and businesses by low-voltage distribution lines.

Table 7-1. TTLs in the Northeast.

States with TTLs:	Connecticut, Maine, Massachusetts, New York, Rhode Island	
Number of TTLs:	18	
Total population:	17,000	
Total area (square miles):	500	
Large TTLs*		
Trust Land Name	**Population****	**Total Area (sq miles)**
1) Allegany Reservation (NY)	6,490	49
2) St. Regis Mohawk Reservation (NY)	3,228	21

*Note: "Large" tribal trust lands are those lands >300 square miles in area and/or with >3,000 Native American residents

**Note: The population of TTLs refers to the number of residents on each TTL according to the 2010 Census, not the number of enrolled members of each tribe.

Sources: U.S. Census Bureau 2010a, U.S. Census Bureau 2010b

Fuel Supply

Since TTLs in the Northeast do not produce natural gas or oil (EIA 2014c), they must rely primarily on pipelines and trucks to deliver natural gas and liquid fuels, including motor gasoline, fuel oil, and propane, from offsite production areas. The region obtains most of its natural gas by pipeline from Canada, the Marcellus Shale, and the Gulf Coast (EIA 2014c). Natural gas is also imported at three liquefied natural gas (LNG) import terminals located in Canada and Massachusetts (EIA 2014c). There are no major liquid fuels pipelines moving into New England,[29] so residents and businesses in the region are dependent on other methods for supply of petroleum products (EIA 2014c). In New York, the TTLs depend on fuel shipments from terminals in New Jersey and Pennsylvania supplied by the Colonial Pipeline (EIA 2014c).

IMPLICATIONS FOR ENERGY SECTOR

Climate change is expected to affect almost every subsector of energy infrastructure serving TTLs through increasing temperatures and flooding associated with increases in heavy precipitation events and in the frequency of intense hurricanes (see Table 7-2). Tribal energy systems in the Northeast are also vulnerable to extreme weather events including winter storms.[30]

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[29] New England includes Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont.

[30] This report describes vulnerabilities of tribal energy systems related to both climate change and extreme weather. "Potential climate change impacts" refer to threats to tribal energy systems that are projected to change (increase, in most instances) compared to historical norms. Climate change impacts in the Northeast include warmer air and water temperatures, increasing annual precipitation and heavy rainfall events, rising sea levels, and increasing frequency of intense hurricanes. "Potential extreme weather impacts" refer to weather events that threaten tribal energy systems, but quantifying the effects of climate change on the frequency, duration, or severity of these events is still an area of active research. Such extreme weather impacts include convective and winter storms. In this report, potential extreme weather impacts are not associated with a trend but rather as a continued threat to tribal energy systems.

Table 7-2. Examples of extreme weather and climate change impacts that could adversely affect the energy infrastructure serving TTLs in the Northeast.

Extreme weather event or climate change trend affecting energy infrastructure	Potential implications for tribes
Severe storms, including convective and winter storms	
• Risk of damage to coastal and inland electric grid and electric generation infrastructure	• Power outages and damage to energy infrastructure on TTLs
• Damage to roads and rail lines, potentially rendering them impassable for energy transport	• Potential disruption in fuel supply
Rising air and water temperatures	
• Increased demand for average and peak cooling energy	• Higher electricity bills for cooling in the summer
• Reduced transmission capacity and efficiency and reduced service life of some electrical equipment	• Greater likelihood of power outages and potential for higher electricity costs
• Decreased available generation capacity of thermoelectric power plants	• Greater likelihood of power outages and potential for higher electricity costs
Increasing annual precipitation and frequency of heavy precipitation events	
• Increased risk of flooding of low-lying coastal and inland electric grid infrastructure	• Greater likelihood of power outages and damage to energy infrastructure on TTLs
Increasing frequency of intense hurricanes and accelerating sea level rise	
• Increased risk of flooding and wind damage to electric grid infrastructure	• Greater likelihood of power outages and damage to energy infrastructure on TTLs
• Increased risk of damage at power plants	• Greater likelihood of power outages and damage to energy infrastructure on TTLs
• Increased risk of damage and disruption of transportation infrastructure	• Disruption in fuel supply

Energy End-Use

Potential climate change impacts:

- Increased electricity demand for cooling in the summer
- Decreased energy demand for propane, fuel oil, wood, electricity, and natural gas for space heating in the winter

Residents and businesses on TTLs in the Northeast rely on energy for heating during cold winters and, to a lesser extent, for cooling during hot summers. Cooling drives electricity demand in the summertime, and summer peak demand is greater than winter peak demand for most utilities in the region, including the Mohegan Tribal Utility Authority (EIA 2013a). In the winter, the region primarily relies on natural gas, fuel oil, propane, and wood for space heating. In 2013, only 14% of households in the Northeast used electricity for heating (EIA 2013g). Propane is the primary heating fuel for residents of the Cattaraugus Reservation (Table 7-3), but throughout all reservations and trust lands in the United States, wood serves as the primary heating fuel (U.S. Census Bureau 1995). In rural areas of New England, including TTLs, nearly 50% of households rely on relatively low-cost wood for heat (EIA 2013g).

Table 7-3. Primary household heating fuel in selected Native American communities in the Southeast.

TTL	Primary heating fuel (percentage of households using fuel)
Cattaraugus Reservation, NY	Tank gas including propane (38%)

Source: U.S. Census Bureau 1995

Higher temperatures are likely to increase the demand for cooling energy (DOE 2013a, NOAA 2013c, USGCRP 2014). Summer air temperatures near the Allegany and St. Regis Mohawk Reservations are projected to increase by 5.5°F and 4.5°F, respectively, by mid-century under a high emissions scenario (NOAA 2013c). As average temperatures and the number of extremely hot days increase, the number of cooling degree days (CDDs), used to estimate cooling energy demand, will also increase (see Figure 7-2).31 The average number of CDDs within a given year is projected to increase by 77% in the Northeast by mid-century (2041–2070, compared to 1971–2000). In New York and New England, an additional 600 CDDs are projected by mid-century (2041–2070, compared to 1980–2000) if emissions continue to increase (NOAA 2013c).

Air conditioning use in the region is historically low, but the increasing number of CDDs may drive residents and businesses on TTLs to use more air conditioning; this may compound the increase in demand for electricity, leading to a nonlinear increase in demand (Auffhammer 2011, DOE 2013a, EIA 2013c) as well as higher energy bills in the summer (DOE 2013a). (For more information on the impact of increasing temperatures on peak energy demand, see box on “Electricity supply vulnerabilities during peak demand periods.”)

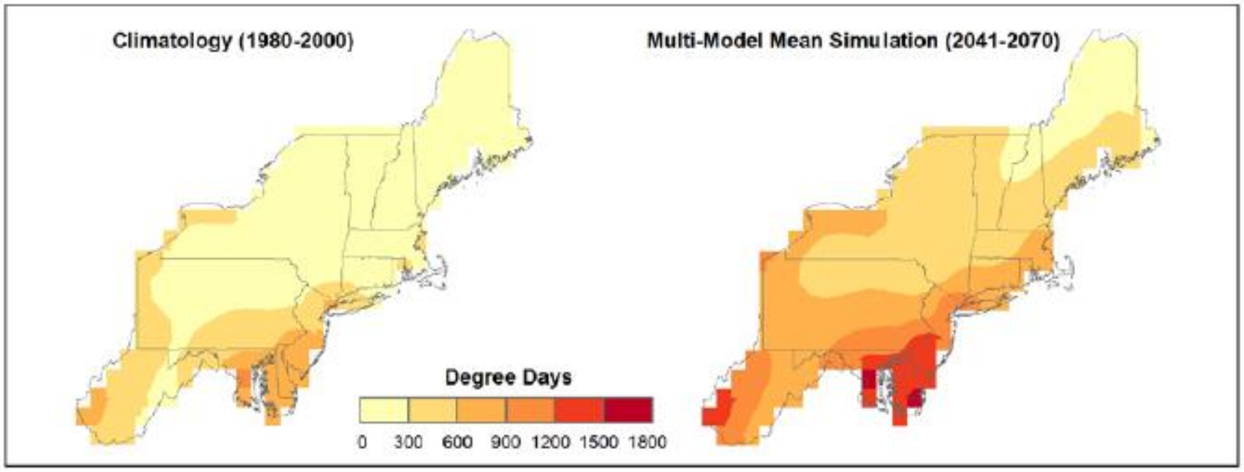

Figure 7-2. The mean annual number of CDDs for the Northeast region is projected to increase significantly from 1980–2000 (left) to 2041–2070 (right) under a high emissions scenario.
Source: NOAA 2013c

Warmer winter temperatures are likely to reduce demand for heating energy (DOE 2013a, NOAA 2013c, USGCRP 2014). Increasing winter temperatures are projected to decrease heating energy demand, measured by the number of heating degree days (HDDs) per year in the region, by 17% by mid-century (2041–2070, compared to 1971–2000).[32] New York and New England are projected to see a decline of 1,100–1,500 HDDs by mid-century under a high emissions scenario (NOAA 2013c).

Fewer extremely cold nights and HDDs may reduce energy demand for heating in the TTLs. For example, the Allegany and St. Regis Mohawk Reservations are projected to see decreases of up to 1,100 and 1,300 HDDs, respectively, which may significantly decrease energy demand for heating (DOE 2013a, NOAA 2013c). A study on energy use in Massachusetts found that, by 2020, the projected decrease in HDDs could lead to a 7%–8% decrease in space heating, which currently makes up 60% of total residential energy use in New England and 56% of total residential energy use in New York (CCSP 2008, EIA 2013f). Depending upon the type of fuel used and changes in the cost of fuel itself, this decreased need for space heating could reduce the dollars spent for heating on TTLs.

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[31] A CDD is calculated from the sum of the daily variation of temperature above a baseline temperature, typically 65°F. It is a proxy for the energy needed to cool a space. See Appendix A for additional information.

[32] An HDD is calculated from the sum of the daily variation of temperature below a baseline temperature, typically 65°F. It is a proxy for the energy needed to heat a space.

Electricity Supply

ELECTRIC GRID

Potential extreme weather impacts:

- Storm damage to grid infrastructure located on or connected to tribal trust lands

Potential climate change impacts:

- Increased risk of flood or heat damage to the grid infrastructure located on or connected to tribal trust lands
- Decreased efficiency and capacity of transmission lines from increasing temperatures

Several electric utilities, including a single tribal utility authority (Table 7-4), provide electric service on TTLs in the Northeast region (EIA 2013a). The TTLs rely on a power transmission and distribution infrastructure that is susceptible to damage and disruption from extreme weather events and rising temperatures. Residents and businesses depend upon the efficient operation of the distribution infrastructure that is located on the tribal lands and may be owned and/or operated by the tribes. Infrastructure located in coastal TTLs, such as the Wampanoag-Aquinnah Trust Land in Massachusetts, Narragansett Reservation in Rhode Island, and Mashantucket Pequot and Mohegan Reservations in Connecticut, may be particularly vulnerable to more frequent and intense hurricanes.

Table 7-4. Tribal energy infrastructure in the Northeast includes a tribal utility authority.

Utility Name	Residential Customer Count	Total Customer Count	Summer Peak Demand (MW)	Winter Peak Demand (MW)
Mohegan Tribal Utility Authority	0	65	27	19

Source: EIA 2013a

No high-voltage transmission lines are located on TTLs in the Northeast (EIA 2014c). Electricity in the region is generated outside of TTL borders, and offsite power lines delivering electricity to onsite communities must be considered when identifying potential vulnerabilities. Damage to or disruption of the infrastructure (e.g., transmission lines and substations) delivering electricity to the distribution lines could lead to widespread or localized power outages, including on TTLs (DOE 2013a).

Winter storms, with associated ice and heavy snowfall, and convective storms can damage electric grid infrastructure (USACE 2014). Winter storms can damage the infrastructure for the electric grid in the Northeast, potentially leading to prolonged power outages on TTLs. In the United States, winter ice storms have caused 5% of the largest blackouts (Campbell 2012). Five of the eight TTLs located in New York, including the two largest TTLs in the Northeast, are adjacent to Lake Erie—where they receive 100–300 inches of snow each year (on average), some of which falls during heavy, lake-effect snow events (Cattaraugus County DPW & Cattaraugus County DES 2006). For example, power was knocked out to more than 80,000 Niagara Mohawk Power Corporation customers in the region of New York bordering the Great Lakes during a 2013 ice storm, and customers experienced recurring outages for several days following the ice storm (National Grid 2014). Niagara Mohawk Power, which provides electric service to eight TTLs in the Northeast, including the

Hurricane Sandy-induced damage to electric grid infrastructure on TTLs

When Hurricane Sandy made landfall in October 2012, the Narragansett Reservation in Rhode Island reported that downed trees on reservation lands damaged the grid infrastructure, causing major power outages. The Indian Health Service sent generators to the reservation, which enabled the continued functioning of the reservation government, but power was out on the rest of the reservation for several weeks (ICTMN 2012).

Allegany and St. Regis Mohawk Reservations, reported that the storm downed 386 lines and damaged 82 poles and 35 transformers in the area (National Grid 2014).

During ice storms, ice can coat transmission and distribution lines, potentially causing the lines to sag and the poles to break (USACE 2014). If ice-covered lines do not break during the storm itself, they may suffer damage from tree branches as they rebound quickly when the ice melts (USACE 2014). During winter storms with high winds, transmission lines and support structures with little ice accretion may be damaged when the lines oscillate or gallop (USACE 2014). [33]

During winter storms, high winds, ice formation, or heavy snow on the trees can cause large branches to break and fall on the power lines, which may then overload the poles, causing them to snap (Abi-Samra et al. 2014, USACE 2014). Failure of a single pole may initiate a long line of pole failures and lead to significant damage (USACE 2014). Similarly, the failure of components in the transmission wire system can trigger a cascading failure of the support structure for ten miles or more (USACE 2014).

Severe convective storms can also cause damage to electric grid infrastructure, as lightning can damage equipment and tornadoes can down transmission and distribution lines and damage poles and transmission structures (Duke Energy 2015). High winds during severe storms can blow lines into other objects, shorting the line (Duke Energy 2015). For instance, in 2008 and 2012, thunderstorms and high winds damaged electric grid infrastructure serving the St. Regis Mohawk Reservation, resulting in power outages on tribal lands (Indian Time 2008, Raymo 2012)

Increasing frequency of intense hurricanes puts transmission and distribution infrastructure at greater risk of damage (DOE 2013a, USGCRP 2014). Intense hurricanes are projected to occur more frequently, making the electric grid infrastructure more vulnerable—particularly near the coasts—to wind and tree damage and the risk of prolonged power outages. During hurricanes, heavy winds and increased tree strikes could bring down transmission and distribution lines, potentially cutting power to TTLs (DOE 2013a, GAO 2014).

Increasing frequency of extreme precipitation events and intense hurricanes may put coastal and inland transmission and distribution infrastructure at greater risk of inundation from flooding and sea level rise-enhanced storm surge (DOE 2013a, USGCRP 2014). The projected greater frequency of both extreme precipitation events and intense hurricanes increases the risk that low-lying coastal and inland electric grid infrastructure will become inundated. Flooded grid equipment can cause outages on TTLs and can be costly and time-consuming to repair. Equipment exposed to salt water can be destroyed if immersed for only a few hours (ConEd 2013).

The risk of flood damage to coastal infrastructure during hurricanes is exacerbated by rising sea levels (USGCRP 2014). Electric grid infrastructure, including infrastructure serving TTLs, is concentrated along the coastline in the Northeast and may be damaged or disrupted by sea level rise-enhanced storm surge (EIA 2014c, FEMA 2015). For example, the high-voltage transmission line serving the two TTLs in Connecticut originates at the Long Island Sound near New London, CT. Similarly, the high-voltage transmission line serving the Narragansett Reservation originates near Narragansett Bay. During Hurricane Sandy, New London was flooded by a 6.5 foot storm surge, and locations along Narragansett Bay saw a 5.1–6.2 foot storm surge (Savageau 2013).

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[33] Power lines “gallop” when ice builds up on the power line, causing it to sway and buck in the wind. In high winds, or with sufficient ice buildup, galloping power lines can be very dangerous, as they may eventually fail, snapping power poles or causing lines to fall.

Increasing air temperatures increase the risk of damage to transformer equipment and reduce transmission capacity and efficiency (Bérubé et al. 2007, DOE 2013a). Elevated temperatures can also lead to the thermal expansion of materials, causing lines to sag and increasing the risk of power outages when lines come into contact with trees, the ground, or other lines (DOE 2013a). Higher temperatures may also damage substations by causing materials in substation transformers to degrade more quickly (Bérubé et al. 2007, DOE 2013a, Hashmi et al. 2013). Higher nighttime-temperatures may also prevent lines from cooling down, potentially amplifying vulnerabilities posed by higher daytime temperatures (DOE 2013a). Higher temperatures increase the resistance of conductors, which reduces the carrying capacity of the transmission lines, and during high-temperature periods, operators may reduce transmission capacity to prevent permanent damage to grid equipment (Sathaye et al. 2012). For example, a 9°F increase in temperature could result in a 7.5% decrease in transmission line capacity and a 1.5%–2.5% decrease in transmission and distribution efficiency, according to one study (Sathaye et al. 2012). System losses are also highest during periods of peak demand (Sathaye et al. 2012), and electricity supply could be disrupted during periods of high demand.

Electricity supply vulnerabilities during peak demand periods

The projected increase in extremely hot days in regions of the Northeast where TTLs are located is expected to increase peak electricity demand in those areas—while simultaneously decreasing the efficiency of and capacity for electricity generation and transmission.

By mid-century, the Allegany Reservation, along with other TTLs in New York, may see up to nine more days per year in which temperatures rise above 95°F (NOAA 2013c). In response to these higher temperatures, residents and businesses on TTLs (as elsewhere) are expected to increase their use of energy for cooling, including air conditioning (Auffhammer 2011, DOE 2013a). Increased demand for average and peak cooling energy across the Northeast region as a whole may tax the ability of the utilities serving TTLs to efficiently deliver power to their customers.

Increasing temperatures also decrease available generation capacity and the capacity of transmission lines (DOE 2013a). To prevent serious damage, utilities may take transmission lines out of service and reduce the capacity of transformers when demand peaks in hot weather (DOE 2013a, Hashmi et al. 2013, USBR 2000). This decrease in generation and transmission capacity during peak demand periods may increase the risk of power outages on TTLs on extremely hot days.

ELECTRIC POWER GENERATION

Potential extreme weather impacts:

- Storm damage to power plants

Potential climate change impacts:

- Decreased efficiency and available generation capacity from thermoelectric power plants due to higher air and water temperatures
- Increased risk of flood damage to power plants due to increasing frequency of intense hurricanes, extreme precipitation events, and sea level rise

While the Mashantucket Pequot Nation can generate electricity on a limited scale, most TTLS do not have electric power generation facilities and rely entirely on off-site power generation (EIA 2013e, EIA 2014c). Climate change impacts such as higher temperatures and increasing frequency of intense hurricanes and extreme precipitation events raise the likelihood of damage or disruption to both on- and off-site power generators.

Thermoelectric power plants, which use fossil fuels, nuclear energy, biomass, and solid waste to heat water and produce steam that will turn the turbines, generate more than 80% of the electricity consumed by states with TTLs in the Northeast (EIA 2013b). Natural gas-fired power plants account for more than half of the generation capacity in these states (EIA 2013b, 2013e). Nuclear power is a significant portion of the generation fuel mix in Connecticut, Massachusetts, and New York, while coal-fired generation represents a relatively small portion (3%) of the fuel mix in the states with TTLs (see Figure 7-4) (EIA 2013b).

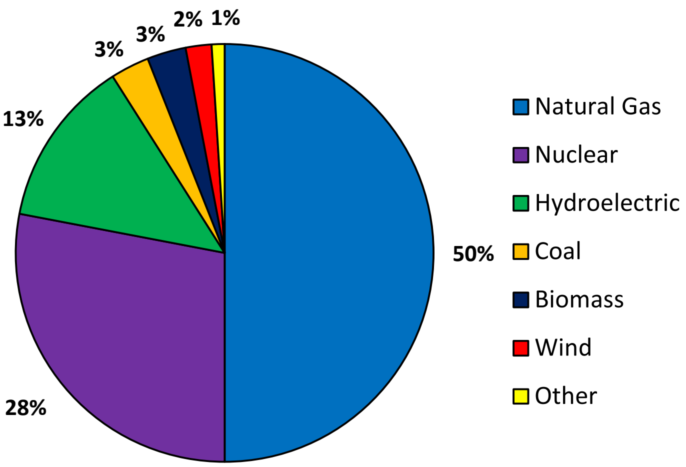

Figure 7-3. Fuels for electricity generation are dominated by natural gas and nuclear power in Northeast states with tribal trust lands, 2012 (Connecticut, Maine, Massachusetts, New York, and Rhode Island).
Source: EIA 2013a

Rising temperatures decrease the efficiency of thermoelectric power plants and could decrease their available generation capacity (DOE 2013a). The efficiency of thermoelectric power plants decreases as air and water temperatures rise. TTLs in the region are served by on- and off-site natural gas-fired generators, which lose 0.6%–0.7% efficiency for every 1.8°F increase in air temperature (DOE 2013a). Summer temperatures at the Mashantucket Pequot Tribal Nation, which uses natural gas-fired generators housed on the reservation, are projected to increase by up to 5.0°F by mid-century (2041–2070, compared to 1971–2000) under a high emissions scenario (NOAA 2013c). This temperature increase could decrease efficiency of the generators, which currently have an 82.5% efficiency rating, by more than 1.6 percent (DOE 2013a, NOAA 2013c, Solar Turbines Inc. 2013).

These losses in efficiency would be compounded by increasing water temperatures. When water temperatures increase, plants require more water for cooling, and the plants operate less efficiently (UCS 2011).

As water temperatures increase, nuclear power plants may be forced to shut down operations, and thermoelectric power plants may also face forced curtailments to avoid exceeding thermal discharge limits imposed to prevent ecological damage (DOE 2013a). For example, in 2012, Dominion Resource had to shut down a reactor at the Millstone Nuclear Plant in Connecticut, an important generation source in the region located less than 20 miles from the Mohegan Reservation, because the water in Long Island Sound rose above 75°F, the highest temperature at which the plant could operate safely (Wald 2012). As a result, approximately 255,000 MWh of power were lost (DOE 2013a).

Figure 7-4. The Millstone Power Station in Connecticut was shut down in 2012 because of high water temperatures.
Source: USNRC 2015

Many coal and natural gas-fired power plants in the region use advanced cooling technologies that are less vulnerable to increasing water temperatures. However, 28% of the generating capacity in states with TTLs in the Northeast use freshwater for once-through cooling systems and could therefore be at risk of curtailments with increasing water temperatures (UCS 2012).

Increasing frequency of intense hurricanes and extreme precipitation events may increase the vulnerability of power plants to damage from flooding and sea level rise-enhanced storm surge (DOE 2013a, USGCRP 2014). Flooding during severe convective storms, extreme precipitation events, and intense hurricanes may damage power plants that are located on or serve TTLs, and facilities along the coast may be susceptible to sea level rise-enhanced storm surge. Thermoelectric power plants are typically located near a major water source, and power plants that are located along the coast, in river valleys, or in other low-lying areas are particularly susceptible to flooding. In the Northeast, estimates suggest that 10 power plants in states with TTLs are less than 4 feet above sea level and may be particularly vulnerable to the combined effects of sea level rise and storm surge (Climate Central 2014).

Fuel Supply

FUEL TRANSPORT

Potential extreme weather impacts:

- Storm damage to transportation infrastructure and possible disruptions in fuel supply

Potential climate change impacts:

- Increased risk of disruption of fuel supply, including gasoline, diesel, fuel oil, and propane, as a result of flooding caused by increasing frequency of intense hurricanes, extremely heavy precipitation, and sea level rise
- Reduced risk of disruption to natural gas supplies due to increasing winter temperatures

Tribal residents and businesses depend upon fuel transport for their energy supplies and products. Customers in New England—where most of the TTLs in the region are located—rely on marine terminals to receive petroleum products, which are then transported further inland by rail, truck, and barge (EIA 2014c). New York receives petroleum products through the Colonial pipelines, but New England has no liquid fuel pipelines bringing fuels into the region (EIA 2014c).

Petroleum products are transported to TTLs in New England from the large ports of Providence, Boston, and Portland. Connecticut receives petroleum products from ports in New Haven, New London, and Bridgeport. Refined products are brought into states containing TTLs in New England through the Port of Providence and ports in Searsport and Calais, Maine. Heating oil is also brought into Maine through the Port of Portsmouth, New Hampshire. Approximately 13% of all natural gas used in New England is imported as LNG through terminals in Everett, Massachusetts, and New Brunswick, Canada, and the remaining natural gas is imported to the region by pipeline (EIA, personal communication, 2015). The region's reliance on imported fuels makes the TTLs in the Northeast particularly vulnerable to disruptions in fuel supply.

Natural gas-fired power generation on TTLs

The Mashantucket Pequot Tribal Nation in Connecticut installed a cogeneration system at its Foxwoods Resort Casino. The system consists of two natural gas-fired generators with a combined capacity of 13.2 MW (EIA 2013f, Hallenbeck 2010). The system provides power to the casino and is expected to supply more than half of all electricity consumed on the Mashantucket Pequot Reservation (Hallenbeck 2010), which is home to 299 people (U.S. Census Bureau 2010a).

The Foxwoods Resort Casino, where the system is located, is within 10 miles of the coast and may be vulnerable to wind damage from increasingly frequent intense hurricanes (DOE 2013a, USGCRP 2014). The system may also be susceptible to flood damage from rainfall during intense hurricanes and extreme precipitation events, but it is situated more than 90 meters above sea level (DOE 2013a, USGCRP 2014).

Severe storms can disrupt fuels transport (DHS 2014)**.** During winter storms, snow, ice, and debris can close roadways, delaying fuel shipments. Heavy snow, as experienced by the Allegany Reservation during lake-effect snowfall, can result in road closures and significantly reduce road capacity and interstate speeds on roads that are not closed (DHS 2014). As snow accumulates on roads and obscures lane markings, capacity may be reduced by as much as 12%–27% and average interstate speed may be reduced by up to 42%, significantly impeding truck transport of fuels to TTLs (DHS 2014, DOT 2006). If the snow blows onto rail switches, freight rail transport of liquid fuels may also be disrupted, and railroads may cancel or delay transport of fuel during severe winter weather events (DHS 2014).

Ice can pose a serious obstacle for marine and inland waterway transport of fuels during extreme cold weather events, including those caused by southward shifts in the polar vortex. If the air temperature is below freezing, port infrastructure, vessel superstructures, and ocean structures may ice over (DHS 2014). If ice forms on a vessel, it can raise its center of gravity, reducing the vessel's stability in the water (DHS 2014). Barge transport of fuels may also be disrupted by ice formation on inland waterways (DHS 2014).

Fuel shipments may also be delayed during severe convective storms. Tornadoes can damage transportation infrastructure, including railcars, rail stations, sections of pipe, and compressor and pumping stations (Kinder Morgan 2008, Unger 2013). High winds during severe storms can derail railcars and damage highway signs, lights, and signals, and lightning can interfere with signaling equipment (CCSP 2008, Rossetti 2007).

Increasing frequency of intense hurricanes and sea level rise-enhanced storm surge increase the risk of damage to coastal transport infrastructure, such as crude oil and petroleum product import terminals (DOE 2013a, USGCRP 2014). The coastal energy transportation infrastructure is vulnerable to heavy winds and storm surge associated with intense hurricanes, and damage and disruption to transportation operations in the region may jeopardize the supply of gasoline, fuel oil, and natural gas to TTLs (DOE 2013a, EIA 2014c, USGCRP 2014). Accelerating sea level rise is expected to magnify the impact of storm surge, which can cause physical damage to the coastal infrastructure and extended disruptions in service (CCSP 2008, USGCRP 2014).

Most TTLs in the Northeast depend on port and marine terminal facilities for petroleum products and natural gas. These installations are susceptible to damage and disruption from projected increases in the frequency of intense hurricanes and associated sea level rise-enhanced storm surge. Terminals are forced to stop or delay operations prior to and during hurricanes. Storm surge during hurricanes can knock down buildings at terminals, dislodge cargo containers, and damage wharf and pier structures. Flood-borne debris can block navigation channels, leading to extensive delays in the transport of energy products throughout the region, including to TTLs. Storm surge can also cause permanent damage by undermining the foundations of terminals (CCSP 2008).

More frequent extreme precipitation events increase the risk of damage to and disruption of service by coastal and inland transportation infrastructure (DOE 2013a, USGCRP 2014). Supplies of energy products to TTLs may also be disrupted by damage and disruption to coastal and inland infrastructure during extreme precipitation events, which are projected to increase in frequency. Inland flooding poses a substantial risk to roads, bridges, and railroads located near rivers and in river floodplains. Roads, bridges, and railroads used to transport energy products to TTLs may be washed out during these extreme precipitation events (DOE 2013a).

Supplies of energy products can also be disrupted by damage to the key highways and railroads used to transport energy products from production areas and ports to TTLs. Almost 1,800 miles of roadways in states containing TTLs are less than 4 feet above sea level and are prone to flooding as a result of increasing frequency of intense hurricanes and accelerating sea level rise (Climate Central 2014). Coastal flooding and storm surge may take key roads and railways used to transport energy products out of service and damage culverts and bridge decks (CCSP 2008). Saltwater can corrode rail lines, electrical distribution systems, and signaling equipment, extensively damaging the coastal rail infrastructure. Prolonged flooding may permanently weaken roadways and the foundations of railroad tracks (USGCRP 2014).

Increasing winter temperatures and fewer days below freezing may reduce natural gas pipeline congestion in winter (NERC 2013, USGCRP 2014). Tribes rely in part on natural gas for winter heating, but competing demands on natural gas for heating and for electricity generation traditionally constrain natural gas pipelines in winter (NERC 2013). Increasing temperatures and decreasing HDDs may benefit the transportation of energy products to TTLs. Projections indicate that the number of freezing days will decrease in New York and New England, which may reduce interruptions in pipeline transport of natural gas from frozen liquids in wellheads, pipelines, and pipeline equipment (NERC 2011).

Chapter 8: SOUTHEAST TRIBAL LANDS

Key Climate Change and Extreme Weather Hazards Affecting Tribal Trust Land Energy Systems in the Southeast

- **Increasing frequency of intense hurricanes:** More frequent Category 4 and 5 hurricanes and associated winds and heavy precipitation increase the risk of power outages and disruptions in fuel supply. Sea level rise-enhanced storm surge magnifies the impact of storms on coastal energy infrastructure.
- **Rising temperatures:** Higher average temperatures and more heat waves are likely to increase electricity demand for cooling and could increase energy bills. Increasing temperatures may also make power outages more likely.
- **Increasing heavy precipitation:** Increasing flooding during extreme precipitation events increases the risk of power outages and disruptions in fuel supply to TTLs.

OVERVIEW OF SOUTHEAST REGION

The Southeast region contains 17 federally recognized tribal trust lands (TTLs). As shown in Figure 8-1, most TTLs in the region are located in central Louisiana, central Mississippi, southern Florida, and in the Appalachians of North Carolina (U.S. Census Bureau 2010b). Alabama and South Carolina also have TTLs. Collectively, the TTLs in the region are home to approximately 22,000 residents (U.S. Census Bureau 2010a). These lands do not contain major energy infrastructure on their property.[34] Instead, residents and businesses rely on infrastructure located outside the TTL boundaries to supply both electricity and fuel.

Figure 8-1. TTLs are located in six states of the Southeast region. *The two large TTLs are identified above as 1 (Eastern Cherokee Reservation) and 2 (Mississippi Choctaw Reservation) (see Table 8-1).*

Graphics source: Energetics 2015; Data source: U.S. Census Bureau 2015

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[34] "Major energy infrastructure" includes the following: high-voltage (>345 kV) transmission lines; large (>1 MW) electric generation plants; oil, natural gas, or coal production areas; oil refineries; natural gas processing plants; and crude oil, petroleum product, or natural gas pipelines.

Electricity Supply

TTLs in the Southeast region do not have major power plants onsite (EIA 2014c) and therefore are dependent on offsite power plants to generate electricity. High-voltage transmission lines carry electric power long distances from major power plants to substations, where large transformers reduce the voltage before routing the electricity through low-voltage distribution lines for delivery to residents and businesses located on TTLs. Third-party electric utilities serve TTLs in the region, with the Tennessee Valley Authority providing service to the majority of tribal customers, including the Eastern Cherokee and Mississippi Choctaw Reservations (EIA 2013a).

Table 8-1. TTLs in the Southeast.

States with Tribal Trust Lands:	Alabama, Florida, Louisiana, Mississippi, North Carolina, South Carolina	
Number of Tribal Trust Lands:	17	
Total population:	22,000	
Total area (square miles):	412	
Large TTLs*		
Trust Land Name	**Population****	**Total Area (sq. miles)**
1) Eastern Cherokee Reservation (NC)	9,018	82
2) Mississippi Choctaw Reservation (MS)	7,436	47

*Note: “Large” TTLs are defined as those lands >300 square miles in area and/or with >3,000 Native American residents.
**Note: The population of TTLs refers to the number of residents on each TTL according to the 2010 Census, not the number of enrolled members of each tribe.
Sources: U.S. Census Bureau 2010a, U.S. Census Bureau 2010b

Fuel Supply

The Southeast utilizes a supply network of pipelines, barges, marine tankers, and trucks for natural gas and petroleum deliveries (EIA 2014c). No TTLs produce oil, natural gas, or coal. Most of the region’s natural gas is supplied by pipeline from Texas, Louisiana, and offshore production areas in the Gulf of Mexico (EIA 2014c). Petroleum products such as gasoline and diesel are transported throughout most of the region by pipeline from oil refineries in Texas, Louisiana, and Mississippi (EIA 2014c). There are no petroleum product pipelines into Florida; the state relies instead on transport of gasoline and diesel by truck from the eight petroleum product ports in the state (EIA 2014c). Coal is transported into the region by rail, barge, and truck (EIA 2014c).

IMPLICATIONS FOR ENERGY SECTOR

As shown in Table 8-2, electricity generation and transmission infrastructure and fuel transportation infrastructure serving TTLs in the Southeast are vulnerable to severe thunderstorms and may be increasingly vulnerable, as climate change may lead to increasing water temperatures, changing precipitation patterns, and intense hurricanes and wildfires.[35] In addition to the effects of climate change on energy infrastructure, electricity demand on regional TTLs is expected to increase with increasing temperatures under current climate change projections.

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[35] This report describes vulnerabilities of tribal energy systems related to both climate change and extreme weather. “Potential climate change impacts” refer to threats to tribal energy systems that are projected to change (increase, in most instances) compared to historical norms. Climate change impacts in the Southeast include warmer air and water temperatures, increasing drought, increasing heavy rainfall events, rising sea levels, increasing frequency of intense hurricanes, and increasing risk of wildfire. “Potential extreme weather impacts” refer to weather events that threaten tribal energy systems, but quantifying the effects of climate change on the frequency, duration, or severity of these events is still an area of active research. Such extreme weather impacts include convective and winter storms. In this report, potential extreme weather impacts are not associated with a trend but rather as a continued threat to tribal energy systems.

Table 8-2. Examples of extreme weather and climate change impacts that could adversely affect the energy infrastructure serving TTLs in the Southeast.

Extreme weather event or climate change trend affecting energy infrastructure	Potential implications for tribes
Strong storms, including thunderstorms, tornadoes, and ice storms, and increasing frequency of extreme precipitation events	
• Risk of flooding and damage to low-lying power generation, transmission, and distribution infrastructure	• Power outages and damage to power lines on and supplying TTLs
• Damage to roads and rail lines, potentially rendering them impassible for energy transport	• Disruption in fuel supply
Rising air and water temperatures	
• Increased electricity demand for air conditioning	• Higher electricity bills for cooling in the summer
• Reduced power line transmission capacity and efficiency and increased risk of damage to grid infrastructure	• Greater likelihood of power outages and potential for higher electricity costs
• Decreased efficiency and available generation capacity of thermoelectric power plants	• Greater likelihood of power outages and potential for higher electricity costs
Increasing drought	
• Increased risk of damage and disruption to fuel transportation infrastructure on both land and critical waterways	• Greater potential for disruption in fuel supply
• Increased risk of cooling water shortages at thermoelectric power plants	• Greater likelihood of power outages
Increasing frequency of intense hurricanes	
• Increased risk of flooding and wind damage to electric power generation, transmission, and distribution infrastructure	• Greater likelihood of power outages and damage to energy infrastructure serving TTLs
• Increased risk of inundation, damage, and disruption to fuel transportation infrastructure	• Greater potential for disruption in fuel supply
Increasing risk of wildfire	
• Increased risk of damage to power transmission and distribution infrastructure	• Greater likelihood of power outages and damage to energy infrastructure serving TTLs

Energy End-Use

Potential climate change impacts:

- Increased electricity demand for cooling in the summer
- Decreased energy demand for propane, fuel oil, wood, electricity, and natural gas for space heating in the winter

In the Southeast region, electricity is the primary source for both heating and cooling energy, and summer peak demand for all utilities serving TTLs in the region is greater than winter peak demand (EIA 2013a, EIA 2013h). Because of climate change, cooling energy demand is projected to increase, while heating energy demand will decrease (NOAA 2013c). Although it is difficult to predict the net result of increasing temperatures on net energy expenditures, cooling is generally more expensive than heating (DOE 2013a). Therefore, tribal residents and businesses may face increasing electricity costs as a result of increasing demand for air conditioning during the summertime.

Higher temperatures are likely to increase cooling energy demand (DOE 2013a, USGCRP 2014). Summer air temperatures on TTLs in the Southeast are expected to increase by 4.0°F–6.0°F by mid-century (2041–2070, compared to 1980–2000) under a high emissions scenario (NOAA 2013c). As a result of increasing average temperatures and extremely hot days, cooling demand, expressed through the number of cooling degree days (CDDs) in the region within a year, is projected to increase by an average of 43% by 2041–2070 (compared to 1971–2000) (USGCRP 2014). On TTLs throughout most of the region, CDDs are projected to increase by 550–1,050 degree days by mid-century (2041–2070, compared to 1980–2000) under a high emissions scenario, but TTLs in southern Florida, such as the Big Cypress and Hollywood Reservations, may experience up to 1,150 more CDDs a year by mid-century (NOAA 2013c).[36]

Higher average temperatures are expected to increase overall cooling demand. However, higher maximum temperatures and an increasing number of extremely hot days will also increase peak electricity demand. More than 96% of residents in Southeast states containing TTLs use air conditioning, and increasing CDDs in the region may result in increased use of air conditioning on TTLs, compounding the increase in demand for electricity (Auffhammer 2011, DOE 2013a, EIA 2013c). Increasing demand for cooling energy may lead to increasing electric bills, a concern for lower-income households and vulnerable communities (USGCRP 2014). Furthermore, to maintain reliable power supplies, utilities serving TTLs may need to invest in additional power generation and delivery infrastructure to meet higher electricity demand, and while such expansion reduces the risk of power outages, the cost of these investments often translates into higher electricity rates for customers.[37]

Warmer winter temperatures are likely to reduce heating energy demand (DOE 2013a, USGCRP 2014). As the number of extremely cold nights (<10°F) in the region is projected to drop to zero and winter air temperature to increase, heating demand, expressed through the average number of heating degree days (HDDs) within a year, is projected to decrease by 19% by mid-century (2041–2070, compared to 1971–2000) (USGCRP 2014). The number of HDDs is projected to decrease by 100–900 degree days a year by mid-century (2041–2070, compared to 1980–2000) under a high emissions scenario on most TTLs throughout the Southeast and by up to 1,100 degree days on the Eastern Cherokee Reservation in North Carolina (NOAA 2013c).[38] The two large TTLs in the Southeast use a variety of fuels for heating energy, including wood and propane (U.S. Census Bureau 1995) (Table 8-3). The Mississippi Choctaw Reservation also uses electricity (U.S. Census Bureau 1995), and more than 60% of all households in the South use electricity for heating energy (EIA 2013b). Decreasing heating demand may decrease electricity use and lead to a concurrent decrease in winter electricity bills.

Table 8-3. Primary household heating fuel in selected Native American communities in the Southeast.

TTL	Primary heating fuel (percentage of households using fuel)
Eastern Cherokee Reservation, NC	Wood (63%)
Mississippi Choctaw Reservation, MS	Tank gas, including propane (34%), wood (31%), electricity (52%)

Source: U.S. Census Bureau 1995

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[36] A CDD is calculated from the sum of the daily variation of temperature above a baseline temperature, typically 65°F. This calculation is a proxy for the energy needed to cool a space.

[37] For more information on the impact of increasing temperatures on peak energy demand, see the sidebar titled “Electricity Supply Vulnerabilities during Peak Demand Periods.”

[38] An HDD is calculated from the sum of the daily variation of temperature below a baseline temperature, typically 65°F. This calculation is a proxy for the energy needed to heat a space.

Electricity Supply

ELECTRIC GRID

Potential extreme weather impacts:

- Storm damage to grid infrastructure located on or connected to TTLs

Potential climate change impacts:

- Increased risk of flood, heat, or wildfire damage to the grid infrastructure located on or connected to TTLs
- Decreased efficiency and capacity of transmission lines from increasing temperatures

As TTLs in the region do not have tribal utility authorities and do not own high-voltage transmission infrastructure, tribal residents and businesses depend on the efficient operation of external transmission and distribution infrastructure. Increased risk of damage and disruption to electric grid infrastructure due to extreme weather events and increasing air temperatures may increase the risk of power outages (DOE 2013a). Tribal residents and businesses may experience a rise in the cost of electricity as utilities may need to invest in additional capacity, maintenance, and repairs to ensure reliable service.

Convective storms and winter storms may damage electric grid infrastructure (DOE 2015a, USACE 2014). During convective storms, winds can blow power lines into branches, towers, or other power lines, shorting them out. Lightning may strike components of the grid. Wind and lightning may cause trees to fall and damage nearby power lines (Duke Energy 2015). Tornadoes that occur during these storms can damage power lines, poles, and transmission structures (Duke Energy 2015).

Electric grid infrastructure serving TTLs in the Southeast may also be damaged during ice storms. For example, Duke Energy's transmission and distribution network in North and South Carolina was severely damaged during a February 2010 ice storm, resulting in power outages to 1,330 homes on the Eastern Cherokee Reservation in North Carolina (McKie 2010). Transmission lines and support structures may be damaged when lines oscillate or gallop during storms, and ice can coat lines, causing them to sag and the poles to break (USACE 2014).[39] Following an ice storm, lines may suffer damage if previously ice-covered lines rebound quickly into tree branches (USACE 2014).

Power disruptions due to Hurricanes Katrina on TTLs along the Gulf Coast

Several TTLs in the Southeast are located along the Gulf Coast and are particularly susceptible to the damaging effects of hurricanes, including prolonged power outages. For example, in 2005, Hurricane Katrina resulted in power outages and severe infrastructure damage on the Mississippi Choctaw Reservation (DOI 2005).

Increasing frequency of intense hurricanes increases the risk of damage or disruption to electric power transmission and distribution infrastructure (DOE 2013a, USGCRP 2014)**.** As a result of increasing frequency of intense hurricanes (Category 4 or 5) in the North Atlantic basin, tribal communities may experience more frequent power outages due to hurricane-associated damage (DOE 2013a).

During hurricanes, high winds and flooding from heavy rainfall or storm surge can knock down power transmission and distribution poles and damage lines (DOE 2013a). Electric power substations are susceptible to inundation from both flooding in low-lying areas and storm surge near coastal areas (DOE 2009). Flooded infrastructure may be time-consuming to repair, and substations exposed to salt water may be destroyed by salt water corrosion.

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[39] Power lines "gallop" when ice builds up on the power line, causing it to sway and buck in the wind. In high winds, or with sufficient ice buildup, galloping power lines can be very dangerous, as they may eventually fail, snapping power poles or causing lines to fall.

Accelerating sea level rise will magnify the impact of wave action and storm surge on coastal electric power infrastructure.

Higher temperatures decrease the capacity and efficiency of electric power lines and increase their vulnerability to physical damage (Bérubé et al. 2007, DOE 2013a). Higher air temperatures will have impacts on electric power transmission and distribution infrastructure serving TTLs in the Southeast, both by increasing the risk of temperature-related physical damage to power lines and by decreasing the amount of electricity that can be delivered by power lines (DOE 2013a). In hot weather, power lines are more vulnerable not only to decreased transmission capacity but also to physical damage, as high temperatures cause lines to sag as they expand, sometimes resulting in contact with trees and other objects (DOE 2013a). Higher ambient temperatures also increase the risk that transformers will reach critical temperatures and fail during emergency overloading (Hashmi et al. 2013). Repairs or upgrades to physical infrastructure may increase the costs of electric power service, which could ultimately be passed on to ratepayers.

Electricity supply vulnerabilities during peak demand periods

As temperatures and the frequency, intensity, and duration of heat waves increase throughout the region, particularly in southern Florida, the efficiency and capacity of electric generation and transmission infrastructure are projected to decrease while peak electricity demand increases (DOE 2013a). The Hollywood, Miccosukee, Big Cypress, Immokalee, Brighton, and Fort Pierce Reservations in Florida may see up to 4,500 CDDs a year by mid-century (2041–2070), compared to an average of 2,500 CDDs a year from 1980–2000. The combination of increasing temperatures' impacts on energy demand, the electric grid, and electric generation infrastructure in the Southeast—particularly in Florida—may tax the ability of the utilities serving TTLs to efficiently deliver power to their customers.

To protect transformers and transmission lines from damage due to elevated ambient temperatures, electric grid operators may reduce available capacity for electricity delivery on hot days (USBR 2000). For example, one study found that a temperature increase of 9°F could decrease electricity transmission capacity by 7%–8% (Sathaye et al. 2012), although summer air temperatures are only supposed to increase by up to 6.0°F in the Southeast by mid-century (NOAA 2013c). This decrease in capacity would be accompanied by a decrease in efficiency; the same study found that a temperature increase of 9°F could decrease electricity transmission and distribution efficiency by 1.5%–2.5% (Sathaye et al. 2012). Without upgrades to existing electric power infrastructure, tribal electricity customers may experience a decrease in the total power available to residences and businesses during heat waves, when system losses are highest (Sathaye et al. 2012).

Increasing frequency and size of wildfires increase the risk of damage to grid infrastructure (DOE 2013a, USGCRP 2014)**.** Transmission and distribution infrastructure in the Southeast is vulnerable to damage from wildfires, and increasing wildfires may lead to damaged infrastructure on TTLs as well as power outages for tribal residents and businesses if transmission lines serving TTLs are damaged. Wildfires can destroy wood poles as well as steel towers, and the soot from the fire and fire retardant can foul transmission lines (DOE 2013a). Utility operators may shut down or reduce loading on lines at risk from wildfires to prevent damage to the lines from smoke and soot, which could result in arcing between lines (DOE 2013a).

ELECTRIC POWER GENERATION

Potential extreme weather impacts:

- Storm damage to power plants

Potential climate change impacts:

- Decreased efficiency and available generation capacity from thermoelectric power plants due to higher air and water temperatures and seasonal water scarcity
- Increased risk of flood damage to power plants due to increasing frequency of intense hurricanes, extreme precipitation events, and sea level rise

The regional power plants that supply electricity to TTLs are vulnerable to a number of different impacts of climate change, including increasing temperature, water scarcity, and flooding. These impacts have the potential to cause curtailments or outages in production at power plants that ultimately serve TTLs, and could lead to cost increases to consumers if utilities upgrade or build additional capacity to ensure reliable electric supply.

Increasing air and water temperatures and seasonal drought decrease the efficiency of thermoelectric power production and decrease available generation capacity (DOE 2013a). Thermoelectric power plants, which use natural gas, coal, biomass, and nuclear fuels to generate electricity through steam, generate more than 95% of the electricity supplied to Southeastern states containing TTLs. These plants are vulnerable to the effects of higher air and water temperatures and seasonal drought.

Increased air temperature can directly reduce the efficiency of a thermoelectric generator (Hellmuth et al. 2014), and when the temperature of surface water used for cooling increases, thermoelectric generators require more water and operate less efficiently (UCS 2011). In addition, when water temperatures rise over a certain threshold, such as during the intense heat waves projected to occur more frequently in the region, power plants may be forced to curtail operations, as the temperature of water discharged from the plant could exceed mandated limits designed for ecological protection (DOE 2013a).

Many thermoelectric power plants in the Southeast that serve TTLs utilize once-through cooling water systems. Such plants are therefore particularly vulnerable to water scarcity due to seasonal drought and increasing rates of evaporation from surface water reservoirs due to high temperatures. Once-through cooling systems rely on large quantities of water from lakes, rivers, and streams (EIA 2012c). During periods of water scarcity, water levels can drop below intake pipes, forcing power plants to curtail operations or shut down completely (DOE 2013a, NERC 2013). For example, Duke Energy customers experienced power outages after heat waves, drought, and high water temperatures forced the company to curtail operations at two coal-fired power plants in North Carolina in 2007 (Beshears 2007).

As a result of increasing temperatures and drought and subsequent decreasing thermoelectric power plant efficiency and generation capacity, utilities may need to invest in additional capacity or water-saving technology to meet customer demand (EEI 2006). Increasing costs for utilities are typically recovered via increased electricity rates for customers, including tribal residents and businesses.

Increasing storms, including extreme precipitation and frequency of intense hurricanes, increase the risk of inundation at inland and coastal power plants (DOE 2013a). Many of the TTLs located in the Southeast are within areas projected to experience an increase in the number of extreme precipitation events, and heavy rainfall events can lead to flooding and inundation of power plants serving these lands (DOE 2013a, NOAA 2013c). Electric generation facilities serving TTLs in the Southeast are vulnerable to flood and wind damage during severe convective storms. The projected increase in frequency of intense hurricanes in the North Atlantic basin and accelerating sea level rise will also increase the risk of flooding and inundation of power plants from storm surge near the coast, while increasing hurricane-associated heavy rainfall may increase the risk of inundation to inland power plants. In 2004, Hurricane Jeanne damaged power plants and power lines, leaving almost 2.6 million Florida customers without power (DOE 2004, NEI 2012); similar impacts on electric power supply may occur more frequently.

Fuel Supply

FUEL TRANSPORT

Potential extreme weather impacts:

- Storm damage to transportation infrastructure and possible disruptions in fuel supply

Potential climate change impacts:

- Increased risk of disruption of fuel supply, including gasoline, diesel, fuel oil, and propane, as a result of flooding caused by increasing frequency of intense hurricanes, extremely heavy precipitation, and sea level rise

There are no major production or processing and refining areas on TTLs in the Southeast (EIA 2014c), and therefore tribal residents and businesses depend on fuel transport for energy supplies and products. Natural gas is transported throughout the Southeast from production areas and processing plants by transmission pipelines, and the natural gas is then distributed to customers by smaller-diameter distribution pipelines (EIA 2014c). Coal is brought into the region by railroad, barge, and truck for electric power generation (EIA 2014c), some of which ultimately serves TTLs.

Petroleum products such as diesel and gasoline are transported by pipelines and dispersed to customers, including those living on TTLs, by truck (EIA 2014c). However, there are no pipelines carrying petroleum products into the state of Florida, so customers in the state instead rely on tanker and barge imports for gasoline and residual fuel oil (EIA 2014c). These fuels are then delivered to customers by truck.

Severe storms can damage fuel transportation infrastructure (CCSP 2008, NOAA 2015b, Rossetti 2007). During severe convective storms, lightning may damage signaling equipment on roadways and railroads, disrupting operations, and high winds can roll over or derail rail cars (CCSP 2008, Rossetti 2007). Tornadoes associated with these storms can damage sections of pipeline, compressor and pumping stations, and cars and railcars (Kinder Morgan 2008, NOAA 2015b, Unger 2013).

Increasing frequency of intense hurricanes and accelerating sea level rise increase the risk of damage and disruption to fuel supply infrastructure (DOE 2013a, USGCRP 2014). TTLs in the Southeast may be vulnerable to increasing disruptions and shortages in fuel supply due to the projected increase in the frequency of Category 4 and 5 Atlantic hurricanes associated with climate change (DOE 2013a, USCGRP 2014). Most of the interstate highways along the Gulf Coast are less than 2 feet above sea level, and about half of the region's arterial roadways are vulnerable to storm surges of 18 feet (CCSP 2008). Coastal fuel transport and storage facilities such as piers, fuel terminals, storage tanks, pipelines, and roads are vulnerable to damage from high winds and storm surge associated with intense hurricanes (DOE 2013a). The flooding brought by hurricane rainfall can also damage and disrupt the transport of fuel on critical inland roadways and railways. Sea level rise may amplify the reach of waves and storm surge brought by hurricanes, compounding the impact of climate change on the coastal facilities that are critical to the Southeastern fuel supply.

Chapter 9: SUMMARY AND DISCUSSION

Tribal trust lands (TTLs) and Alaska Native villages (ANVs) are already facing challenges to the reliable delivery of affordable energy posed by climate change and extreme weather. Air and water temperatures are increasing, precipitation patterns and water availability is changing, droughts and wildfires are becoming more frequent and intense, hurricanes are becoming stronger, and sea levels are rising faster. In addition, intense convective storms, winter storms, and coastal storms continue to threaten energy equipment. While tribal energy infrastructure is designed to function under a range of weather conditions, these types of events have the potential to significantly impact tribal communities by damaging critical energy components and forcing the present energy systems to operate outside of their designed range.

Tribal communities are, for the most part, closely integrated with broader U.S. energy networks, where infrastructure located off of tribal property is interdependent with infrastructure located onsite. Most tribes rely entirely on non-tribal entities to produce and deliver their energy. However, as sovereign nations, several tribes do own and operate their own energy infrastructure, and they face many of the same vulnerabilities as their non-tribal counterparts. Tribes that own their energy infrastructure have greater self-determination in evaluating and deciding which measures are appropriate to implement in response to their climate and weather risks.

In all regions and across the major segments of the energy system—including energy end-use, electricity supply, and fuel supply—infrastructure critical for tribal energy users is threatened by climate change and extreme weather events.

As climate change progresses, tribal **end-users** are likely to experience a greater risk of power outages and fuel supply disruptions as well as higher electricity bills—particularly in the summer. Higher summer temperatures and heat waves are likely to increase the frequency of power outages attributed to extreme heat (DOE 2013a), putting vulnerable populations at risk of heat-related illness and death (USGCRP 2014). Many of the largest TTLs in the country are concentrated in the Southwest, the hottest region in the United States and a region that is expected to experience longer, hotter, and more frequent heat waves (USGCRP 2014).

Tribal residents are likely to increase their energy use for cooling to cope with the projected hotter summer temperatures and more frequent heat waves. This is expected to lead to higher summer electricity bills, which can have a significant effect on many tribal residents who are already struggling with poverty and unemployment. Average retail prices for electricity nationwide have increased almost 3% per year since 2002, and price increases are projected to continue even without considering the potential costs associated with climate change impacts (EIA 2014f, EIA 2015c).

While **electricity supply** overall in the United States is extremely reliable, the number of grid disturbances due to weather has increased across the United States, with extreme weather events such as convective and winter storms leading to hundreds of grid disruptions a year (DOE 2015a). As climate change increases the risk of weather-related grid disturbances across the United States, the expected number of disruptions to the grid delivery of power to TTLs and ANVs are likely to increase as well, unless measures are taken to increase resilience. For example, projected increases in the frequency of hurricanes with the capacity to inflict “catastrophic” damage in the North Atlantic basin increase the risk of power outages on TTLs along the Gulf and Atlantic coasts (NOAA 2015c, USGCRP 2014), and tribes in the western United States and Alaska will be at higher risk of brownouts and blackouts due to projected increases in wildfire length and intensity.

To minimize power outages from climate change and extreme weather events, utilities can invest in upgrades or install additional grid and power generation infrastructure. Investments in additional generating capacity may be necessary both to meet increasing electricity demand and to counteract the decreasing efficiency and capacity that today's power plants experience in the extreme that comes with climate change (DOE 2013a, EEI 2006). In addition, utilities may need to further invest in reinforcing the aging electric grid as climate change increases the risk of damage to grid infrastructure (EEI 2006).

Climate change and extreme weather events can disrupt critical **fuel supplies** to TTLs and ANVs throughout the United States. Like jurisdictions of similar size, tribal communities typically lack the onsite capacity to produce and refine fuel products such as natural gas, propane, and residual fuel oil for heating or gasoline for transportation (EIA 2014c). Consequently, damage or disruption to any portions of the fuel supply infrastructure located onsite or offsite could have severe impacts on those living on TTLs and ANVs. For example, residents of TTLs in southern Florida rely on marine, truck, and rail transport to obtain their propane and gasoline (EIA 2014c), and their region is projected to see an increase in the frequency of intense hurricanes and sea level rise-enhanced storm surge—which can damage critical port facilities, rail tracks, and roads leading to TTLs (DOE 2013a).

Some tribes that are committed to enhance their resilience climate change and extreme weather impacts may feel challenged by their dependence on energy infrastructures that are neither owned nor operated by the tribe and are not on their property. In such cases, tribes may be able to enhance resilience through collaboration with other stakeholders to ensure that tribal interests and needs are understood and factored into energy planning processes.

Tribes may also be able to utilize alternative or complementary energy supply to enhance their energy resilience. For example, many tribes are developing renewable energy projects on TTLs and ANVs to supplement the electricity they receive from offsite utilities. The Southern Ute Indian Tribe is evaluating the feasibility of installing an 800 kW photovoltaic system that would provide energy to ten tribal buildings on their reservation (DOE 2015b), and the Penobscot Indian Nation is developing a 227 MW wind project (DOE 2015c). Solar PV and wind energy are more resilient to changes in temperature and water availability than most conventional electricity generation technologies. Implementation of microgrid technology and distributed generation can also contribute to enhanced resilience. Many tribes have also been working to decrease their energy usage, which would reduce the burden and costs that accrue with increasing temperatures. The Forest County Potawatomi Community, for example, conducts quarterly energy audits on tribal facilities and has reduced their energy usage per square foot by 13.6% since 2007 (DOE 2015d). As tribes work to ensure reliable, secure, and affordable energy, identifying vulnerabilities and evaluating resilience strategies in the context of an interconnected energy system will help illuminate the array of response solutions available for tribal communities.

Appendix A: CLIMATE CHANGE TRENDS AND EXTREME WEATHER EVENTS

Tribal trust lands (TTLs) and Alaska Native villages (ANVs) throughout the United States rely on largely dependable energy systems that are built to withstand a range of typical weather conditions. However, climate change and extreme weather may force some energy systems to operate beyond the conditions for which they were designed. This can lead to damaged infrastructure, disrupted energy supply, and increased costs for tribal residents. This chapter provides (1) an overview of the climate change trends and projections for the United States as a whole and by region and (2) a summary of extreme weather hazards.

Climate Change Trends and Projections

TTLs and ANVs throughout the United States are expected to see increasing temperatures and associated increases in heat waves and wildfires; changing water availability, including increases in drought risk in some regions; increasing wildfires in some regions; and increases in heavy rainfall events and the most intense Atlantic hurricanes (Category 4 and 5), along with associated flooding and accelerating sea level rise.

Increasing Temperatures

Since 1895, air temperatures across the United States have increased an average of 0.13°F every decade, and this warming has increased at an accelerating rate—with the most recent decade the hottest on record (NOAA 2013a, USGCRP 2014). As shown in Figure A-1., average air temperatures have increased to varying degrees across every region of the United States. This increase in average air temperatures has also occurred in all seasons.

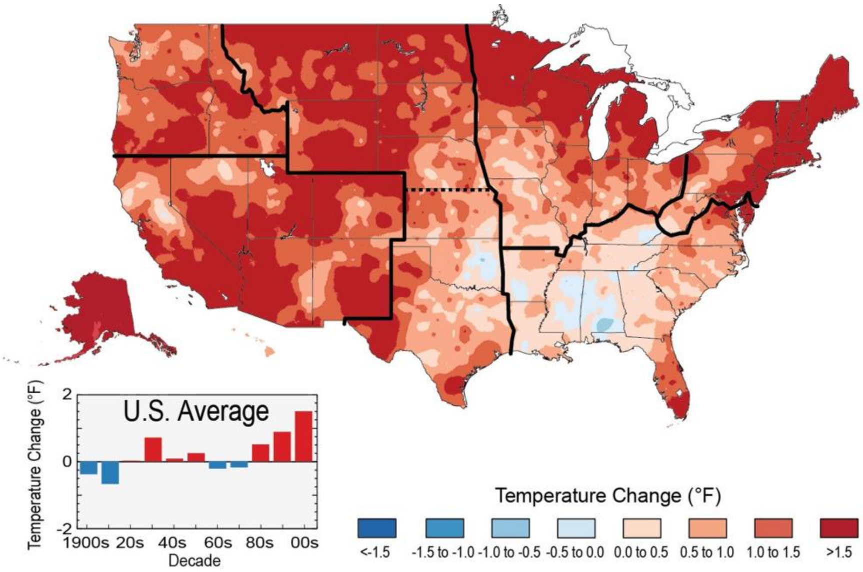

Figure A-1. Average temperatures increased in almost every region of the United States (1991–2012 compared to 1901–1960).
Source: USGCRP 2014

Both the frequency and intensity of heat waves—which are defined as periods of abnormally hot and humid weather lasting for two or more days—have also been increasing, with the greatest increases in the western United States (NOAA 2009, USGCRP 2014).

Average air temperatures are projected to continue to rise. Warming varies by region and season, but warming in the summer is projected to increase more than in other seasons for most of the United States. Some northern states may be the exception in that they are projected to see the largest increase in temperatures during winter (NOAA 2013a). As average air temperatures have increased, freshwater and coastal surface water temperatures have also risen—a trend that is projected to continue (USGCRP 2014).

Projected increases in air temperatures in the United States are expected to cause an increase in the frequency, intensity, and duration of extreme temperature-related events, including extreme high temperatures and heat waves (USGCRP 2014). Projections indicate that the hottest days will become more frequent: those extremely hot, single-day events that now occur only once every twenty years are likely to occur every two to three years by the end of the century (USGCRP 2014). Under a high emissions scenario, these single-day events are also projected to become more intense, with average temperatures on the hottest days increasing by up to 4°F–15°F in portions of the United States by century's end (USGCRP 2014). For an overview of low and high greenhouse gas emissions scenarios, see Appendix B.

Northwest

The average annual air temperature in the Northwest typically ranges from 30°F in the mountainous regions of the Nez Perce and Yakama Nation Reservations to 55°F at lower elevations of the Quinault Reservation in the west (NOAA 2013b).

Since 1895, average air temperatures have increased almost 1.4°F; the largest temperature increases have been in winter (0.20°F per decade) and summer (0.12°F per decade) (NOAA 2013b). By the end of the century,[40] air temperatures on TTLs in the Northwest are projected to increase an additional 3.5°F–8.5°F, depending on the location and emissions scenario (NOAA 2013b). The largest increase in seasonal air temperatures could occur in the summer, with seasonal averages projected to increase by 3.5°F–6°F under a high emissions scenario by mid-century[41] (NOAA 2013b). TTLs in southeastern Idaho, including the Fort Hall Reservation, are projected to experience the largest increases in both average and seasonal air temperatures, whereas TTLs near the Pacific coast, including the Quinault Reservation, will experience milder temperature changes (NOAA 2013b, U.S. Census Bureau 2010b).

As average and seasonal air temperatures increase, TTLs in the Northwest are projected to experience an increase in the frequency and length of heat waves. The number of extremely hot days (>95°F) every year is projected to increase by 3–12 days throughout most of the Northwest by mid-century under a high emissions scenario, and TTLs in southeastern Idaho may see increases of up 18 days (NOAA 2013b). Under a high emissions scenario, the maximum number of consecutive extremely hot days every year is projected to increase by 6–10 days in southeastern Idaho and by up to 4 days in other areas by mid-century (NOAA 2013b).

Extremely cold days (<10°F) are projected to be less common, and the freeze-free season is projected to lengthen. By mid-century, the annual number of extremely cold days in northeastern Idaho near the Nez Perce and Coeur d'Alene Reservations is projected to drop to 10–20 days a year, and the average number of extremely cold days throughout the rest of the region may drop to zero throughout most of the Northwest under a high emissions scenario (NOAA 2013b). The largest increase in the length of the freeze-free season is projected to occur along the Pacific Coast. Under a high emissions scenario, TTLs in low-lying western regions are projected to experience a 35–45 day

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[40] For temperature projections, "end of the century" refers to the period 2070–2099, compared to 1971–1999 unless a different time range is specifically noted.

[41] For temperature projections, "mid-century" refers to the period 2041–2070, compared to 1980–2000 unless a different time range is specifically noted.

increase in the length of the freeze-free season by mid-century, while the rest of the region is projected to experience a 25–35 day increase (NOAA 2013b).

Southwest

In the Southwest, average annual air temperatures range from 21°F–45°F in the Rocky Mountains and Sierra Nevada to 61°F–80°F in southern California and Arizona (NOAA 2014).

Average air temperature has increased almost 2°F since 1895 and is projected to continue increasing (NOAA 2013f). By the end of the century, TTLs in California such as the Hoopa Valley Reservation and Agua Caliente Indian Reservation are projected to experience increases of 3.5°F–7.5°F, depending on the emissions scenario, and TTLs throughout the rest of the region including the Navajo Nation and Uintah and Ouray Reservation are projected to experience 3.5°F–8.5°F increases in average air temperatures (NOAA 2013f) (Figure A-2).

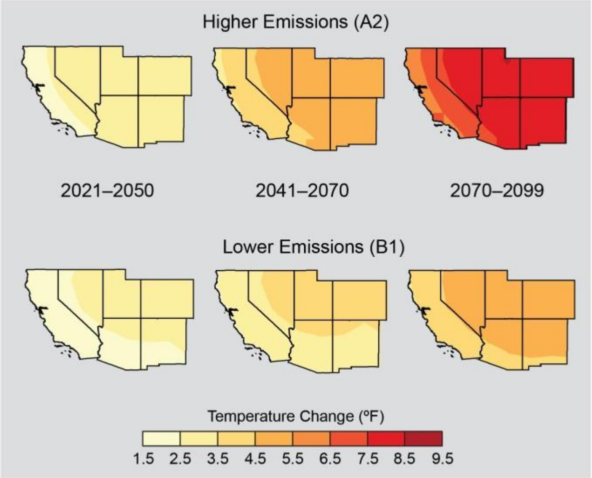

Figure A-2. Average air temperatures are projected to increase significantly (compared to 1971–1999).
Source: USGCRP 2014

Along with increasing average air temperatures, TTLs in the Southwest are projected to see an increase in the number of extremely hot days and an increase in the intensity, frequency, and duration of heat waves (USGCRP 2014). Summer air temperatures are projected to increase by 5.0°F–6.0°F by mid-century (2041–2070, compared to 1971–2000) under a high emissions scenario throughout most of the region, and residents of TTLs in portions of Colorado and northwestern Utah, such as the Uintah and Ouray Reservation, may see a 6.5°F increase in summer air temperatures (NOAA 2013f). The annual number of extremely hot days (>95°F) throughout most of the region is projected to increase by up to 30 days by mid-century under a high emissions scenario, but TTLs in southern Arizona and New Mexico, including portions of the Tohono O’odham Nation and Pascua Pueblo Yaqui Reservations, may see up to 40 more extremely hot days a year (NOAA 2013f). TTLs in southern California and Arizona, such as the Colorado River Indian and Torres-Martinez Reservations, currently experience heat waves with temperatures over 95°F that can last over 40 consecutive days (NOAA 2013f). With increasing air temperatures, these TTLs may see heat waves that are 20–28 days longer by mid-century under a high emissions scenario (NOAA 2013f). The length of heat waves on TTLs along the California coast is projected to increase by 8–16 days by mid-century under the same scenario (NOAA 2013f). Additionally, heat waves are projected to be more widespread throughout the region (Figure A-3). TTLs in Arizona, Colorado, and Utah, including portions of the Navajo Nation and Uintah and Ouray Reservations, are projected to see an up-to-20-day increase in the length of heat waves by mid-century (NOAA 2013f).

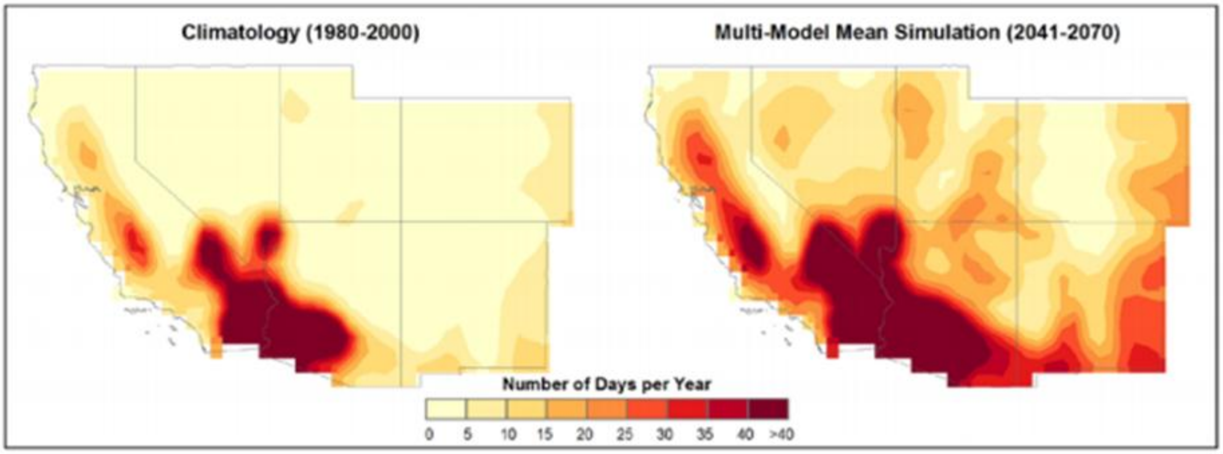

Figure A-3. The maximum number of consecutive extremely hot days (>95°F) each year is projected to significantly increase in the Southwest by mid-century under a high emissions scenario.
Source: NOAA 2013f

TTLs in the Southwest are projected to experience fewer extremely cold nights and a longer freeze-free season as air temperatures increase. By mid-century, the number of nights when temperatures drop below 10°F in Arizona, California, Nevada, and New Mexico is projected to drop to zero, and the number of extremely cold nights (<10°F) in Colorado and Utah is projected to decrease by 15–30 days under a high emissions scenario (NOAA 2013f). The freeze-free season is projected to increase by 25–45 days by mid-century under a high emissions scenario (NOAA 2013f).

Great Plains

Because of the large north–south span of the Great Plains region, there is significant variation in historical and projected increases in average air temperatures for TTLs in the region, as well as accompanying changes in heat waves and the length of the freeze-free season.

The majority of TTLs in the region are in the northern Great Plains (Montana, Nebraska, North Dakota, South Dakota, and Wyoming). Annual average air temperatures on TTLs in these states typically range from 41°F–50°F, although temperatures on TTLs located in the Rocky Mountains or along the northern border are much cooler: 31°F–40°F (1981–2010) (NOAA 2013d). Average air temperatures in this region have increased over 2°F since 1895 and are projected to increase another 3.5°F–9.5°F by the end of the century, depending on the emissions scenario and location (NOAA 2013d).

Temperatures in southern TTLs are much warmer and have historically been warming at a slower rate. For example, the Osage Reservation experiences an annual average temperature of 61°F–65°F (NOAA 2013d). The rate of warming in the southern plains states for the last century has been about half of the rate in the northern states, and projected future warming is also expected to be slightly less than in the northern states (NOAA 2013d).

Increasing air temperatures in the region are expected to lead to warmer winter temperatures and a longer freeze-free season, affecting TTLs in the northern Great Plains. Winters in the region have warmed faster than the other seasons, and winter air temperatures on TTLs in the northern Great Plains are projected to increase by up to 6.5°F by mid-century under a high emissions scenario (NOAA 2013d). Under a high emissions scenario, as winter air temperatures increase, TTLs in the northern Great Plains are projected to experience 10–30 fewer extremely cold nights (<10°F) per year. Additionally, the average freeze-free season is projected to lengthen by 15–27 days by mid-century—and even longer in the mountains (NOAA 2013d). TTLs in the Rocky Mountains and North Dakota are projected to see the largest changes in winter temperatures, extremely cold nights, and the length of the freeze-free season (NOAA 2013d).

As average air temperatures in the Great Plains increase, summer air temperatures and the length and intensity of heat waves are also projected to increase, particularly on TTLs in the southern Great Plains. By mid-century, summer temperatures in the southern Great Plains and southernmost portion of Wyoming are projected to increase by 4.0°F–6.5°F, depending on the emissions scenario (NOAA 2013d). The region is also expected to see an increase in both the number of extremely hot days and the maximum number of consecutive hot days, an indicator of heat waves. Under a high emissions scenario, TTLs in Kansas, Nebraska, Oklahoma, and Texas may see an average of 16–28 more days per year with temperatures over 100°F by mid-century (2041–2070, compared to 1971–2000), and the annual maximum consecutive number of hot days (>95°F) is projected to increase by 4–24 days per year (compared to 1980–2000) (NOAA 2013d, USGCRP 2014).

Midwest

Average air temperatures in the region have increased approximately 1.5°F across the region since 1895 and are projected to continue to increase as a result of climate change (NOAA 2013e). TTLs in the Midwest region are also projected to experience an increase in the frequency and length of heat waves because of climate change (NOAA 2013e).

Depending on the emissions scenario, TTLs in the Midwest are projected to experience a 4.5°F–9.5°F increase in average air temperatures by the end of the century (NOAA 2013e). TTLs in the region are also projected to experience an up-to-15-day increase in extremely hot days (>95°F) by mid-century under a high emissions scenario; the Sac and Fox/Meskwaki Settlement in Iowa may see a 4–8 day increase in the number of consecutive extremely hot days over the same period (NOAA 2013e).

As air temperatures increase, winter temperatures are expected to warm, and the frequency of extremely cold days (<10°F) on TTLs in the Midwest is projected to decrease. TTLs throughout the Midwest region are projected to experience a 5.0°F–6.0°F increase in winter temperatures by mid-century under a high emissions scenario, and TTLs in Minnesota, including the Leech Lake, Red Lake, and White Earth Reservations, are likely to experience the largest increase in winter temperatures (NOAA 2013e). TTLs in northern Minnesota are also projected to experience a 20–25 day decrease in the number of days when temperatures drop below 10°F, and TTLs throughout the rest of the Midwest region are projected to experience a 10–20 day decrease in the number of extremely cold days under a high emissions scenario by mid-century (NOAA 2013e).

Northeast

Average air temperatures in the Northeast region have increased by almost 1.8°F since 1895, and temperatures in New York and New England are projected to increase another 3.5°F–8.5°F by the end of the century, depending upon the amount and timing of additional greenhouse gas emissions released into the atmosphere (NOAA 2013c). Increasing average air temperatures are accompanied by an increase in the number of extremely hot days (>90°F). In parts of Connecticut, Massachusetts, New York, and Rhode Island, the average number of extremely hot days per year could reach 50 by mid-century under a high emissions scenario, with even greater numbers in Delaware, Maryland, and southern New Jersey (USGCRP 2014).

As air temperatures increase, TTLs in the Northeast are expected to endure fewer extremely cold nights (low temperatures <10°F). By mid-century, extremely cold nights in New York and New England are projected to decrease by 5–25 days, and the freeze-free season is projected to lengthen by 20–30 days under a high emissions scenario (NOAA 2013c).

Southeast

In the Southeast, the average annual air temperature has increased by almost 2.0°F over the past century, and temperatures in the Southeastern states that contain TTLs are projected to increase another 3.5°F–7.5°F by the end of the century, depending on the emissions scenario and location (NOAA 2013g). In the summer, temperatures are projected to increase by 4.0°F–5.5°F by mid-century under a high emissions scenario (NOAA 2013g).

An increase in the frequency, intensity, and duration of heat waves is projected for the Southeast. Throughout most of the region, the number of extremely hot days (>95°F) is projected to increase by 20–30 days per year by mid-century under a high emissions scenario (NOAA 2013g). Some parts of Louisiana, such as the location of the Jena Band of Choctaw in central Louisiana, may see as many as 80 days above 95°F by mid-century, while parts of southern Florida may see up to 40 more extremely hot days (see Figure A-4) (NOAA 2013g). Projections indicate that TTLs in the Southeast may experience more intense heat waves, showing a 4–20 day increase in the length of consecutive days with temperatures over 95°F by mid-century under a high emissions scenario (NOAA 2013g).

As average air temperatures increase, TTLs in the Southeast are projected to experience fewer extremely cold nights (<10°F). Much of the Southeast has not had to endure extremely cold nights in the past in an average winter, and projections indicate that the number of extremely cold nights could drop to zero for all TTLs in the region by mid-century under a high emissions scenario (NOAA 2013g).

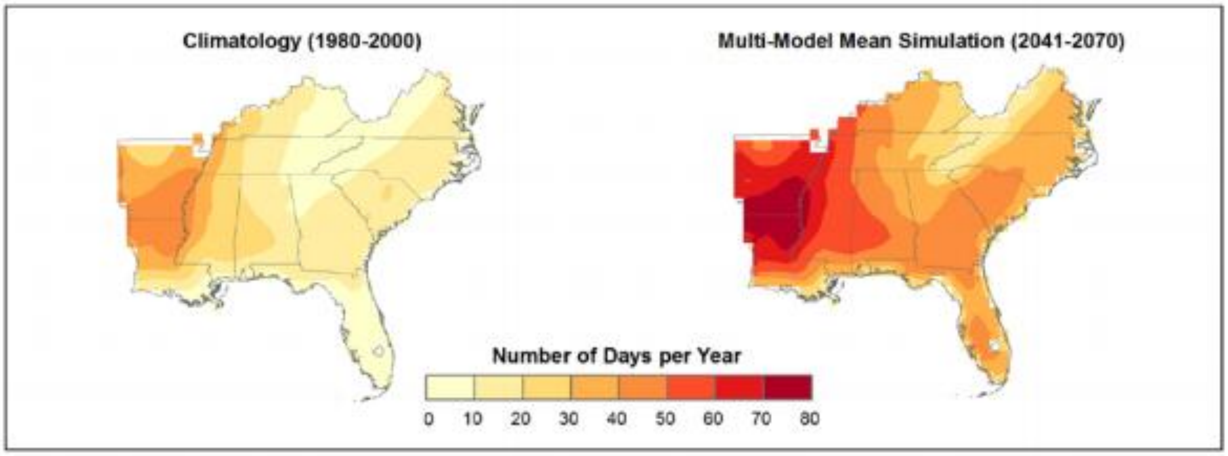

Figure A-4. The mean annual number of extremely hot days (>95°F) in the Southeast region is projected to increase significantly from 1980–2000 (left) to 2041–2070 (right) under a high emissions scenario.
Source: NOAA 2013g

Alaska

The average annual air temperature in Alaska varies significantly by region; average air temperatures in southern and southeastern coastal areas, the Aleutian Islands, and the Bristol Bay region range from 32°F–52°F, while average air temperatures on the Northern Slope and in high elevation areas can range from -4°F–10°F (NOAA 2013h). There is also dramatic variability in interseasonal temperature variation, with interior Alaska seeing a 90°F difference in temperature between summer highs and winter lows (NOAA 2013h).

Since 1949, average annual air temperature in Alaska has increased 3.0°F (NOAA 2013h, USGCRP 2014). Seasonally, the largest temperature increase over this period has been in winter (6.0°F) (NOAA 2013h, USGCRP 2014). As average annual air temperatures have increased, extremely cold temperatures have occurred less frequently, and extremely warm temperatures have occurred more frequently. From 1950–2008, all observed weather stations in Alaska except those in the Southeast experienced an increase in the occurrence of the hottest 1% of days and decrease in the occurrence of the coldest 1% of days (NOAA 2013h).

Under a high emissions scenario, air temperatures on ANVs in the northern and interior regions may increase an additional 10°F–12°F and 8°F–10°F, respectively, by the end of the century (USGCRP 2014). Air temperatures elsewhere in the state are projected to increase 6°F–8°F by the end of the century under a high emissions scenario (USGCRP 2014). As shown in Figure A-5, under a low emissions scenario, air temperatures are projected to increase 3.5°F–7.5°F by the end of the century, with the north seeing the largest increases (USGCRP 2014). As temperatures increase, the spring thaw is projected to advance by 2–3 weeks, and autumn freeze-up is projected to occur 2 weeks later (2090–2099, compared to 1961–1990) in much of interior Alaska (NOAA 2013h). Along Alaska's northern and western coastlines, the autumn freeze is projected to be delayed even more—by 40–60 days—as a result of sea ice decline (NOAA 2013h).

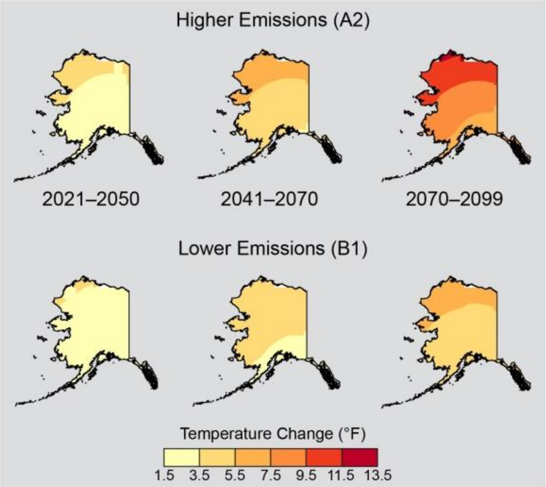

Figure A-5. Average air temperatures are projected to significantly increase in Alaska (relative to 1971–1999).
Source: USGCRP 2014

Changing Water Availability

Average annual precipitation in the United States has increased about 5% since 1900 (USGCRP 2014). The Northeast, Midwest, and southern states of the Great Plains have experienced increasing average annual precipitation, while precipitation patterns have been mixed in the Northwest, Southwest, and Southeast, and in the northern states of the Great Plains (USGCRP 2014).

Seasonal precipitation, the most relevant factor in determining regional water availability, varies widely across regions. Among seasons and regions of the United States, only summer precipitation in the Southeast has demonstrated a significant rate of decline over the last century (NOAA 2013a).

Drought,[42] snowpack, and streamflow are also important factors in determining water availability within a region. Drought conditions have become more widespread, with a larger percentage of the contiguous United States experiencing drought since 1971 (USACE 2013). Snowpack serves as an important natural reservoir in the western United States, but it has been affected by increasing temperatures and changing precipitation patterns over the past five decades. As temperatures have risen, a larger percentage of precipitation has fallen as rain rather than snow throughout much of the country, and the amount of water stored in snowpack[43] has declined significantly in the western United States (Hamlet et al. 2005). Snowmelt is also occurring earlier in the season, contributing to a trend toward earlier peak flows in rivers across the western United States and Alaska (USGCRP 2014).

As shown in Figure A-6, the United States is projected to experience changes in precipitation along a north–south gradient; average annual precipitation is projected to increase in states in the northern portion and decrease in states in the southern portion of the country (NOAA 2013a, USGCRP 2014).

Seasonal precipitation projections vary significantly across the United States (Table A-1). The majority of the nation is projected to experience drier summers, and portions of the Great Plains and Southwest may see a greater-than-15% decrease in summer precipitation by mid-century[44] under a high emissions scenario (NOAA 2013a). Decreasing snowpack and earlier snowmelt due to climate change are expected to further restrict water availability (NOAA 2013a).

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[42] Droughts are defined as extended periods without precipitation that may be exacerbated by low snowpack and high evaporation rates (DOE 2013a).

[43] Snowpack is typically measured in snow water equivalent (SWE): the depth of water that would result if the entire snowpack were melted instantaneously.

[44] For changing water availability projections, mid-century refers to 2041–2070 compared to 1971–1999.

As temperatures increase and summer precipitation decreases, seasonal drought is projected to intensify throughout most of the United States, and longer-term droughts are projected to intensify in parts of the Southwest, southern Great Plains, and Southeast (USGCRP 2014). Under high emissions scenarios, droughts throughout the central and southern United States are expected to occur more frequently and for longer periods (USGCRP 2014).

Changing precipitation patterns and increasing temperature may also affect groundwater storage in parts of the United States. While the impacts of climate change on groundwater storage are expected to vary by location and aquifer, groundwater aquifers in the Southeast, Southwest, and Great Plains may be increasingly stressed by climate change (USGCRP 2014). These regions rely on groundwater as the main water supply source and are projected to see some of the highest increases in water demand due to climate change alone (USGCRP 2014). Additionally, studies on soil moisture indicate that aquifers in the Southeast, Southwest, and Great Plains may experience declining recharge rates due to climate change (USGCRP 2014).

Table A-1. Climate indicators that affect water availability.

Climate indicator	Projected change	Geographic coverage
Annual precipitation	Increasing	Northern United States
	Decreasing	Southern United States
Summer precipitation	Decreasing	United States
Proportion of precipitation falling as snow	Decreasing	Northeast, Northwest, and high elevations across the United States
Mountain snow water equivalent	Decreasing	Western United States
Peak streamflow	Occurring earlier	Western and Northeast United States
Annual runoff and streamflow	Increasing	Midwest and Northeast
	Decreasing	Southwest
Duration, frequency, and intensity of droughts	Increasing	Southern United States

Source: DOE 2013a

Northwest

Annual precipitation in the Northwest varies widely. On TTLs west of the Cascade range, such as the Tulalip Reservation, annual precipitation ranges from 51 inches to over 75 inches, with portions of the Olympic Peninsula, including the Quinault and Makah Indian Reservations, seeing over 150 inches of precipitation a year (NOAA 2013b). Contrastingly, on TTLs east of the Cascades, such as the Warm Springs and Umatilla Reservations, annual precipitation typically ranges from >10 to 20 inches of precipitation a year (NOAA 2013b). By the end of the century, precipitation throughout most of the Northwest is projected to increase by up to 9% depending on the emissions scenario, with the largest increases expected in northern Washington in the region containing the Colville, Yakama Nation, and Quinault Reservations (NOAA 2013b).

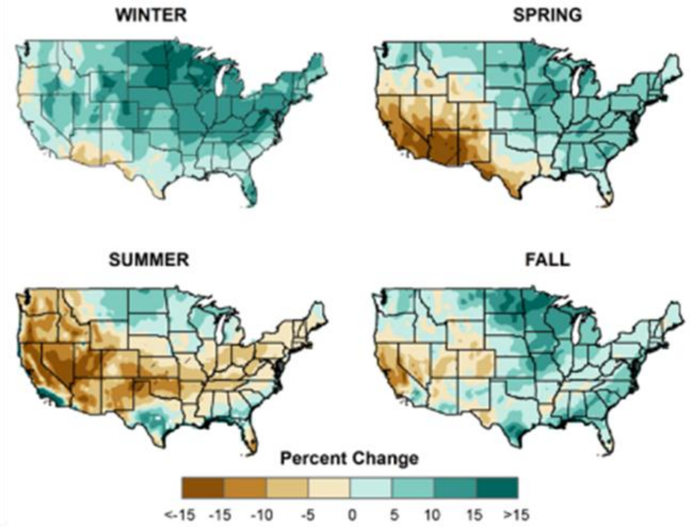

Figure A-6. Seasonal precipitation patterns are projected to vary across the United States by mid-century (2041–2070, compared to 1971–1999) under a high emissions scenario.
Source: NOAA 2013a

The Northwest region's water flows are heavily influenced by melting snowpack. Increasing temperatures result in reduced precipitation stored as snowpack and earlier snowmelt and, thus, are projected to cause increased water flow earlier in the year and decreased flow in the summertime (USGCRP 2014) (Figure A-7). Historically, water flows have peaked around June, but models project that, by 2080 under a high emissions scenario, maximum streamflow will occur as early as February (USGCRP 2014).

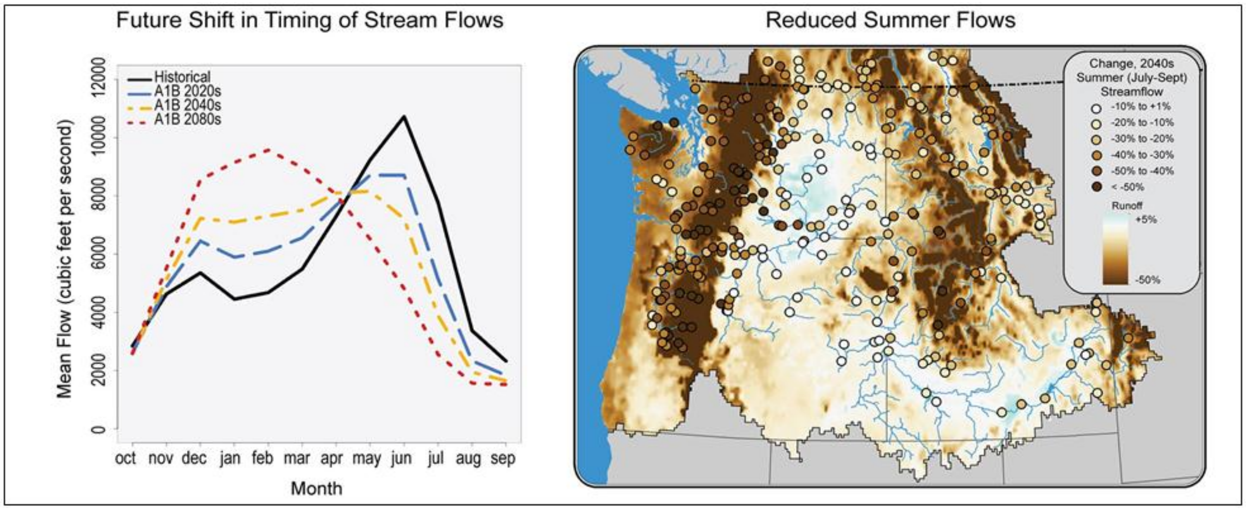

Figure A-7. Climate change is projected to shift the timing of peak streamflow in the Northwest.
Source: USGCRP 2014

Even as average annual precipitation in the region increases, TTLs in the Northwest are projected to experience a decrease in summer precipitation. In all portions of the Northwest except along the Oregon coast, summer precipitation is projected to decrease by up to 20% by mid-century under a high emissions scenario. Projections indicate that, by mid-century under a high emissions scenario, all TTLs in the Northwest will see an increase in the maximum number of days with little or no precipitation, and TTLs in western Oregon will experience up to 15 days with <0.1 inches of precipitation (NOAA 2013b).

Southwest

The majority of the Southwest region, with the exception of the Sierra Nevada and northwest California, is typically dry with average precipitation ranging from <10 inches to 15 inches a year (NOAA 2013f). Under a high emissions scenario, annual precipitation on TTLs in the Southwest region is projected to decrease by up to 12% by the end of the century, with TTLs in Arizona, southern California, and eastern New Mexico—such as the Tohono O'odham Reservation, Gila Indian Reservation, and Colorado River Indian Reservation—expected to experience the largest decreases in annual precipitation (NOAA 2013f).

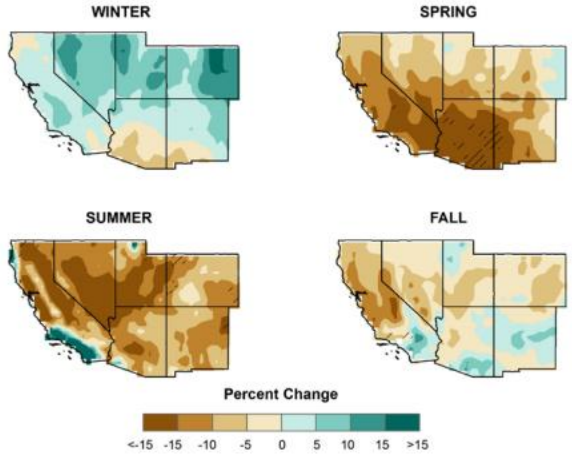

Figure A-8. Seasonal precipitation is projected to decrease in spring and summer and increase in winter by mid-century in the Southwest under a high emissions scenario.
Source: NOAA 2013b

Seasonal precipitation is projected to decrease in spring and summer in areas containing TTLs throughout most of the Southwest (Figure A-8). Most of the Southwest region is projected to experience a 5%–15% decrease in spring and summer precipitation by mid-century under a high emissions scenario (NOAA 2013f). TTLs in portions of California, Nevada, and New Mexico, including the Hualapai Indian Reservation, may see summer precipitation levels decrease by more than 15% by mid-century (NOAA 2013f). TTLs in portions of Arizona, California, and New Mexico, such as the Navajo Nation, Hopi Reservation, and San Carlos and Apache Reservations, are expected to see a similar decrease in spring precipitation levels by mid-century under a high emissions scenario (NOAA 2013f).

Along with decreasing average and seasonal precipitation, TTLs in the Southwest are projected to experience an increase in the number of days with no precipitation. TTLs that are already prone to periods of drought, such as those in Arizona, California, and Nevada, including the Navajo Nation and Colorado River Indian Reservation, may see a 25-day increase in the number of consecutive days with little or no precipitation (<0.1 inches) by mid-century under a high emissions scenario (NOAA 2013f). Decreasing seasonal precipitation increases the risk of drought in the region, and the frequency, intensity, and duration of drought in major river basins such as the Colorado River Basin are projected to increase (USGCRP 2014).

Great Plains

Average annual precipitation on TTLs in the Great Plains region varies on a west–east gradient. TTLs in the far western portions of the region, such as the Wind River Reservation and Rocky Boy's Reservation, receive <15 inches of rain a year on average, but TTLs in the southeastern portion of the Great Plains, such as the Osage Reservation, typically receive 41–50 inches of rain a year (NOAA 2013d).

The projected change in average precipitation on TTLs in the Great Plains varies across the region, seasons, and emissions scenario being modeled. In a higher emissions scenario, total annual precipitation is projected to increase 6%–12% on TTLs in the northeast Great Plains region, particularly those in North and South Dakota and eastern Montana, and decrease by up to 3% in the mountains of western Montana and Wyoming and by more than 6% in western Texas by the middle of this century (NOAA 2013d). Projections indicate that seasonal changes may be larger. In the same scenario, most of the region is projected to see increases in precipitation in winter, spring, and fall by mid-century, with the largest increases in the northern and eastern parts of the region (NOAA 2013d). Projected decreases are largest in summer in the central part of the region (including TTLs in Kansas, Nebraska, and Oklahoma), in the mountains, and in southern Texas in the spring (NOAA 2013d). The number of consecutive days without rain[45] in the southern plains and mountainous areas is projected to increase by 3–15 days by mid-century (NOAA 2013d).

Midwest

Average precipitation in the portions of the Midwest region containing TTLs ranges from 16 inches in the western portion of Minnesota, where TTLs such as the Leech Lake and White Earth Reservations are located, to 36 inches in southern Iowa and Michigan, where the Huron Potawatomi and Pokagon Reservations are located (NOAA 2013e). Since 1895, average annual precipitation in the Midwest has increased almost 3.5 inches, and climate change projections indicate that average precipitation will continue to increase (NOAA 2013e).

Under a high emissions scenario, average precipitation in areas of the Midwest region where TTLs are located is projected to increase by 6%–12% by mid-century (NOAA 2013e). This increase in average precipitation is expected to be accompanied by an increase in seasonal precipitation; average winter and spring precipitation are projected to increase 10% and 20%, respectively, by the end of the century under a high emissions scenario (USGCRP 2014). TTLs located in the northern portion of the Midwest, such as the Red Lake and L'Anse Reservations, are expected to experience the largest increases in annual and seasonal precipitation (NOAA 2013e).

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[45] Measured as consecutive days with fewer than 3 mm of precipitation.

Northeast

TTLs in western New York, such as the Tonawanda and Tuscarora Nation Reservations, typically receive <35 inches of rain a year, while average precipitation can reach up to 60 inches on TTLs in eastern New York and New England, including the Penobscot and Indian Township Reservations (NOAA 2013c). Since 1895, annual precipitation in the region has increased by almost 4.3 inches, a trend which is projected to continue (NOAA 2013c).

Average precipitation on TTLs throughout the Northeast is projected to increase 3%–9% by the end of the century (NOAA 2013c). Under a high emissions scenario, TTLs along the coast in the Northeast, such as the Narragansett and Mashantucket Pequot Reservations, may see up to a 6% increase in precipitation by mid-century, and TTLs throughout the region may see an 8%–12% increase in winter precipitation (NOAA 2013c).

Southeast

Average annual precipitation reaches over 68 inches on TTLs in southeastern Florida and the Gulf Coast regions of the Southeast, including the Poarch Creek and Chitimacha Reservations, while TTLs located further inland, such as the Eastern Cherokee Reservation, typically receive 44–60 inches of precipitation a year (NOAA 2013g).

Climate change's projected impact on water availability on TTLs in the Southeast varies by location and emissions scenario. Under a low emissions scenario, annual precipitation is projected to increase by up to 6% on TTLs in Alabama, North Carolina, South Carolina, and eastern Mississippi and decrease by 3% on TTLs in southern Florida and portions of Louisiana and western Mississippi (NOAA 2013g). Under a high emissions scenario, annual precipitation by the end of the century is not projected to change in TTLs in the Carolinas, but it is projected to decrease 3%–9% on TTLs in southern Florida, Alabama, Louisiana, and Mississippi (NOAA 2013g).

Seasonal changes in precipitation, which can lead to drought and flooding, are more salient regarding the availability of water for the energy sector than are annual changes. Some TTLs in the Southeast, particularly the six TTLs concentrated in southern Florida, are projected to endure drier summers (NOAA 2013g). By mid-century, southern Florida is projected to see up to a 15% decrease in summer precipitation (Figure A-9) and a 4–8 day increase in the average number of consecutive days with <0.1 inches of rain (NOAA 2013g). Additionally, by 2060, water availability in the western portion of the Southeast is projected to decrease up to 6.4% relative to 2010 levels (USGCRP 2014).

Some Southeastern TTLs may experience a significant increase in precipitation in the summer, and TTLs in southern Alabama and eastern Mississippi, such as the Poarch Creek Reservation and parts of the Mississippi Choctaw Reservations, may see more than a 20% increase in summer precipitation by mid-century (2041–2070, compared to 1971–2000) (NOAA 2013g).

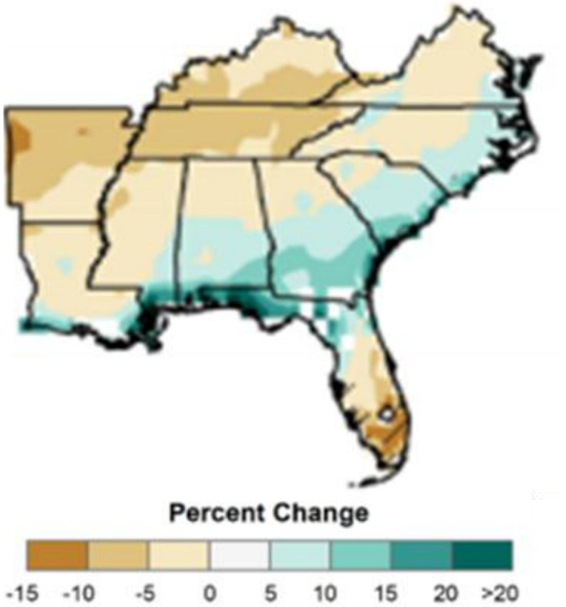

Figure A-9. Summer precipitation is expected to decrease for many TTLs in the Southeast by mid-century under a high emissions scenario.
Source: NOAA 2013g

Alaska

Average annual precipitation in Alaska is highly variable by region; the coastal mountain ranges in the Southeastern panhandle receive 200 inches of precipitation a year, while the Arctic region typically gets <6 inches of precipitation a year (NOAA 2013h).

Average annual precipitation in Alaska has increased by about 10% from 1949–2005, but the southeastern Alaska panhandle and the Arctic coast have experienced decreases in both seasonal and annual precipitation (NOAA 2013h). Annual precipitation is projected to increase in Alaska, particularly in the northwestern region of the state, but total water availability in the state is expected to decrease as a result of increasing evaporation with increasing temperatures and longer growing seasons that enable more vegetation (USGCRP 2014). Annual precipitation is projected to increase 15%–35% (with smaller increases in southeastern Alaska) under a high emissions scenario and 5%–20% under a low emissions scenario by the end of the century (2070–2099, compared to 1971–1999), and seasonal precipitation is projected to increase in all four seasons (NOAA 2013h, USGCRP 2014). As winter temperatures increase, the amount of precipitation that falls as rain rather than snow may also increase, reducing the water available from snowpack (Cherry et al. 2010).

Water availability in Alaska is also expected to be affected by glacial melt. Alaska's glaciers have demonstrated the highest rates of decline anywhere on earth, and the rate of glacial melt in North America tripled from the mid-1990s to 2000 (relative to the melt rate from the mid-1950s to the mid-1990s) (ADNR 2014, Zemp and Haberli 2007). As temperatures increase, glaciers are projected to retreat, with those that empty directly into the ocean at the highest risk (ACIA 2005, USGCRP 2014). While this may lead to an increase in river discharge in the short term, it may reduce input to reservoirs in the long term (USGCRP 2014).

Increasing Wildfires

Increasing temperatures, decreasing water availability, shifting forest range and composition, and tree death associated with climate change have contributed to longer wildfire seasons and increased burn area of wildfires in Alaska and the western and southeastern portions of the country (USGCRP 2014). In some areas of the country, the combined effects of extended periods of high temperatures and drought resulted in dry conditions that drive wildfires, and water deficits increase tree stress and mortality, fuel flammability, and tree vulnerability to insect outbreak (USGCRP 2014). Climate change may also affect populations of insects that kill trees, such as the bark beetle, thus contributing to wildfires by making crown fires more likely (USGCRP 2014). Warmer winters in the United States have contributed to outbreaks of bark beetle populations in western forests, as beetle populations are now able to survive and reproduce throughout winter (USGCRP 2014).

Climate change is projected to continue to exacerbate the main factors leading to wildfire (heat, drought, and tree death), and as a result, the southern and western United States and Alaska are projected to experience large wildfires that are both more intense and more frequent (USGCRP 2014). As temperatures rise, the elevation of suitable habitats for mountain pine beetles is projected to increase, which may increase the range of beetle outbreaks, and shifting forest range and composition due to climate change may further increase risk of wildfire in some regions (USGCRP 2014). While eastern forests are less likely to see immediate increases in wildfire, forests in the western United States and Alaska are projected to be increasingly at risk from large and intense fires occurring more frequently (USGCRP 2014).

Northwest

Increasing summer air temperatures and decreasing summer precipitation are expected to contribute to increased risk of wildfire in the Northwest and lead to longer wildfire seasons. By the 2080s, the median annual burn area in the Northwest is projected to quadruple (compared to 1916–2007) to 2 million acres under a high emissions scenario (USGCRP 2014). As shown in Figure A-10, precipitation and temperature changes may increase burn area by more than 600% in some locations (USGCRP 2014). In a given year, the probability that the Northwest would experience a 2.2 million-acre burn area would increase from 5% to 50%, although the probability that a given area would burn is dependent on forest type, land use, and other factors (USGCRP 2014).

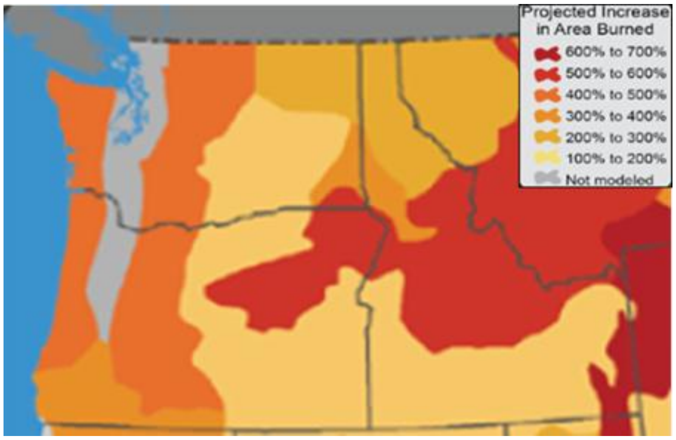

Figure A-10. The burn area in the Northwest would significantly increase with regional temperature and precipitation changes associated with 2.2°F warming.
Source: USGCRP 2014

Southwest

Prolonged periods of high temperatures and dry conditions, as well as accumulation of woody biomass and insect outbreaks, are projected to increase the risk of wildfire and lengthen wildfire season in the Southwest region. Warm, dry conditions between 1970 and 2003 resulted in a 650% increase in the area burned by wildfire in western mid-elevation conifer forests in the Southwest (USGCRP 2014). Some models suggest that burned area may double in the southern Rocky Mountains and increase by 74% in California because of climate change (USGCRP 2014).

Great Plains

TTLs in Montana and Wyoming, including the Blackfeet, Flathead, and Wind River Reservations, are projected to experience an increase in the burn area as higher air temperatures contribute to drier soil, increased pest range, greater accumulation of biomass in forests, and more frequent and extensive tree die-offs (NRC 2011, USGCRP 2014). Together with changing water availability, these impacts are projected to increase the number, size, intensity, and duration of wildfires (USDA 2013). Projections indicate that a global air temperature increase of 1.8°F could increase wildfire burn area in Montana and Wyoming by up to 650% relative to the median area burned from 1950–2003 (NRC 2011).

Southeast

Increasing air temperatures, along with changing precipitation patterns and changing land use patterns that limit prescribed burning practices, are projected to contribute to increased fire frequency and size in the Southeast (USGCRP 2014). Drought often correlates with large wildfires in the Southeast, and projections indicate that portions of the Southeast will experience decreasing water availability and high temperatures, which may contribute to increased drought in the region (USGCRP 2014). However, wildfires are frequently initiated by lightning in the Southeast. Lightning strikes may be affected by increasing temperatures and changing atmospheric patterns due to climate change, but the link between lightning strikes and climate change is an area of active research (USGCRP 2014).

Alaska

In the past decade, more large fires have burned in Alaska than any decade since record-keeping began in the 1940s. Warming temperatures have contributed to drier conditions and a longer growing season in Alaska, and the range of spruce forests and other vegetation has expanded northward, increasing fuel for wildfires (USGCRP 2014). Additionally, deeper permafrost active layers may allow fires to persist in some areas (NOAA 2013h). Climate change is projected to lead to more extensive and severe wildfires in Alaska. Average annual burn area is projected to double in size by mid-century and may triple by the end of the century (USGCRP 2014).

Fires can also affect the health and depth of permafrost. They can reduce insulating vegetation from the active layer of soil (the topmost layer that freezes and thaws annually) and increase soil drainage, which can lead to rapid local permafrost thaw or even long-term transition to permafrost-free soil (LTER 2006). When combined with the effects of warming permafrost temperatures, fire-related changes to local permafrost conditions may affect soil stability.

Increasing Heavy Rainfall, Hurricanes, Sea Level Rise, and Erosion

Higher air temperatures increase the capacity of air to hold water, contributing to an increase in the intensity of precipitation events. As a result, the United States has seen an increase both in the intensity of rainstorms and in the frequency of extreme rainstorms, defined as an event depositing more than an inch of rain in a single day (NOAA 2013a, USGCRP 2014). The amount of rain that falls during these extreme precipitation events has been above average since 1991, and, as shown in Figure A-11, the Northeast and Midwest regions have seen the largest increases in the amount of rain that falls in heavy events (USGCRP 2014). As the frequency and intensity of extreme precipitation events has increased, the Midwest, Northeast, and parts of the Great Plains have experienced an increase in flooding events (USGCRP 2014).

As temperatures continue to rise, the intensity of rainstorms and frequency of extreme precipitation events is projected to continue to increase across the United States, even in regions such as the Southwest, where average precipitation is projected to decrease (USGCRP 2014). This may cause increased flooding throughout the country. Flood frequency and severity are projected to increase in the Northeast and Midwest in particular (USGCRP 2014).

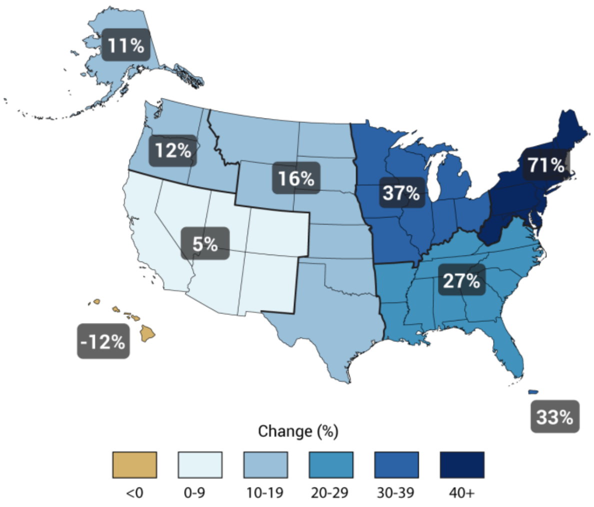

Figure A-11. The contiguous United States has experienced an increase in the amount of precipitation that falls in very heavy events (the heaviest 1% of all daily events) from 1958–2012.
Source: USGCRP 2014

Hurricanes have increased in intensity and duration in the North Atlantic basin since the 1980s, and the most intense hurricanes, those rated as Category 4 or 5, have occurred more frequently (USGCRP 2014). While this remains an area of active research, current climate change projections indicate that only the intense (Category 4 or 5) hurricanes will increase in frequency (USGCRP 2014). The rainfall rates within these storms are also projected to increase (USGCRP 2014).

Increasing temperatures have caused increased melting of glaciers and ice sheets as well as the thermal expansion of ocean water. The resulting rise in global sea level can amplify the flooding and storm surge associated with heavy precipitation events and hurricanes. Relative sea level rise along a given coastline, however, depends both on global sea level and on changes in land elevation. Land subsidence along the Gulf and Atlantic coasts has resulted in high relative sea level rise in that region, and uplift in the Northwest and Alaska is responsible for low relative sea level rise there (USGCRP 2014). Sea level rise is projected to accelerate with climate change, and relative sea level along the Gulf Coast may increase by up to 2.3 feet by 2050 (relative to sea level in 1992), depending on future ice sheet melt (USGCRP 2014).

Melting ice sheets and thawing permafrost due to increasing temperatures have also contributed to accelerating coastal and riverbank erosion in Alaska (USGCRP 2014). While Alaska has not seen a large increase in relative sea level, the northern and western coastlines are increasingly vulnerable to erosion due to climate change-induced melting ice and thawing permafrost, and riverbanks may experience accelerating rates of erosion due to permafrost thaw (USGCRP 2014).

Northwest

Extremely heavy precipitation events (>1 inch) are projected to become more frequent in some portions of the Northwest. TTLs east of the Cascades that currently see fewer than 5 days a year with more than an inch of precipitation may see a more than 40% increase in the number of days with extreme precipitation by mid-century[46] (NOAA 2013b).

Relative sea level change in the Northwest from the middle of the 20th century to 2006 ranged from a 0.06-inch-per-year decrease in relative sea level to a 0.11-inch-per-year increase in relative sea level (NOAA 2009). Depending on future ice sheet melt, relative sea level in the Northwest may rise up to 1.7 feet by 2050 (compared to 1992 sea level) in some locations. Because of tectonic uplift, relative sea level rise along the Northwest coast is not as severe as in other regions, and relative sea level rise in the Northwest is projected to be modest compared to most regions in the United States (USGCRP 2014).

Southwest

Despite decreasing annual precipitation, portions of the Southwest region are projected to experience an increase in extreme precipitation events (>1 inch per day). Under a high emissions scenario, TTLs in Nevada, Utah, and western Colorado, including the Pyramid Lake Paiute Reservation and Walker River Reservation, are projected to see the frequency of extreme precipitation events increase by 10%–60+% by mid-century (NOAA 2013f). The frequency of extreme precipitation events is projected to decrease in Arizona, eastern Colorado, and the Sierra Nevada (NOAA 2013f).

Sea level on the California coast has risen 6.7–7.9 inches in the past 100 years and is projected to rise at an accelerated rate in the future as a result of climate change (USGCRP 2014). Depending on the emissions scenario, relative rea levels in 2100 are projected to be 17–66 inches higher than sea levels in 2000 along the California coastline (NRC 2012).

Great Plains

Changes in extreme precipitation events in the Great Plains are not projected to be dramatic (USGCRP 2014). In both low and high emissions scenarios, TTLs in portions of the northern plains states are projected to see increases in the number of days with heavy precipitation (USGCRP 2014). Under a higher emissions scenario, increases are projected to be 15%–60% by mid-century, although given the current low occurrence of heavy precipitation events, these increases may be on the order of only one more day per year (NOAA 2013d, USGCRP 2014).

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[46] For storm projections, “mid-century” refers to the period 2041–2070, compared to 1980–2000 unless a different time range is specifically noted.

Midwest

As shown in Figure A-12, the frequency of extreme precipitation events (>1 inch) is projected to increase in states containing TTLs in the Midwest; by mid-century (2041–2070, compared to 1971–2000), the number of days with more than an inch of precipitation is supposed to increase by 20%–40% throughout most of the area containing regional TTLs under a high emissions scenario (NOAA 2013e). Additionally, the amount of rain that falls during the heaviest rainfalls is projected to increase in portions of the Midwest. TTLs throughout most of the region are projected to see a 0.2–0.6 inch increase in the amount of rain that falls in the wettest 5-day period each year, and TTLs in southern Michigan, such as the Pokagon Reservation, may see an increase of >1 inch in the amount of rain that falls during this period each year (USGCRP 2014).

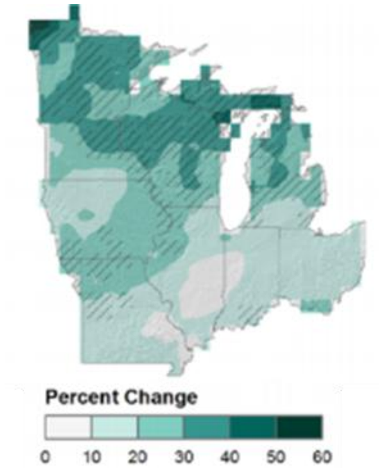

Figure A-12. The annual number of days in the Midwest with extreme precipitation events (>1 inch) is expected to increase significantly by mid-century under a high emissions scenario.
Source: NOAA 2013e

Northeast

The region has experienced more than a 70% increase in the amount of precipitation falling in very heavy events (the heaviest 1% of all daily events) from 1958–2010, and extreme precipitation events (>1 inch) in New York and New England are projected to increase by 10%–30% by mid-century under a high emissions scenario (Figure A-13) (NOAA 2013c, USGCRP 2014).

TTLs in the Northeast are also vulnerable to the projected increase in the frequency of intense hurricanes (Categories 4 and 5) in the North Atlantic basin and increasing rainfall rates within 60 miles of tropical storm centers (USGCRP 2014).

Accelerating sea level rise in the Northeast region will enhance storm surge associated with hurricanes and flooding during extreme precipitation events in the region. Relative sea levels along the region's coastline rose by an average of 0.07–0.22 inches per year from the middle of the 20th century to 2006 (NOAA 2009). Depending on future ice sheet melt, sea levels are projected to rise by an average rate of 0.06–0.41 inches per year between 1992 and 2050 (USGCRP 2014). Global mean sea level rise is made more acute by land subsidence in the Northeast. In the areas along Long Island Sound, where most coastal TTLs are located, the odds of storm surge exceeding the 100-year flood level are projected to increase from 2%–9% at current sea levels to 23% –37% by 2030 (Strauss et al. 2012).

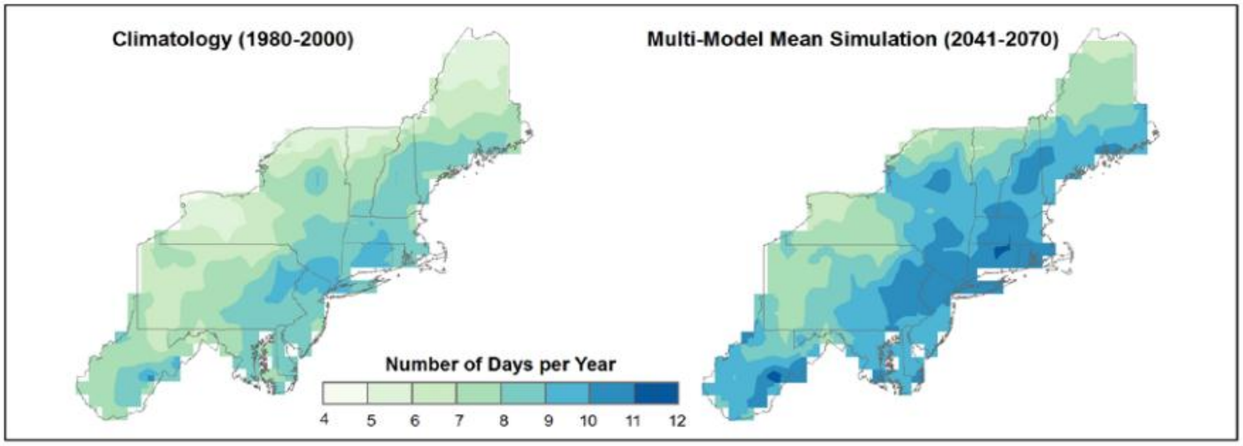

Figure A-13. The mean annual number of days with more than one inch of precipitation for the Northeast region is projected to increase significantly from 1980–2000 (left) to 2041–2070 (right).
Source: NOAA 2013c

Southeast

The projected increase in the frequency of Category 4 and 5 hurricanes in the North Atlantic basin and rainfall rates associated with tropical storms will likely have an impact on TTLs in the Southeast region (USGCRP 2014). Additionally, all TTLs in the region are projected to see an increase in the frequency of extreme precipitation events (>1 inch) under a high emissions scenario (NOAA 2013g). Under a high emissions scenario, the Eastern Cherokee Reservation in North Carolina is projected to experience a 15%–25% increase in extreme precipitation events by mid-century, and TTLs in southern Alabama and eastern Mississippi that previously experienced 13–16 days a year with precipitation over an inch may see almost 18 days a year with these conditions (NOAA 2013g).

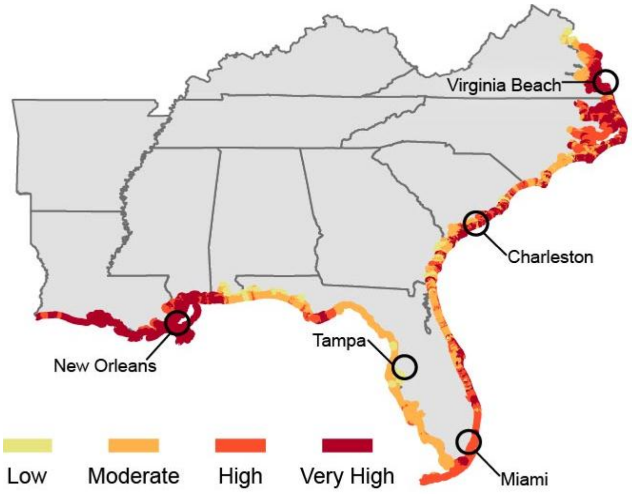

Figure A-14. Relative risk from sea level rise in the Southeast (based on index measuring coastal system susceptibility to change and the area's natural ability to adapt).
Source: USGCRP 2014

Although there are few TTLs near the coast, residents of the Southeast—including those on TTLs—are dependent on energy infrastructure located along the coast. Coastal energy infrastructure in the region is particularly vulnerable to accelerating sea level rise, as global mean sea level rise due to climate change is amplified by land subsidence (Figure A-14). Relative sea levels along the Southeast coastline rose by an average of 0.03–0.38 inches per year from the middle of the 20th century to 2006 (NOAA 2009). Depending on future ice sheet melt, sea levels are projected to rise by an average rate of 0.06–0.48 inches per year between 1992 and 2050 (USGCRP 2014). Because of their proximity to the coast and low elevation, infrastructure on TTLs in coastal Louisiana and Florida may be significantly affected by accelerating sea level rise. For example, the Chitimacha Reservation in Saint Mary County is located in an area of southern Louisiana that is sited less than five feet above sea level (Kosovich 2008). Storm surge associated with hurricanes and flooding during heavy precipitation events will be amplified by accelerating sea level rise in the region. For example, the area flooded by storm surge during a Category 5 hurricane may increase by 4%–7%, depending on the magnitude of sea level rise (Maloney & Preston 2014).

Alaska

Declining sea ice and thawing permafrost may increase the rate of coastal and riverbank erosion in Alaska.

As global air temperatures have increased, Arctic sea ice extent and thickness have significantly decreased. Sea ice extent has decreased by more than 40% in late summer, when sea ice is typically at its least extensive, and the past seven Septembers have had the lowest ice extent since 1979 (USGCRP 2014). On February 25, 2015, Arctic sea ice reached its lowest seasonal maximum ever recorded, with winter sea ice failing to reach the Bristol Bay (NSIDC 2015). Sea ice becomes thinner as it declines and is more vulnerable to further melting; ice thickness decreased by more than 50% from 1958–1976 to 2003–2008 (USGCRP 2014).

Decline of sea ice cover is expected to continue. Models project that the Arctic will be virtually ice-free in September by the 2030s (USGCRP 2014). Winter sea ice is projected to decline by about 10% by 2040, but by the end of the century, winter sea ice is projected to decline such that Alaska's southwestern coastline on the Bering Sea may be ice-free (ACIA 2005, USGCRP 2014).

Additionally, approximately 80% of Alaska is underlain by permafrost, and for much of Alaska's interior and western coastlines, increasing air temperatures are contributing to increasing permafrost temperatures, which can lead to reduced permafrost depth and increasing thaw (NOAA 2013h, USGCRP 2014). Permafrost, soil that has remained frozen for at least two years, includes a top "active layer" that thaws during the summer and refreezes during winter and a lower layer that can be several to several hundred meters deep (NOAA 2013h). Permafrost depth and temperature is determined primarily by mean annual temperature and wintertime snow depth (in addition to soil properties and ground slope), and increasing temperatures have resulted in thawing permafrost in Alaska, which may induce settling or slumping of soil and altered hydrology (NOAA 2013h).

Since the 1970s, permafrost near the Arctic coast has warmed 4°F–5°F at a 65-foot depth, and permafrost at a 3.3-foot depth has warmed 6°F–8°F since the mid-1980s (USGCRP 2014). In areas with discontinuous permafrost,[47] increasing temperatures are projected to lead to loss of permafrost, and some models project that large parts of Alaska will be free of near-surface permafrost by the end of the century (Figure A-15) (ACIA 2005, USGCRP 2014). Regions that are underlain by continuous permafrost may see a decline in permafrost layer thickness and an increase in active layer thickness (ACIA 2005, USGCRP 2014).

Rapid coastal erosion can occur during severe winter storms when sea ice is not present to protect the shoreline from wave action and storm surge. Sea ice protects coastlines along Alaska's northern and western coastlines from erosion during powerful winter storms, and reduces the height of storm surge and risk of coastal flooding (USGCRP 2014). Permafrost can also increase the resistance of shorelines to erosion, as coastal bluffs have historically been "cemented" by ice-rich permafrost (USGCRP 2014). Permafrost also plays a role in protecting inland riverbanks from erosion, and loss of ice-rich permafrost may weaken riverbank soils (ACIA 2005, McNamara 2010).

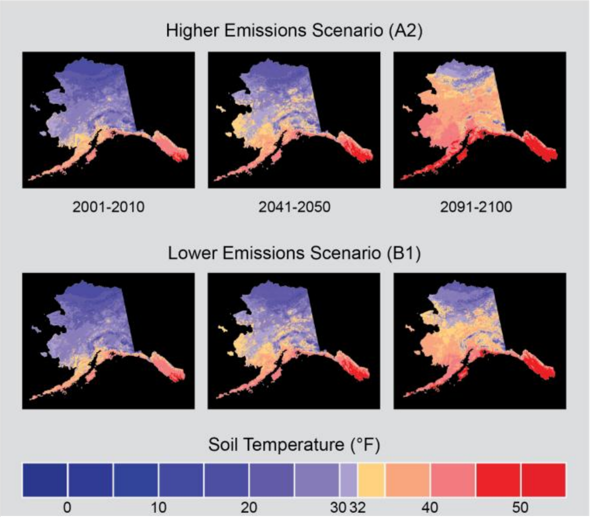

Figure A-15. Annual average ground temperature at 3.3 feet is projected to increase from below freezing (indicated by blue shades) to above freezing for much of Alaska.

Source: USGCRP 2014

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[47] Not all soil in Alaska is underlain by permafrost, but regions can be described as occurring in one of three types of zones, depending on how common permafrost occurs. Continuous permafrost zones are defined as those with >90% of the land area underlain by permafrost. Discontinuous zones are those underlain by 50%–90% permafrost. Sporadic permafrost regions are those underlain by 10%–50% permafrost (ACIA 2005).

Extreme Weather

Winter Storms

TTLs in the northern United States are particularly susceptible to winter storms producing heavy snow, high winds, and extremely low wind chill temperatures. In the northern states in the Great Plains region, where TTLs including Fort Berthold, Fort Peck, Fort Belknap, and the Blackfeet Reservations are located, winter storms can lead to blizzard conditions, and the probability of blizzard conditions in North and South Dakota in a given year is higher than 50% (NOAA 2013d).[48] Similarly, TTLs in the Northeast experience serious winter storms known as nor'easters, which can lead to crippling snowfall and hurricane-force winds (NOAA 2013a). In the Midwest and Northeast, TTLs such as the L'Anse, Bad River, Tuscarora Nation, Tonawanda, Oneida Nation, Onondaga Nation, Cattaraugus, Allegany, and Oil Springs Reservations are vulnerable to lake-effect snow, which occurs when cold air masses pass over and absorb moisture from unfrozen Great Lakes (NOAA 2013c, 2013e). As shown in Figure A-16, portions of the Midwest see up to eight snowstorms a year that produce at least 6 inches of snow a day (NOAA 2013e).

In the southern United States, TTLs are vulnerable to damaging ice storms. For example, most of the Great Plains region experiences one to three days of freezing rain each year, but TTLs from northeast Oklahoma to southeastern North Dakota may see 3–4 days of freezing rain (NOAA 2013d). Similarly, in the Southeast, winter storms with more than 6 inches of snow can occur two to three times a year in the Southern Appalachians, where the Eastern Cherokee Reservation is located, but this region also experiences about three to four days of freezing rain a year and is susceptible to damaging ice storms (NOAA 2013g).

TTLs in the Northwest region are located in areas that typically see little snow, but occasional cold systems move through the coastal area. Major ice storms lasting up to four days can occur in the region, typically in the Columbia Basin area, where the Yakama Reservation is located (NOAA 2013a). Similarly, most TTLs in the Southwest are located in regions that receive little snow, but TTLs in the Sierra Nevada, such as the Stewart Community and Carson Colony, may see 20–25 winter storms of moderate intensity annually (NOAA 2013b).

Climate change and winter storms

Although national assessments link climate change to increasing temperatures, changing precipitation patterns, more frequent intense hurricanes, and accelerating sea level rise, the link between climate change and winter storms is still an area of active research (Kim et al. 2014, UCS 2014, USGCRP 2014). Despite the lack of a confirmed causal linkage, the frequency and intensity of winter storms have increased in the Northern hemisphere since 1950, and the number of extremely heavy snowstorms (≈13 inches of snow per day) in the northern and eastern portions of the United States also increased in the 20th century (NOAA 2015c, USGCRP 2014).

Recent studies have found that sea ice melt in the Arctic can destabilize the polar vortex and produce severe winter weather in regions such as New England (Kim et al. 2014). Since lake-effect snowstorms occur when air masses move over unfrozen lakes and warming temperatures continue to extend the ice-free periods in the Great Lakes, these snowstorms could well occur over a longer season (NOAA 2013a). However, extremely heavy snowstorms have been less frequent in the 21st century, and overall snow cover in the region has decreased as a result of increasing temperatures (USGCRP 2014).

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[48] Blizzard conditions are defined as winds of 35 mph or over with heavy snowfall; during blizzard conditions, visibility is reduced to less than 0.25 miles for three hours or longer (NOAA 2013d).

ANVs experience some of the most severe winter weather in the United States, and most disasters in Alaska can be attributed to severe weather such as winter storms. The Arctic, Interior, and southwestern portions of the state are particularly vulnerable to severe winter weather, and temperatures can dip low enough to freeze liquid fuels (State of Alaska 2013). In the mountainous regions of the state, heavy snow can build glaciers and cause avalanches, and heavy snow is common both in the Interior and the southern coast of Alaska (State of Alaska 2013). High winds blowing along the Arctic coast can develop into blizzards with wind chill temperatures that drop to -75°F, and heavy snow is common for ANVs in the Interior and along the southern coast (State of Alaska 2013).

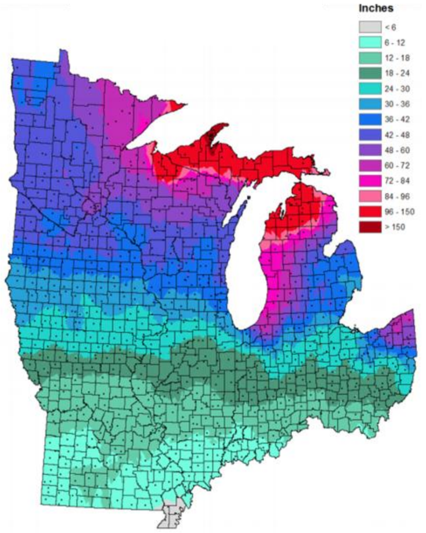

Figure A-16. Normal annual snowfall (1981–2010) in Midwestern states ranges from <6 inches in the southern portion of the region to >150 inches in northern Michigan.
Source: NOAA 2013e

Convective Storms

Convective storms, which refer to the vertical flow of moisture in certain storms, can bring damaging lightning, large hail, wind, tornadoes, and heavy rainfall. [49]

Convective storms that produce damaging lightning and tornadoes occur throughout the United States, but such storms occur most frequently in the Southeast, Midwest, and Great Plains regions. TTLs in the Great Plains are located in regions that experience frequent convective storms in the spring and summer. Several TTLs in the Great Plains, such as the Osage Reservation, are located in the southern and central Great Plains, known as “tornado alley” because of the frequency of tornadoes in the region (NOAA 2013d); on average, there are more than 150 tornadoes a year in Texas and more than 50 tornadoes a year in Kansas, Nebraska, and Oklahoma (NOAA 2015a). Similarly, TTLs in Iowa and Minnesota, which average 51 and 45 tornadoes a year, respectively, are particularly vulnerable to damage from convective storms (NOAA 2015a).

Climate change and convective storms

The relationship between climate change and convective storms is uncertain, as these events are very difficult to reproduce in climate models. However, a recent study suggests that under a high emissions scenario, climate change may increase the frequency of conditions that are favorable for formation of severe convective storms by the end of this century, with the strongest findings in the Central and Southern Plains (Diffenbaugh et al. 2013, USGCRP 2014).

The Southeast frequently experiences thunderstorms during the summer and severe thunderstorms in the late winter and spring, which can be accompanied by high winds, large hail, and tornadoes. TTLs in Alabama, Louisiana, Mississippi, and Tennessee are more likely to experience damaging winds and hail, and these states typically see the highest number of tornadoes rated F2 or higher (NOAA 2013g). Thunderstorms in the Southeast are often associated with cloud-to-ground lightning, with the Gulf Coast and Florida seeing the highest frequencies of lightning strikes of any region in the United States (NOAA 2013g).

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[49] Sometimes these storms are referred to as thunderstorms, but the term “convective storms” is used in this report to include the class of non-thundering storms that can produce hazardous weather.

Coastal Alaskan Storms and Spring Flooding

ANVs are also vulnerable to severe coastal storms generated in the Bering Sea, Arctic Ocean, or North Pacific. A large majority of storms crossing the North Pacific track along the Aleutian Island chain, the Alaska Peninsula, and the coast of the Gulf of Alaska (WRCC 2015). These storms can result in winds in excess of 50 miles per hour (mph). ANVs in the southwest are most vulnerable to these windstorms, which can have hurricane force winds of over 100 mph (State of Alaska 2013, WRCC 2015). ANVs along the western and northern coasts are vulnerable to storms that generate in the Bering Sea and Arctic Ocean and move northward (WRCC 2015). These storms can result in damaging flooding and winds in excess of 50 mph (WRCC 2015).

Coastal storms can also result in damaging storm surge, but one of the most damaging weather events in the state is spring flooding. Spring flooding in Alaska's rivers can present a seasonal hazard for ANVs. These floods typically occur when temperatures rise rapidly and produce excess runoff, or when river ice causes temporary damming and produces what are called ice jam floods. Ice jam floods can produce very large flood stages in the immediate area that can result in severe damage to infrastructure and accelerated erosion.

Spring flooding and climate change in Alaska

Spring flooding along Alaska's river banks is a seasonal hazard for many native villages, but the impacts of climate change on river ice dynamics and flooding are complex and not well documented (USGCRP 2014). In some parts of Alaska, projected increases in precipitation and accelerating glacial melt and glacial retreat may lead to unstable glacial lakes that can result in damaging "glacial outburst" floods (ACIA 2005, USGCRP 2014).

Spring flooding may affect ANVs through riverbank erosion, which may be worsened by climate change. In areas underlain by continuous or discontinuous permafrost, permafrost thaw may further contribute to riverbank erosion by weakening and exposing thawed soils and causing undercutting or collapse of entire banks (ACIA 2005, McNamara 2010).

Appendix B: GREENHOUSE GAS EMISSIONS SCENARIOS

Two greenhouse gas (GHG) emissions scenarios, “high emissions” and “low emissions,” are used in this report to characterize the range of likely climate change projections. “High emissions” refers to the A2 scenario group generated by the Intergovernmental Panel on Climate Change (IPCC). “Low emissions” refers to the B1 scenario group similarly generated by the IPCC. These scenario groups are well-used in climate change literature (NOAA 2013a).

The high (A2) emissions scenario assumes high population growth in which economic development and technological change are distinctly regional and relatively slow to occur compared to other scenarios (IPCC 2015). Under this emissions scenario, annual global GHG emissions increase from the current level of 40 gigatons (Gt) of carbon dioxide equivalent (CO_2e) to approximately 140 Gt CO_2e by 2100, and the concentration of GHGs in the atmosphere exceeds 800 parts per million (ppm) (NOAA 2013a). As a result, global mean temperature is projected to increase by 6.5°F (NOAA 2013a).

The low (B2) emissions scenario assumes that global population peaks by mid-century, clean technology is introduced, and the economy shifts toward a service and information economy (IPCC 2015). Under this emissions scenario, the concentration of GHGs in the atmosphere increases to about 500 ppm by 2100 and annual GHG emissions increase to 50 Gt CO_2e (NOAA 2013a). This scenario is projected to yield a 3.2°F increase in global mean temperature (NOAA 2013a).

Appendix C: SUMMARY OF ENERGY INFRASTRUCTURE ON TRIBAL TRUST LANDS AND ALASKA NATIVE VILLAGES

Alaska Native Villages and Tribal Trust Land*	**Census Information**			**Electricity Fuel Mix**			**On-site Electricity Generation and Transmission Infrastructure**				**On-site Fuel Production Infrastructure**			**On-site Fuel Transport Infrastructure**		
	State (s)	Population**	Total Area (sq miles)	Thermoelectric (Coal, Natural Gas, Oil, and Nuclear)	Hydroelectric	Other Renewables	Thermoelectric Power Plants	Renewable Power Plants	Total Generation Capacity (MW)	Electric Transmission Line (>345 kV) Transects	Oil and Gas Wells (approximate)	Natural Gas Processing Plants [Capacity (MMcf/d)]	Coal Production (thousand short tons)	Liquid Fuels Pipeline Transects	NG Pipeline Transects	Crude Oil by Rail Terminals
Alaska		**242,613**	**22,191**				**15**	**4**	**368**	**1**	**162**	**-**	**-**	**-**	**4**	**-**
Knik ANVSA	AK	65,768	7,365	91%	9%	-	-	-	-	1	6	-	-	-	-	-
Chickaloon ANVSA	AK	23,087	6,017	91%	9%	-	-	1	44	-	-	-	-	-	-	-
Kenaitze ANVSA	AK	32,902	2,056	91%	9%	-	5	-	205	-	115	-	-	-	1	-
Ninilchik ANVSA	AK	14,512	1,429	91%	9%	-	-	-	-	-	41	-	-	-	1	-
Elim ANVSA	AK	330	316	83%	17%	-	1	-	1	-	-	-	-	-	-	-
Ketchikan ANVSA	AK	12,742	22	1%	99%	-	1	1	27	-	-	-	-	-	-	-
Bethel ANVSA	AK	6,080	49	100%	-	-	2	-	15	-	-	-	-	-	-	-

Douglas ANVSA	AK	5,474	77	1%	99%	-	-	-	-	-	-	-	-	-	-	-
Sitka ANVSA	AK	4,480	3	1%	99%	-	-	-	-	-	-	-	-	-	-	-
Unalaska ANVSA	AK	4,376	86	100%	-	-	3	-	23	-	-	-	-	-	-	-
Barrow ANVSA	AK	4,212	21	-	100%	-	1	-	20	-	-	-	-	-	2	-
Nome ANVSA	AK	3,681	134	100%	-	-	1	1	18	-	-	-	-	-	-	-
Kotzebue ANVSA	AK	3,201	29	100%	-	-	1	1	15	-	-	-	-	-	-	-
Northwest		**167,345**	**9,607**				**0**	**16**	**3,967**	**0**	**0**	**0**	**0**	**2**	**1**	**0**
Yakama Nation Reservation and Off-Reservation Trust Land	WA	31,272	2,188	49%	44%	7%	-	2	3	1	-	-	-	-	-	-
Colville Reservation and Off-Reservation Trust Land	WA	7,687	2,185	49%	44%	7%	-	3	2,783	-	-	-	-	-	-	-
Nez Perce Reservation	ID	18,437	1,204	49%	44%	7%	-	1	400	1	-	-	-	-	-	-
Warm Springs Reservation and Off-Reservation Trust Land	OR	4,012	1,023	49%	44%	7%	-	4	489	1	-	-	-	-	-	-
Fort Hall Reservation and Off-Reservation Trust Land	ID	5,767	856	49%	44%	7%	-	2	37	2	-	-	-	1	1	-
Coeur d'Alene Reservation	ID	6,760	537	49%	44%	7%	-	1	6	-	-	-	-	-	-	-
Duck Valley Reservation	ID NV	1,309	453	49%	44%	7%	-	-	-	-	-	-	-	-	-	-
Quinault Reservation	WA	1,408	324	49%	44%	7%	-	-	-	-	-	-	-	-	-	-
Umatilla Reservation	OR	3,031	270	49%	44%	7%	-	1	123	-	-	-	-	1	-	-
Tulalip Reservation and Off-Reservation Trust Land	WA	10,631	52	49%	44%	7%	-	-	-	-	-	-	-	-	-	-
Lummi Reservation	WA	4,706	37	49%	44%	7%	-	-	-	-	-	-	-	-	-	-
Puyallup Reservation and Off-Reservation Trust Land	WA	46,816	29	49%	44%	7%	-	-	-	-	-	-	-	-	-	-
Swinomish Reservation and Off-Reservation Trust Land	WA	3,010	21	49%	44%	7%	-	-	-	-	-	-	-	-	-	-
Port Madison Reservation	WA	7,640	12	49%	44%	7%	-	-	-	-	-	-	-	-	-	-
Southwest		**351,842**	**56,580**				**5**	**5**	**4,443**	**30**	**1,123**	**5 [699]**	**15978**	**6**	**36**	**1**
Navajo Nation Reservation and Off-Reservation Trust Land	AZ NM UT	173,667	24,156	49%	44%	7%	2	-	4,350	6	258	-	15,978	1	6	-
Uintah and Ouray Reservation and Off-Reservation Trust Land	UT	24,369	6,825	49%	44%	7%	-	1	1	1	100	3 [112]	-	-	1	1
Tohono O'odham Nation Reservation	AZ	10,201	4,454	91%	6%	3%	-	-	-	1	-	-	-	-	1	-

and Off-Reservation Trust Land																
San Carlos Reservation	AZ	10,068	2,927	91%	6%	3%	-	-	-	-	-	-	-	-	1	-
Fort Apache Reservation	AZ	13,409	2,631	91%	6%	3%	-	-	-	1	-	-	-	-	-	-
Hopi Reservation and Off-Reservation Trust Land	AZ	7,185	2,533	91%	6%	3%	-	-	-	1	-	-	-	-	2	-
Hualapai Indian Reservation and Off-Reservation Trust Land	AZ	1,335	1,605	91%	6%	3%	-	-	-	1	-	-	-	-	-	-
Jicarilla Apache Nation Reservation and Off-Reservation Trust Land	NM	3,254	1,374	91%	6%	3%	1	1	10	1	150-550	-	-	-	2	-
Southern Ute Reservation	CO	12,153	1,063	90%	4%	6%	1	-	6	1	525	1 [585]	-	-	2	-
Ute Mountain Reservation and Off-Reservation Trust Land	CO NM UT	1,742	901	90%	4%	6%	-	-	-	1	90	1 [2]	-	-	-	-
Laguna Pueblo and Off-Reservation Trust Land	NM	4,043	785	91%	6%	3%	-	-	-	-	-	-	-	-	4	-
Pyramid Lake Paiute Reservation	NV	1,660	730	49%	44%	7%	-	-	-	1	-	-	-	-	1	-
Zuni Reservation and Off-Reservation Trust Land	AZ NM	7,891	726	91%	6%	3%	-	-	-	1	-	-	-	-	-	-
Mescalero Reservation	NM	3,613	719	91%	6%	3%	-	-	-	-	-	-	-	-	-	-
Acoma Pueblo and Off-Reservation Trust Land	NM	3,011	596	91%	6%	3%	-	-	-	-	-	-	-	-	2	-
Gila River Indian Reservation	AZ	11,712	585	91%	6%	3%	-	-	-	1	-	-	-	1	2	-
Walker River Reservation	NV	746	531	49%	44%	7%	-	-	-	-	-	-	-	-	-	-
Colorado River Indian Reservation	CA AZ	8,764	464	91%	6%	3%	-	1	20	-	-	-	-	-	-	-
Isleta Pueblo	NM	3,400	331	91%	6%	3%	-	1	5	1	-	-	-	2	-	-
Taos Pueblo and Off-Reservation Trust Land	NM	4,384	156	90%	6%	3%	-	-	-	-	-	-	-	-	-	-
Hoopa Valley Reservation	CA	3,041	142	74%	15%	10%	-	-	-	-	-	-	-	-	-	-
Santo Domingo Pueblo	NM	3,255	106	90%	6%	3%	-	-	-	-	-	-	-	-	-	-
Salt River Reservation	AZ	6,289	85	90%	6%	3%	-	1	6	-	-	-	-	-	-	-
San Felipe Pueblo	NM	3,563	80	90%	6%	3%	-	-	-	-	-	-	-	-	-	-
Santa Clara Pueblo	NM	11,021	77	90%	6%	3%	-	-	-	-	-	-	-	-	-	-
Agua Caliente Indian Reservation and Off-Reservation Trust Land	CA	24,781	54	74%	15%	10%	-	-	-	-	-	-	-	-	-	-
Torres-Martinez Reservation	CA	5,594	49	90%	6%	3%	-	-	-	-	-	-	-	-	-	-
Sandia Pueblo	NM	4,965	39	90%	6%	3%	-	-	-	-	-	-	-	-	-	-

Ohkay Owingeh	NM	6,309	27	90%	6%	3%	-	-	-	-	-	-	-	-	-	-
Pueblo of Pojoaque and Off-Reservation Trust Land	NM	3,316	21	90%	6%	3%	-	-	-	-	-	-	-	-	-	-
Pascua Pueblo Yaqui Reservation	AZ	3,484	2	90%	6%	3%	-	-	-	-	-	-	-	-	-	-
Great Plains		**243,236**	**40,108**				**4**	**10**	**2,134**	**8**	**2180**	**7 [196]**	**5,557**	**15**	**13**	**2**
Cheyenne River Reservation and Off-Reservation Trust Land	SD	8,090	4,419	83%	6%	11%	-	-	-	-	-	-	-	-	-	-
Pine Ridge Reservation	NE SD	18,834	4,354	83%	6%	11%	-	-	-	-	-	-	-	-	-	-
Standing Rock Reservation	ND SD	8,217	3,663	83%	6%	11%	-	-	-	2	-	-	-	-	-	-
Crow Reservation and Off-Reservation Trust Land	MT	6,863	3,607	49%	44%	7%	1	1	389	-	40	-	5,557	1	2 (2)	-
Wind River Reservation and Off-Reservation Trust Land	WY	26,490	3,533	90%	4%	6%	-	2	19	-	-	2 [84]	-	-	2 (2)	-
Fort Peck Indian Reservation and Off-Reservation Trust Land	MT	10,008	3,302	83%	6%	11%	-	-	-	-	50	-	-	2	2 (1)	-
Blackfeet Indian Reservation and Off-Reservation Trust Land	MT	10,405	2,400	49%	44%	7%	-	-	-	-	120	1 [25]	-	1	3 (19)	-
Osage Reservation	OK	47,472	2,304	89%	4%	6%	1	2	116	2	1,100	3 [27]	-	9	5	-
Flathead Reservation	MT	28,359	2,058	49%	44%	7%	-	1	206	1	-	-	-	-	-	-
Rosebud Indian Reservation and Off-Reservation Trust Land	SD	10,869	1,975	83%	6%	11%	-	-	-	-	-	-	-	-	-	-
Fort Berthold Reservation	ND	6,341	1,583	83%	6%	11%	-	-	-	-	1,000	1 [60]	-	1	-	2
Lake Traverse Reservation and Off-Reservation Trust Land	ND SD	10,922	1,509	83%	6%	11%	1	-	2	1	-	-	-	-	-	-
Fort Belknap Reservation and Off-Reservation Trust Land	MT	2,851	1,018	49%	44%	7%	-	-	-	-	-	-	-	-	-	-
Northern Cheyenne Indian Reservation and Off-Reservation Trust Land	MT SD	4,789	707	49%	44%	7%	-	-	-	-	-	-	-	-	-	-
Yankton Reservation	SD	6,465	685	83%	6%	11%	-	1	360	1	-	-	-	-	-	-
Crow Creek Reservation	SD	2,010	461	83%	6%	11%	-	1	520	-	-	-	-	-	-	-
Spirit Lake Reservation	ND	4,238	399	83%	6%	11%	-	1	-	-	-	-	-	-	1	-
Lower Brule Reservation and Off-Reservation Trust Land	SD	1,505	390	83%	6%	11%	-	1	520	-	-	-	-	-	-	-
Omaha Reservation	IA NE	4,773	310	83%	6%	11%	1	-	2	1	-	-	-	1	1	-
Turtle Mountain Reservation and Off-	MT ND	8,669	237	49%	44%	7%	-	-	-	-	-	-	-	-	-	-

Reservation Trust Land	SD															
Kickapoo (KS) Reservation	KS	4,134	237	95%	0%	5%	-	-	-	-	-	-	-	-	-	-
Rocky Boy's Reservation and Off-Reservation Trust Land	MT	3,323	171	49%	44%	7%	-	-	-	-	-	-	-	-	-	-
Midwest		**27,193**	**5,673**				**0**	**0**	**0**	**0**	**0**	**1 [2]**	**0**	**16**	**8**	**0**
Leech Lake Reservation and Off-Reservation Trust Land	MN	10,660	1,311	83%	6%	11%	-	-	-	-	-	-	-	4	1	-
Red Lake Reservation	MN	5,896	1,258	83%	6%	11%	-	-	-	-	-	-	-	-	-	-
White Earth Reservation and Off-Reservation Trust Land	MN	9,562	1,167	83%	6%	11%	-	-	-	-	-	-	-	2	-	-
Menominee Reservation and Off-Reservation Trust Land	WI	3,141	363	91%	3%	5%	-	-	-	-	-	-	-	-	-	-
Isabella Reservation	MI	26,274	218	97%	0%	3%	-	-	-	-	-	1 [2]	-	-	3 (1)	-
Fond du Lac Reservation and Off-Reservation Trust Land	MN WI	4,250	159	91%	3%	5%	-	-	-	-	-	-	-	4	1	-
Lac du Flambeau Reservation	WI	3,442	135	91%	3%	5%	-	-	-	-	-	-	-	-	-	-
L'Anse Reservation and Off-Reservation Trust Land	MI	3,703	110	91%	3%	5%	-	-	-	-	-	-	-	-	-	-
Mille Lacs Reservation and Off-Reservation Trust Land	MN	4,907	103	83%	6%	11%	-	-	-	-	-	-	-	-	-	-
Oneida (WI) Reservation and Off-Reservation Trust Land	WI	22,776	102	91%	3%	5%	-	-	-	-	-	-	-	-	1 (2)	-
Northeast		**16,997**	**516**				**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**4**	**0**
Allegany Reservation	NY	6,490	49	67%	28%	4%	-	-	-	-	-	-	-	-	1	-
St. Regis Mohawk Reservation	NY	3,228	21	67%	28%	4%	-	-	-	-	-	-	-	-	-	-
Southeast		**20,008**	**412**				**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Eastern Cherokee Reservation	NC	9,018	82	93%	7%	1%	-	-	-	-	-	-	-	-	-	-
Mississippi Choctaw Reservation	MS	7,436	47	93%	7%	1%	-	-	-	-	-	-	-	-	-	-

*Note: Tribal trust lands and Alaska Native Villages (ANVs) listed in the table include those that are greater than 300 square miles or have more than 3,000 residents.

**Population reflects the total number of residents living within each community according to the 2010 Census.

Source: U.S. Census Bureau 2010a, U.S. Census Bureau 2010b, Fay et al. 2013b, EPA 2014a, EIA 2014b

Appendix D: ILLUSTRATIVE EXAMPLES OF TRIBAL UTILITY AUTHORITY OPERATIONS

Utility Name	Associated TTL/ANV	Residential Customer Count	Commercial Customer Count	Total Customer Count	Summer Peak Demand (MW)	Winter Peak Demand (MW)
Navajo Tribal Utility Authority	Navajo Nation	36,217	4,179	40,544	122	137
	Navajo Nation (AZ)	27,548	3,311	30,862		
	Navajo Nation (NM)	8,031	782	8,958		
	Navajo Nation (UT)	638	86	724		
Aha Macav Power Service	Fort Mojave Reservation	687	192	964	11	6
Ak-Chin Electric Utility Authority	Maricopa (Ak Chin) Indian Reservation	193	109	429	7	4.5
Mohegan Tribal Utility Authority	Mohegan Reservation	0	65	65	27	19
Mission Valley Power	Flathead Reservation	14,512	5,339	20,893	56.1	79.5
TDX North Slope Generating Company	Tanadgusix Village Corporation (AK)	0	74	74	7	12.5

Source: EIA 2013a

*Note: Data on customer count and peak demand were not available from EIA 2013a for four of the tribal utility authorities: Yakama Power, Jicarilla Power Authority, Gila River Indian Community Utility Authority, and Tohono O'odham Utility Authority.

Appendix E: LIST OF ELECTRIC UTILITIES SERVING ALASKA NATIVE VILLAGES

Utility Name	Alaska Native Village Name	Net In-Village Generation by Fuel Type by Certified Utilities (MWh), 2011				Notes
		Oil	Gas	Hydro	Wind	
Akhiok, City of	Akhiok	N/A	N/A	N/A	N/A	
Akiachak Native Community	Akiachak	1,852	0	0	0	
Akiak City Council	Akiak	1,030	0	0	0	
Akutan, City of	Akutan	490	0	0	0	
Alaska Electric Light & Power Company	Douglas	N/A	N/A	N/A	N/A	No information available.
Alaska Power & Telephone Company	Alatna	N/A	N/A	N/A	N/A	Receives power from Allakaket via intertie.
	Chistochina	N/A	N/A	N/A	N/A	Receives power from Slana via intertie.
	Craig	2,779	0	0	0	Provides power to Hollis, Klawock, Thorne Bay/Kasaan and Hydaburg via intertie.
	Dot Lake	N/A	N/A	N/A	N/A	Receives power from Tok via intertie.
	Eagle	750	0	0	0	Provides power to Eagle Village via intertie. Includes Eagle Village's information.
	Evansville	N/A	N/A	N/A	N/A	Receives power from Bettles.
	Healy Lake	83	0	0	0	
	Hydaburg	23	0	0	0	Part of Alaska Power Company's Grid on Prince of Wales Island. Receives power from Craig.
	Kasaan	N/A	N/A	N/A	N/A	Part of Alaska Power Company's Grid on Prince of Wales Island. Receives power from Craig.
	Klawock	N/A	N/A	N/A	N/A	Receives power from Craig via intertie.
	Mentasta Lake	N/A	N/A	N/A	N/A	
	Northway	1,286	0	0	0	Provides power to Northway Village via intertie. Includes Northway Village's information.
	Skagway	0	0	7,965	0	Part of Alaska Power Company's grid in the Upper Lynn Canal Service area.
	Tanacross	N/A	N/A	N/A	N/A	Receives power from Tok via intertie.

Utility Name	Alaska Native Village Name	Net In-Village Generation by Fuel Type by Certified Utilities (MWh), 2011				Notes
		Oil	Gas	Hydro	Wind	
Alaska Village Electric Cooperative	Tetlin	N/A	N/A	N/A	N/A	Receives power from Tok via intertie.
	Alakanuk	1,946	0	0	0	
	Ambler	1,278	0	0	0	
Alaska Village Electric Cooperative	Andreafsky	N/A	N/A	N/A	N/A	Receives power from St. Mary's via intertie.
	Anvik	405	0	0	0	
	Brevig Mission	1,176	0	0	6	
	Chevak	1,657	0	0	0	
	Eek	801	0	0	0	
	Ekwok	262	0	0	0	
	Elim	1,159	0	0	0	
	Emmonak	3,090	0	0	0	
	Gambell	1,496	0	0	0	
	Goodnews Bay	773	0	0	0	
	Grayling	569	0	0	0	
	Holy Cross	594	0	0	0	
	Hooper Bay	2,711	0	0	0	
	Huslia	1,006	0	0	66	
	Kalskag	1,472	0	0	0	
	Kaltag	727	0	0	0	
	Kasigluk	2,286	0	0	0	
	Kiana	1,512	0	0	0	
	Kivalina	1,212	0	0	0	
	Kotlik	1,966	0	0	0	
	Koyuk	1,316	0	0	0	
	Lower Kalskag	N/A	N/A	N/A	N/A	Receives power from Upper Kalskag.
	Marshall	1,644	0	0	0	
	Mekoryuk	709	0	0	0	
	Minto	653	0	0	0	
	Mountain Village	2,797	0	0	0	
	New Stuyahok	1,466	0	42	0	
	Nightmute	N/A	N/A	N/A	N/A	Receives power from Toksook Bay via intertie.
	Noatak	1,801	0	0	239	

		Net In-Village Generation by Fuel Type by Certified Utilities (MWh), 2011				
Utility Name	Alaska Native Village Name	Oil	Gas	Hydro	Wind	Notes
Alaska Village Electric Cooperative	Noorvik	2,001	0	0	0	
	Nulato	1,110	0	0	0	
	Nunapitchuk	N/A	N/A	N/A	N/A	Receives power from Kasigluk via intertie.
	Old Harbor	788	0	0	0	
	Pilot Station	1,751	0	0	0	
	Pitkas Point	N/A	N/A	N/A	N/A	Receives power from St. Mary's via intertie.
	Russian Mission	1,124	0	0	0	
	Savoonga	1,754	0	0	44	
	Scammon Bay	1,736	0	0	0	
	Selawik	2,746	0	0	0	
	Shageluk	369	0	0	0	
	Shaktoolik	904	0	0	0	
	Shishmaref	1,594	0	0	0	
	Shungnak	1,527	0	0	0	
	St. Michael	1,735	0	10,803	0	
	Stebbins	1,354	0	0	0	
	Teller	838	0	0	0	
	Togiak	3,045	0	0	0	
	Toksook Bay	2,592	0	0	0	
	Tununak	N/A	N/A	N/A	N/A	Receives power from Toksook Bay via intertie.
	Wales	582	0	0	0	
Alutiiq Power Company	Karluk	253	0	0	0	
Aniak Light & Power	Aniak	2,619	0	0	0	
Arctic Village Electric Company	Arctic Village	N/A	N/A	N/A	N/A	No intertie; no fuel information available.
Atka, City of	Atka	444	0	0	0	
Atmautluak Tribal Utilities	Atmautluak	797	0	0	0	
Barrow Utilities & Electric Cooperative Inc.	Barrow	0	50,211	0	0	
Beaver Joint Utilities	Beaver	318	0	0	0	
Bethel Utilities Corporation	Bethel	41,800	0	0	0	
	Oscarville	N/A	N/A	N/A	N/A	Receives power from Oscarville via intertie.
Buckland, City of	Buckland	1,592	0	0	0	
Chalkyitsik Village Council	Chalkyitsik	304	0	0	0	

		Net In-Village Generation by Fuel Type by Certified Utilities (MWh), 2011				
Utility Name	**Alaska Native Village Name**	**Oil**	**Gas**	**Hydro**	**Wind**	**Notes**
Chenega Ira Council	Chenega	308	0	0	0	
Chignik Lagoon Power Utility	Chignik Lagoon	507	0	0	0	
Chignik Lake Electric Utility	Chignik Lake	199	0	0	0	
Chignik, City of	Chignik	868	0	0	0	
Chitina Electric Inc	Chitina	519	0	0	0	
Chugach Electric Assn Inc	Tyonek	N/A	N/A	N/A	N/A	Railbelt utility.
Circle Electric Utility	Circle	390	0	0	0	
Clark's Point, City of	Clarks Point			0	0	
Copper Valley Elec Assn Inc	Copper Center	0	0	0	387	
	Gakona	N/A	N/A	N/A	N/A	No information available.
	Gulkana	N/A	N/A	N/A	N/A	No information available.
	Tazlina	N/A	N/A	N/A	N/A	No information available.
Cordova Electric Cooperative	Eyak	9,068	0	0	0	
Egegik Light & Power Co	Egegik	282	0	0	0	
False Pass, City of	False Pass	461	0	0	0	
Galena, City of	Galena	2,907		0	0	
Golden Valley Elec Assn Inc, Aurora Energy LLC Chena, Alaska Environmental LLC	Cantwell	0	0	0	742	
	Nenana	0	0	3,102	0	
Golovin Power Utilities	Golovin	756	0	0	0	
Gwitchyaa Zhee Utilities Company	Fort Yukon	3,062	0	0	0	
Homer Electric Assn Inc	Nanwalek	N/A	N/A	N/A	N/A	Railbelt utility.
	Ninilchik	0	0	0	360	Railbelt utility.
	Port Graham	N/A	N/A	N/A	N/A	Railbelt utility.
	Salamatof	N/A	N/A	N/A	N/A	Railbelt utility.
	Seldovia	N/A	N/A	N/A	N/A	Railbelt utility.
Hughes Power & Light	Hughes	372	0	0	0	
Igiugig Electric Company	Igiugig	308	0	0	0	
I-N-N Electric Coop, Inc	Iliamna	84	0	0	0	Power produced at Tazimina hydroelectric project and the Newhalen plant is shared by Iliamna, Newhalen, and Nondalton.
	Newhalen	0	0	0	497	Power produced at Tazimina hydroelectric project and the Newhalen plant is shared by Iliamna, Newhalen, and Nondalton.

Utility Name	Alaska Native Village Name	Net In-Village Generation by Fuel Type by Certified Utilities (MWh), 2011				Notes
		Oil	Gas	Hydro	Wind	
	Nondalton	0	0	0	560	Power produced at Tazimina hydroelectric project and the Newhalen plant is shared by Iliamna, Newhalen, and Nondalton.
Inside Passage Electric	Angoon	2,025	0	0	0	
	Chilkat	68	0	184	0	Power purchased from AP&T.
	Hoonah	0	0	0	108	
	Kake	2,769	0	0	0	
Ipnatchiaq Electric Company	Deering	336	0	0	0	
Ketchikan Public Utilities	Ketchikan	0	0	46,676	0	
King Cove, City of	King Cove	1,712	0	0	0	
Kipnuk Light Plant	Kipnuk	1,583	0	0	0	
Kobuk Valley Electric Company	Kobuk	N/A	N/A	N/A	N/A	Receives power from Shungnak via intertie.
Kodiak Electric Assn Inc	Kodiak	21,852	0	12,364	0	
	Port Lions	N/A	N/A	N/A	N/A	Receives power via intertie.
Kokhanok Village Council	Kokhanok	407	0	0	921	
Kotzebue Electric Association	Kotzebue	20,300	0	0	0	
Koyukuk, City of	Koyukuk	314	0	0	0	
Kwethluk Incorporated	Kwethluk	1,378	0	0	0	
Kwigillingok Power Company	Kwigillingok	1,168	0	0	0	
Larsen Bay Utility Company	Larsen Bay	159	0	0	0	
Levelock Electrical Coop	Levelock	472	0	0	0	
Lime Village Electric Utility	Lime Village	33	0	0	0	
Manokotak Power Company	Manokotak	1,366	0	16,760	0	
Matanuska Electric Association, Enerdyne, LLC	Chickaloon	N/A	N/A	N/A	N/A	Railbelt utility.
	Eklutna	N/A	N/A	N/A	N/A	Railbelt utility.
	Knik	N/A	N/A	N/A	N/A	Railbelt utility.
Mcgrath Light & Power	McGrath	2,841	0	0	1,503	
Middle Kuskokwim Electric	Chuathbaluk	221	0	0	0	
	Crooked Creek	303	0	0	0	
	Red Devil	106	0	0	0	
Middle Kuskokwim Electric	Sleetmute	259	0	0	0	

Utility Name	Alaska Native Village Name	Net In-Village Generation by Fuel Type by Certified Utilities (MWh), 2011 Oil	Gas	Hydro	Wind	Notes
	Stony River	128	0	0	0	
Minchumina Power Company	Lake Minchumina	N/A	N/A	N/A	N/A	No intertie; no fuel information available.
Naknek Electric Association	King Salmon	N/A	N/A	N/A	N/A	Receives power from Naknek via intertie.
	Naknek	19,900	0	0	0	
	South Naknek	N/A	N/A	N/A	N/A	Receives power from Naknek via intertie.
Napakiak Ircinraq	Napakiak	N/A	N/A	N/A	N/A	Purchases power from Bethel Utilities Corporation.
Napaskiak Electric Utility	Napaskiak	979	0	0	0	
Naterkaq Light Plant	Chefornak	1,631	0	0	0	
Native Village of Perryville	Perryville	176	0	0	0	
Nelson Lagoon Electrical Coop	Nelson Lagoon	392	0	0	0	
Nikolai, City of	Nikolai	399	0	0	0	
Nome Joint Utility Systems, Banner Wind LLC	Nome	33,500	0	0	0	
North Slope Borough Power & Light	Anaktuvuk Pass	3,599	0	0	0	
	Atqasuk	3,241	0	0	0	
	Kaktovik	4,550	0	0	0	
	Nuiqsut	1,754	1,475	0	0	
	Point Hope	6,153	0	0	0	
	Point Lay	3,085	0	0	0	
	Wainwright	6,258	0	0	0	
Nunam Iqua Electric Company	Nunam Iqua	829	0	0	0	
Nushagak Electric Cooperative	Aleknagik	N/A	N/A	N/A	N/A	Receives power from Dillingham via intertie.
	Dillingham	18,800	0	0	0	
Ouzinkie, City of	Ouzinkie	329	0	0	0	
Pedro Bay Village Council	Pedro Bay	212	0	0	0	
Petersburg, City of	Petersburg	618	0	0	0	
Pilot Point Electric Utility	Pilot Point	443	0	0	0	
Platinum, City of	Platinum	N/A	N/A	N/A	N/A	No intertie; no fuel information available.
Port Heiden Utilities	Port Heiden	490	0	0	0	
Puvurnaq Power Company	Kongiganak	672	0	0	0	
Rampart Village Council	Rampart	N/A	N/A	N/A	N/A	No intertie; no fuel information available.
Ruby, City of	Ruby	733	0	0	0	
Saint George, City of	St. George	421	0	0	0	

Utility Name	Alaska Native Village Name	Net In-Village Generation by Fuel Type by Certified Utilities (MWh), 2011				Notes
		Oil	Gas	Hydro	Wind	
Saint Paul Municipal Electric	St. Paul	4,296	0	0	0	
Sitka, City & Borough of	Sitka	N/A	N/A	N/A	N/A	No intertie; no fuel information available.
Stevens Village Ira Council	Stevens Village	N/A	N/A	N/A	N/A	No intertie; no fuel information available.
Takotna Community Assoc Inc	Takotna	195	0	0	0	
Tanalian Electric Cooperative	Port Alsworth	648	0	0	0	
Tanana Power Company Inc	Tanana	1,147	0	0	0	
Tatitlek Village Ira Council	Tatitlek	472	0	0	0	
TDX Corporation	Sand Point	4,314	0	0	0	
TDX Manley Generating LLC	Manley Hot Springs	434	0	0	0	
Tuluksak Traditional	Tuluksak	607	0	0	0	
Tuntutuliak Community	Tuntutuliak	971	0	0	0	
Twin Hills Village Council	Twin Hills	282	0	0	0	
Umnak Power Company	Nikolski	212	0	0	0	
Unalakleet Valley Electric Cooperative	Unalakleet	3,498	0	0	0	
Unalaska, City of	Unalaska	43,500	0	0	0	
Ungusraq Power Company	Newtok	427	0	0	0	
Venetie Village Electric	Venetie	N/A	N/A	N/A	N/A	No intertie; no fuel information available
White Mountain, City of	White Mountain	369	0	0	0	
Wrangell, City of	Wrangell	1,374	0	0	0	
Yakutat Power Inc	Yakutat	6,512	0	0	0	

Sources: U.S. Census Bureau 2010a, Fay et al. 2013b

*Note: Only those communities for which utilities are listed in Fay et al. 2013b are included in this list.

Appendix F: TRIBAL TRUST LANDS AND ALASKA NATIVE VILLAGE STATISTICAL AREAS BY REGION

Alaska	State	Population	Total Area (sq miles)
Knik	AK	65,768	7,365
Chickaloon	AK	23,087	6,017
Kenaitze	AK	32,902	2,056
Ninilchik	AK	14,512	1,429
Elim	AK	330	316
Ketchikan	AK	12,742	22
Bethel	AK	6,080	49
Douglas	AK	5,474	77
Sitka	AK	4,480	3
Unalaska	AK	4,376	86
Barrow	AK	4,212	21
Nome	AK	3,681	134
Kotzebue	AK	3,201	29
Tetlin	AK	130	194
St. George	AK	102	182
Mountain Village	AK	813	140
Togiak	AK	817	133
Chitina	AK	96	120
Crooked Creek	AK	105	107
Port Lions	AK	194	107
Circle	AK	104	107
Yakutat	AK	662	104
Cantwell	AK	219	100
South Naknek	AK	79	96
Ugashik	AK	12	92
Skagway	AK	967	87
Naknek	AK	544	82
Tanacross	AK	136	81
Lime Village	AK	29	79
Dillingham	AK	2,378	74
Egegik	AK	109	71
Tununak	AK	327	60
Healy Lake	AK	13	56
McGrath	AK	346	54
Port Heiden	AK	102	51
Kodiak	AK	0	49

Alaska (continued)	State	Population	Total Area (sq miles)
Chulloonawick	AK	0	46
Georgetown	AK	2	45
Nulato	AK	264	44
Atqasuk	AK	233	42
St. Paul	AK	479	42
Alakanuk	AK	677	40
Mentasta Lake	AK	92	39
Northway	AK	242	39
Angoon	AK	459	39
Stebbins	AK	556	38
Iliamna	AK	109	38
Holy Cross	AK	178	37
Manokotak	AK	442	37
Gakona	AK	122	37
New Stuyahok	AK	510	35
Canyon Village	AK	0	34
Point Lay	AK	189	32
Chenega	AK	76	30
Napaimute	AK	2	28
Red Devil	AK	23	28
Andreafsky	AK	83	28
Kaltag	AK	190	28
Platinum	AK	59	27
Chistochina	AK	78	27
St. Michael	AK	401	27
Old Harbor	AK	218	27
Sleetmute	AK	86	26
Karluk	AK	37	25
Paimiut	AK	0	25
Kwigillingok	AK	321	24
Takotna	AK	52	24
Galena	AK	470	24
Twin Hills	AK	74	23
Port Alsworth	AK	159	23
Council	AK	0	22
Igiugig	AK	50	22
Beaver	AK	84	21
Kokhanok	AK	170	21
Nikolski	AK	18	20
Kipnuk	AK	639	20
Chignik Lake	AK	73	19
Pedro Bay	AK	42	19
Aleknagik	AK	219	19
Nunam Iqua	AK	187	18
Alatna	AK	32	18
Wainwright	AK	556	18
Ekwok	AK	115	18
Huslia	AK	275	17
New Koliganek	AK	209	17
Eagle	AK	69	17
Noatak	AK	514	17
Craig	AK	1,478	17
Kobuk	AK	151	17
Shishmaref	AK	563	16

Alaska (continued)	State	Population	Total Area (sq miles)
Akiachak	AK	627	16
Chignik	AK	91	16
Arctic Village	AK	152	16
Tanana	AK	246	16
Copper Center	AK	442	15
Manley Hot Springs	AK	89	15
Kake	AK	557	15
Ouzinkie	AK	172	15
Eyak	AK	128	15
Seldovia	AK	427	15
Unalakleet	AK	688	14
Toksook Bay	AK	563	14
King Cove	AK	938	14
Aniak	AK	501	14
Chignik Lagoon	AK	78	14
Tyonek	AK	177	13
Tazlina	AK	319	13
Kasigluk	AK	569	13
Stevens Village	AK	78	13
Portage Creek	AK	2	13
Gambell	AK	681	13
False Pass	AK	35	13
Shageluk	AK	83	12
Levelock	AK	69	12
Venetie	AK	149	12
Anvik	AK	85	12
Kwethluk	AK	721	12
Perryville	AK	113	11
Pilot Point	AK	68	11
Grayling	AK	194	11
Ambler	AK	258	11
Akhiok	AK	71	10
King Salmon	AK	167	10
Tatitlek	AK	88	10
Shungnak	AK	262	10
Nuiqsut	AK	402	9
Emmonak	AK	762	9
Allakaket	AK	171	9
Birch Creek	AK	33	9
Ohogamiut	AK	0	9
Atka	AK	61	9
Nondalton	AK	164	9
Chalkyitsik	AK	69	9
Solomon	AK	0	9
Eklutna	AK	54	9
Hooper Bay	AK	1,093	9
Nunapitchuk	AK	496	8
Newtok	AK	354	8
Nanwalek	AK	254	8
Salamatof	AK	980	8
Newhalen	AK	190	8
Sand Point	AK	976	8
Ruby	AK	166	8

Alaska (continued)	State	Population	Total Area (sq miles)
Larsen Bay	AK	87	8
Fort Yukon	AK	583	7
Hoonah	AK	760	7
Kasaan	AK	49	6
Chefornak	AK	418	6
Port Graham	AK	177	6
Mekoryuk	AK	191	6
Savoonga	AK	671	6
Evansville	AK	26	6
Nenana	AK	378	6
Russian Mission	AK	312	6
Koyukuk	AK	96	6
Kwinhagak	AK	669	5
Nightmute	AK	261	5
Hamilton	AK	0	5
Chuathbaluk	AK	118	5
Deering	AK	122	5
Hughes	AK	78	5
Napakiak	AK	354	5
Anaktuvuk Pass	AK	324	5
Point Hope	AK	674	5
Nikolai	AK	94	5
Stony River	AK	54	5
Koyuk	AK	332	5
Nelson Lagoon	AK	52	5
Marshall	AK	414	5
Kotlik	AK	577	5
Gulkana	AK	136	4
Dot Lake	AK	62	4
Lake Minchumina	AK	11	4
Ekuk	AK	2	4
Ivanof Bay	AK	7	4
Kalskag	AK	210	4
Selawik	AK	829	4
Clarks Point	AK	62	4
Napaskiak	AK	405	4
Kivalina	AK	374	4
Goodnews Bay	AK	243	4
Golovin	AK	156	4
Belkofski	AK	0	3
Minto	AK	210	3
Tuluksak	AK	373	3
Inalik	AK	115	3
Oscarville	AK	70	3
Brevig Mission	AK	388	3
Petersburg	AK	2,347	3
Lesnoi	AK	0	3
Wales	AK	145	3
Bill Moore's	AK	0	2
Algaaciq	AK	424	2
Pilot Station	AK	568	2
Tuntutuliak	AK	382	2
Teller	AK	229	2
Chilkat	AK	99	2

Alaska (continued)	**State**	**Population**	**Total Area (sq miles)**
White Mountain	AK	190	2
Rampart	AK	24	2
Kongiganak	AK	439	2
Lower Kalskag	AK	282	2
Telida	AK	3	2
Buckland	AK	416	2
Pitkas Point	AK	109	2
Akutan	AK	1,003	2
Noorvik	AK	668	1
Kiana	AK	363	1
Shaktoolik	AK	251	1
Akiak	AK	346	1
Eek	AK	296	1
Chevak	AK	938	1
Atmautluak	AK	277	1
Saxman	AK	411	1
Klawock	AK	591	1
Kaktovik	AK	239	1
Wrangell	AK	1,189	1
Scammon Bay	AK	474	1
Hydaburg	AK	376	1
Mary's Igloo	AK	0	<1
Chilkoot	AK	441	<1

Northwest	**State**	**Population**	**Total Area (sq miles)**
Yakama Nation Reservation and Off-Reservation Trust Land	WA	31,272	2,188
Colville Reservation and Off-Reservation Trust Land	WA	7,687	2,185
Nez Perce Reservation	ID	18,437	1,204
Warm Springs Reservation and Off-Reservation Trust Land	OR	4,012	1,023
Fort Hall Reservation and Off-Reservation Trust Land	ID	5,767	856
Coeur d'Alene Reservation	ID	6,760	537
Duck Valley Reservation	ID/NV	1,309	453
Quinault Reservation	WA	1,408	324
Umatilla Reservation	OR	3,031	270
Tulalip Reservation and Off-Reservation Trust Land	WA	10,631	52
Lummi Reservation	WA	4,706	37
Puyallup Reservation and Off-Reservation Trust Land	WA	46,816	29
Swinomish Reservation and Off-Reservation Trust Land	WA	3,010	21
Port Madison Reservation	WA	7,640	12
Muckleshoot Reservation and Off-Reservation Trust Land	WA	3,870	6
Spokane Reservation and Off-Reservation Trust Land	WA	2,096	250
Makah Indian Reservation	WA	1,414	47
Burns Paiute Indian Colony and Off-Reservation Trust Land	OR	128	19
Grand Ronde Community and Off-Reservation Trust Land	OR	434	16
Kalispel Reservation and Off-Reservation Trust Land	WA	231	11
Coquille Reservation	OR	323	10
Skokomish Reservation	WA	730	8
Nisqually Reservation	WA	575	8
Chehalis Reservation and Off-Reservation Trust Land	WA	649	7

Northwest (continued)	State	Population	Total Area (sq miles)
Siletz Reservation and Off-Reservation Trust Land	OR	506	7
Cow Creek Reservation and Off-Reservation Trust Land	OR	104	5
Nooksack Reservation and Off-Reservation Trust Land	WA	884	4
Squaxin Island Reservation and Off-Reservation Trust Land	WA	431	3
Kootenai Reservation and Off-Reservation Trust Land	ID	82	3
Lower Elwha Reservation and Off-Reservation Trust Land	WA	609	2
Port Gamble Reservation	WA	682	2
Quileute Reservation	WA	460	2
Shoalwater Bay Indian Reservation and Off-Reservation Trust Land	WA	82	1
Hoh Indian Reservation	WA	116	1
Klamath Reservation	OR	26	<1
Stillaguamish Reservation and Off-Reservation Trust Land	WA	4	<1
Coos, Lower Umpqua, and Siuslaw Reservation and Off-Reservation Trust Land	OR	47	<1
Jamestown S'Klallam Reservation and Off-Reservation Trust Land	WA	11	<1
Celilo Village	OR	74	<1
Upper Skagit Reservation	WA	220	<1
Snoqualmie Reservation	WA	-	<1
Sauk-Suiattle Reservation	WA	71	<1

Southwest	State	Population	Total Area (sq miles)
Navajo Nation Reservation and Off- Reservation Trust Land	AZ/NM/UT	173,667	24,156
Uintah and Ouray Reservation and Off-Reservation Trust Land	UT	24,369	6,825
Tohono O'odham Nation Reservation and Off-Reservation Trust Land	AZ	10,201	4,454
San Carlos Reservation	AZ	10,068	2,927
Fort Apache Reservation	AZ	13,409	2,631
Hopi Reservation and Off-Reservation Trust Land	AZ	7,185	2,533
Hualapai Indian Reservation and Off-Reservation Trust Land	AZ	1,335	1,605
Jicarilla Apache Nation Reservation and Off-Reservation Trust Land	NM	3,254	1,374
Southern Ute Reservation	CO	12,153	1,063
Ute Mountain Reservation and Off-Reservation Trust Land	CO/NM/UT	1,742	901
Laguna Pueblo and Off-Reservation Trust Land	NM	4,043	785
Pyramid Lake Paiute Reservation	NV	1,660	730
Zuni Reservation and Off-Reservation Trust Land	AZ/NM	7,891	726
Mescalero Reservation	NM	3,613	719
Acoma Pueblo and Off-Reservation Trust Land	NM	3,011	596
Gila River Indian Reservation	AZ	11,712	585
Walker River Reservation	NV	746	531
Colorado River Indian Reservation	CA/AZ	8,764	464
Isleta Pueblo	NM	3,400	331
Taos Pueblo and Off-Reservation Trust Land	NM	4,384	156
Hoopa Valley Reservation	CA	3,041	142
Santo Domingo Pueblo	NM	3,255	106
Salt River Reservation	AZ	6,289	85
San Felipe Pueblo	NM	3,563	80
Santa Clara Pueblo	NM	11,021	77
Agua Caliente Indian Reservation and Off-Reservation Trust Land	CA	24,781	54
Torres-Martinez Reservation	CA	5,594	49

Southwest (continued)	State	Population	Total Area (sq miles)
Sandia Pueblo	NM	4,965	39
Ohkay Owingeh	NM	6,309	27
Pueblo of Pojoaque and Off-Reservation Trust Land	NM	3,316	21
Pascua Pueblo Yaqui Reservation	AZ	3,484	2
Havasupai Reservation	AZ	465	276
Zia Pueblo and Off-Reservation Trust Land	NM	737	191
Kaibab Indian Reservation	AZ	240	190
Goshute Reservation	NV/UT	143	188
Washoe Ranches Trust Land	CA/NV	2,916	146
Jemez Pueblo	NM	1,815	140
Moapa River Indian Reservation	NV	260	111
Santa Ana Pueblo	NM	621	101
Yurok Reservation	CA	1,238	88
Tule River Reservation and Off-Reservation Trust Land	CA	1,049	84
Pueblo de Cochiti	NM	1,727	82
Fort Yuma Indian Reservation	AZ/CA/NV	2,197	70
Fort McDermitt Indian Reservation	NV/OR	334	54
Morongo Reservation and Off-Reservation Trust Land	CA	913	54
Fort Mojave Reservation and Off-Reservation Trust Land	AZ/CA/NV	1,477	53
Paiute (UT) Reservation	UT	273	51
Chemehuevi Reservation	CA	308	48
San Ildefonso Pueblo and Off-Reservation Trust Land	NM	1,752	47
Los Coyotes Reservation	CA	98	39
Fort McDowell Yavapai Nation Reservation	AZ	971	39
Round Valley Reservation and Off-Reservation Trust Land	CA	401	36
Maricopa (Ak Chin) Indian Reservation	AZ	1,001	33
Nambe Pueblo and Off-Reservation Trust Land	NM	1,611	32
Cahuilla Reservation	CA	187	29
Skull Valley Reservation	UT	23	28
Picuris Pueblo	NM	1,886	27
Tesuque Pueblo and Off-Reservation Trust Land	NM	841	27
South Fork Reservation and Off-Reservation Trust Land	NV	122	27
Campo Indian Reservation	CA	362	26
Capitan Grande Reservation	CA	-	25
Santa Ysabel Reservation	CA	330	23
Pala Reservation	CA	1,315	20
Summit Lake Reservation and Off-Reservation Trust Land	NV	1	20
Santa Rosa Reservation	CA	71	17
XL Ranch Rancheria	CA	60	15
La Jolla Reservation	CA	476	13
Fallon Paiute-Shoshone Reservation and Off-Reservation Trust Land	NV	581	13
Timbi-Sha Shoshone Reservation and Off-Reservation Trust Land	AZ/CA/NV	24	13
Soboba Reservation and Off-Reservation Trust Land	CA	482	11
Cocopah Reservation	AZ	817	10
Pauma and Yuima Reservation	CA	206	9
Barona Reservation	CA	640	9
Ewiiaapaayp Reservation	CA	-	9
Yomba Reservation	NV	95	7

Southwest (continued)	State	Population	Total Area (sq miles)
Manzanita Reservation and Off-Reservation Trust Land	CA	78	7
Pechanga Reservation	CA	346	7
La Posta Indian Reservation	CA	55	6
Duckwater Reservation	NV	156	6
Las Vegas Indian Colony	NV	154	6
Rincon Reservation	CA	1,215	6
Ely Reservation	NV	202	6
Fort Bidwell Reservation and Off-Reservation Trust Land	CA	94	5
Stewart Community	NV	147	4
Reno-Sparks Indian Colony	NV	919	3
Paskenta Rancheria	CA	-	3
Cabazon Reservation	CA	835	3
Mesa Grande Reservation	CA	98	3
Campbell Ranch	NV	443	3
Viejas Reservation	CA	520	3
San Pasqual Reservation	CA	1,097	2
Yavapai-Prescott Reservation	AZ	192	2
Auburn Rancheria and Off-Reservation Trust Land	CA	-	2
Susanville Indian Rancheria and Off-Reservation Trust Land	CA	549	2
Karuk Reservation and Off-Reservation Trust Land	CA	506	2
Bishop Reservation	CA	1,588	1
Inaja and Cosmit Reservation	CA	-	1
Sycuan Reservation	CA	211	1
Dresslerville Colony	NV	314	1
Cortina Indian Rancheria	CA	21	1
Quartz Valley Reservation and Off-Reservation Trust Land	CA	187	1
Battle Mountain Reservation	NV	148	1
San Manuel Reservation	CA	112	1
Yavapai-Apache Nation Reservation	AZ	718	1
Augustine Reservation	CA	-	1
Fort Independence Reservation	CA	93	1
Ramona Village	CA	13	1
Sherwood Valley Rancheria and Off-Reservation Trust Land	CA	168	1
Rumsey Indian Rancheria	CA	77	1
Upper Lake Rancheria	CA	87	1
Santa Rosa Rancheria	CA	652	1
Woodfords Community, CA	CA	214	1
Twenty-Nine Palms Reservation	CA	12	1
Tuolumne Rancheria	CA	185	1
Manchester-Point Arena Rancheria	CA	212	1
Benton Paiute Reservation and Off-Reservation Trust Land	CA	76	1
Winnemucca Indian Colony	NV	53	1
Jackson Rancheria	CA	-	1
Mooretown Rancheria and Off-Reservation Trust Land	CA	181	<1
Big Pine Reservation	CA	499	<1
Elk Valley Rancheria and Off-Reservation Trust Land	CA	99	<1
Redwood Valley Rancheria	CA	238	<1
Pit River Trust Land	CA	4	<1

Southwest (continued)	State	Population	Total Area (sq miles)
Colusa Rancheria	CA	76	<1
Big Sandy Rancheria	CA	118	<1
Lone Pine Reservation	CA	212	<1
North Fork Rancheria and Off-Reservation Trust Land	CA	60	<1
Resighini Rancheria	CA	31	<1
Robinson Rancheria and Off-Reservation Trust Land	CA	207	<1
Smith River Rancheria and Off-Reservation Trust Land	CA	113	<1
Laytonville Rancheria	CA	212	<1
Northwestern Shoshone Reservation	UT	-	<1
Picayune Rancheria and Off-Reservation Trust Land	CA	69	<1
Elko Colony	NV	736	<1
Carson Colony	NV	242	<1
Shingle Springs Rancheria	CA	102	<1
Hopland Rancheria and Off-Reservation Trust Land	CA	38	<1
Santa Ynez Reservation	CA	271	<1
Table Mountain Rancheria	CA	64	<1
Middletown Rancheria	CA	56	<1
Big Valley Rancheria	CA	139	<1
Berry Creek Rancheria and Off-Reservation Trust Land	CA	152	<1
Fallon Paiute-Shoshone Colony and Off-Reservation Trust Land	NV	130	<1
Pinoleville Rancheria	CA	129	<1
Cold Springs Rancheria	CA	184	<1
Trinidad Rancheria and Off-Reservation Trust Land	CA	132	<1
Grindstone Indian Rancheria	CA	164	<1
Coyote Valley Reservation	CA	144	<1
Tonto Apache Reservation	AZ	120	<1
Roaring Creek Rancheria	CA	14	<1
Dry Creek Rancheria	CA	-	<1
Wells Colony	NV	70	<1
Montgomery Creek Rancheria	CA	12	<1
Table Bluff Reservation	CA	103	<1
Greenville Rancheria	CA	33	<1
Blue Lake Rancheria and Off-Reservation Trust Land	CA	58	<1
Sulphur Bank Rancheria	CA	61	<1
Guidiville Rancheria and Off-Reservation Trust Land	CA	52	<1
Big Bend Rancheria	CA	9	<1
Rohnerville Rancheria	CA	38	<1
Stewarts Point Rancheria	CA	78	<1
Enterprise Rancheria	CA	1	<1
Lookout Rancheria	CA	11	<1
Bridgeport Reservation	CA	35	<1
Cedarville Rancheria and Off-Reservation Trust Land	CA	15	<1
Chicken Ranch Rancheria and Off-Reservation Trust Land	CA	4	<1
Redding Rancheria	CA	34	<1
Alturas Indian Rancheria	CA	-	<1
Lovelock Indian Colony	NV	88	<1
Yerington Colony	NV	151	<1

Southwest (continued)	State	Population	Total Area (sq miles)
Jamul Indian Village	CA	-	<1
Lytton Rancheria	CA	-	<1
Big Lagoon Rancheria	CA	17	<1
Likely Rancheria	CA	-	<1

Great Plains	State	Population	Total Area (sq miles)
Cheyenne River Reservation and Off-Reservation Trust Land	SD	8,090	4,419
Pine Ridge Reservation	NE/SD	18,834	4,354
Standing Rock Reservation	ND/SD	8,217	3,663
Crow Reservation and Off-Reservation Trust Land	MT	6,863	3,607
Wind River Reservation and Off-Reservation Trust Land	WY	26,490	3,533
Fort Peck Indian Reservation and Off-Reservation Trust Land	MT	10,008	3,302
Blackfeet Indian Reservation and Off-Reservation Trust Land	MT	10,405	2,400
Osage Reservation	OK	47,472	2,304
Flathead Reservation	MT	28,359	2,058
Rosebud Indian Reservation and Off-Reservation Trust Land	SD	10,869	1,975
Fort Berthold Reservation	ND	6,341	1,583
Lake Traverse Reservation and Off-Reservation Trust Land	ND/SD	10,922	1,509
Fort Belknap Reservation and Off-Reservation Trust Land	MT	2,851	1,018
Northern Cheyenne Indian Reservation and Off-Reservation Trust Land	MT/SD	4,789	707
Yankton Reservation	SD	6,465	685
Crow Creek Reservation	SD	2,010	461
Spirit Lake Reservation	ND	4,238	399
Lower Brule Reservation and Off-Reservation Trust Land	SD	1,505	390
Omaha Reservation	IA/NE	4,773	310
Turtle Mountain Reservation and Off-Reservation Trust Land	MT/ND/SD	8,669	237
Kickapoo (KS) Reservation	KS	4,134	237
Rocky Boy's Reservation and Off-Reservation Trust Land	MT	3,323	171
Kickapoo (KS) Reservation/Sac and Fox Nation Trust Land joint-use area	KS	-	237
Santee Reservation	NE	901	185
Winnebago Reservation and Off-Reservation Trust Land	IA/NE	2,694	178
Prairie Band of Potawatomi Nation Reservation	KS	1,469	122
Sac and Fox Nation Reservation and Off-Reservation Trust Land	KS/NE	173	24
Iowa (KS-NE) Reservation and Off-Reservation Trust Land	KS/NE	166	20
Alabama-Coushatta Reservation and Off-Reservation Trust Land	TX	608	13
Ysleta del Sur Pueblo and Off-Reservation Trust Land	TX	804	5
Flandreau Reservation	SD	418	3
Kickapoo (TX) Reservation	TX	366	0
Ponca (NE) Trust Land	IA/NE	10	0

Midwest	State	Population	Total Area (sq miles)
Leech Lake Reservation and Off-Reservation Trust Land	MN	10,660	1,311
Red Lake Reservation	MN	5,896	1,258
White Earth Reservation and Off-Reservation Trust Land	MN	9,562	1,167
Menominee Reservation and Off-Reservation Trust Land	WI	3,141	363
Isabella Reservation	MI	26,274	218
Fond du Lac Reservation and Off-Reservation Trust Land	MN/WI	4,250	159
Lac du Flambeau Reservation	WI	3,442	135
L'Anse Reservation and Off-Reservation Trust Land	MI	3,703	110

Midwest (continued)	State	Population	Total Area (sq miles)
Mille Lacs Reservation and Off-Reservation Trust Land	MN	4,907	103
Oneida (WI) Reservation and Off-Reservation Trust Land	WI	22,776	102
Bois Forte Reservation	MN	874	212
Bad River Reservation	WI	1,479	197
Lac Courte Oreilles Reservation and Off-Reservation Trust Land	WI	2,803	124
Grand Portage Reservation and Off-Reservation Trust Land	MN	565	76
Stockbridge Munsee Community	WI	644	24
Red Cliff Reservation and Off-Reservation Trust Land	WI	1,123	23
Forest County Potawatomi Community and Off-Reservation Trust Land	WI	588	19
Ho-Chunk Nation Reservation and Off-Reservation Trust Land	MN/WI	1,375	11
Sac and Fox/Meskwaki Settlement	IA	1,062	10
Hannahville Indian Community and Off-Reservation Trust Land	MI	523	9
Bay Mills Reservation and Off-Reservation Trust Land	MI	1,014	6
Sokaogon Chippewa Community and Off-Reservation Trust Land	WI	414	5
Pokagon Reservation and Off-Reservation Trust Land	MI	29	5
St. Croix Reservation and Off-Reservation Trust Land	WI	768	4
Ontonagon Reservation	MI	-	4
Prairie Island Indian Community and Off-Reservation Trust Land	MN	217	3
Lower Sioux Indian Community	MN	419	3
Shakopee Mdewakanton Sioux Community and Off-Reservation Trust Land	MN	658	2
Upper Sioux Community and Off-Reservation Trust Land	MN	148	2
Sault Sainte Marie Reservation and Off-Reservation Trust Land	MI	1,747	2
Little River Reservation and Off-Reservation Trust Land	MI	57	2
Grand Traverse Reservation and Off-Reservation Trust Land	MI	608	1
Little Traverse Bay Reservation and Off-Reservation Trust Land	MI	51	1
Minnesota Chippewa Trust Land	MN	64	1
Lac Vieux Desert Reservation	MI	137	<1
Huron Potawatomi Reservation and Off-Reservation Trust Land	MI	52	<1
Match-e-be-nash-she-wish Band of Pottawatomi Reservation	MI	-	<1

Northeast	State	Population	Total Area (sq miles)
Allegany Reservation	NY	6,490	49
St. Regis Mohawk Reservation	NY	3,228	21
Penobscot Reservation and Off-Reservation Trust Land	ME	631	176
Passamaquoddy Trust Land	ME	-	149
Indian Township Reservation	ME	718	44
Cattaraugus Reservation	NY	2,185	34
Tonawanda Reservation	NY	517	12
Onondaga Nation Reservation	NY	468	9
Tuscarora Nation Reservation	NY	1,152	9
Narragansett Reservation	RI	-	3
Mashantucket Pequot Reservation and Off-Reservation Trust Land	CT	299	3
Aroostook Band of Micmac Trust Land	ME	197	2
Houlton Maliseet Reservation and Off-Reservation Trust Land	ME	213	1
Pleasant Point Reservation	ME	749	1
Oil Springs Reservation	NY	1	1
Mohegan Reservation and Off-Reservation Trust Land	CT	48	1
Wampanoag-Aquinnah Trust Land	MA	76	1
Oneida Nation Reservation	NY	25	<1

Southeast	State	Population	Total Area (sq miles)
Eastern Cherokee Reservation	NC	9,018	82
Mississippi Choctaw Reservation	MS	7,436	47
Miccosukee Reservation and Off-Reservation Trust Land	FL	406	136
Big Cypress Reservation	FL	591	82
Brighton Reservation	FL	694	57
Coushatta Reservation and Off-Reservation Trust Land	LA	88	2
Catawba Reservation	SC	841	2
Tunica-Biloxi Reservation and Off-Reservation Trust Land	LA	121	1
Immokalee Reservation	FL	127	1
Hollywood Reservation	FL	1,742	1
Chitimacha Reservation	LA	555	1
Poarch Creek Reservation and Off-Reservation Trust Land	AL/FL	287	1
Jena Band of Choctaw Reservation	LA	-	<1
Fort Pierce Reservation	FL	60	<1
Tampa Reservation	FL	-	<1
Coconut Creek Trust Land	FL	-	<1
Seminole (FL) Trust Land	FL	-	<1

Sources: U.S. Census Bureau 2010a, U.S. Census Bureau 2010b

Note: Tribal trust lands and Alaska Native Village Statistical Areas in the table that are shaded in dark blue are greater than 300 square miles or have more than 3,000 residents. Information on the energy infrastructure present on these TTLs and ANVs are provided in Appendix C.

Appendix G: SELECTED RESOURCES TO ASSIST WITH CLIMATE RESILIENCE PLANNING

The following contains examples of resources that may be useful when examining vulnerabilities of energy infrastructure and identifying possible options for improving climate resilience.

United States Climate Resilience Toolkit

Available at: https://toolkit.climate.gov/

The climate resilience toolkit was developed to assist citizens, communities, businesses, resource managers, planners, and policy leaders manage climate change-related risk and build resilience to extreme weather events. The toolkit contains scientific tools, case studies, and training courses that are available to the public, including:

"Cities Impacts and Adaptation Tool (CIAT)," University of Michigan Climate Center

Available at: http://graham-maps.miserver.it.umich.edu/ciat/home.xhtml

This tool was developed to support climate adaptation planning in the Great Lakes region, but includes examples of adaptation strategies that are applicable to communities throughout the United States. This tool requires the user to select a location, and then directs the user to a report that includes adaptation strategies. From the adaptation strategies bar, the user can select climate drivers and/or climate impacts to access adaptation strategies.

Federal Support Toolbox for Integrated Water Resources Management

Available at: http://watertoolbox.us/intro/f?p=689:1:0

The Water Toolbox was developed to serve as a resource for information sharing and best management practices for the water resources community. It contains databases, tools, and models, as well as examples of collaborations between different organizations within the water resources community.

"Climate Commons," California Landscape Conservation Cooperative

Available at: http://climate.calcommons.org/

Climate Commons contains datasets, documents, and other web resources that are related to climate change impacts and adaptation in California. This resource includes guidance and tools for scenario planning and conducting vulnerability assessments.

"Coastal Resilience," The Nature Conservancy

Available at: http://maps.coastalresilience.org/network/

This interactive tool allows users to visualize flood risks due to sea level rise and storm surge and identify risk areas. The tool was developed to help decision-makers identify ways to reduce risk and build resilience.

"Coastal Resilience Index," Mississippi-Alabama Sea Grant Consortium and the National Oceanic and Atmospheric Administration's Coastal Storms Program

Available at: http://masgc.org/assets/uploads/publications/662/coastal_community_resilience_index.pdf

The Coastal Resilience Index is a self-assessment tool that is designed to help community leaders in guiding the discussion of resilience to coastal hazards.

"Vulnerability, Consequences, and Adaptation Planning Scenarios (VCAPS)," Social and Environmental Research Institute

Available at: http://www.vcapsforplanning.org/

VCAPS is a process that was developed to help communities increase resilience to extreme weather and climate change.

"Adaptation Tools and Publications," U.S. Department of Transportation Federal Highway Administration Office of Planning, Environment, & Realty

Available at: http://www.fhwa.dot.gov/environment/climate_change/adaptation/publications_and_tools/

The Federal Highway Administration developed several tools and reports that can be used by communities to analyze the vulnerability of their resources to climate change and build resilience. Tools include a sensitivity matrix that documents transportation asset vulnerabilities to climate impacts and a spreadsheet tool that allows transportation planners to view relevant climate change statistics. The list of publication includes a summary document on building resilient transportation.

"Transportation and Climate Change Clearinghouse: Adaptation Planning," U.S. Department of Transportation

Available at: http://climate.dot.gov/impacts-adaptations/planning.html

DOT developed the Transportation and Climate Change Clearinghouse as a source of information on transportation and climate change issues. The adaptation planning section includes resources that contain approaches for planning for the impacts of climate change on transportation.

"Climate Change Impacts and Adapting to Change," U.S. Environmental Protection Agency

Available at: http://www.epa.gov/climatechange/impacts-adaptation/index.html

This resource allows users to view climate change impacts and adaptation efforts by region or by sector. The sections containing adaptation efforts include examples of adaptation, key points, and links related to adaptation in the region or sector.

"Climate Change," U.S. Department of the Interior Bureau of Indian Affairs

Available at: http://www.bia.gov/WhoWeAre/BIA/climatechange/index.htm

BIA identifies funding opportunities for tribes for projects to address climate change adaptation and environmental planning and list federal resources associated with climate change.

"Hardening and Resiliency: U.S. Energy Industry Response to Recent Hurricane Seasons," U.S. Department of Energy, Office of Electricity Delivery and Energy Reliability

Available at: http://www.oe.netl.doe.gov/docs/HR-Report-final-081710.pdf

DOE developed this report to document industry efforts to harden and improve resiliency of assets following the 2005 and 2008 hurricane seasons.

“Adaptation Clearinghouse,” Georgetown Climate Center

Available at: http://www.georgetownclimate.org/adaptation/clearinghouse

Georgetown Climate Center’s Adaptation Clearinghouse contains over 1,000 resources (including adaptation plans, assessment guidance, case studies, tools, websites, etc.) to help communities adapt to different impacts of climate change. The database allows users to search by resource type, sector (including energy and infrastructure/built environment), and climate change impact.

“Tribal Climate Change Project,” University of Oregon and the U.S. Department of Agriculture Forest Service Pacific Northwest Research Station

Available at: http://tribalclimate.uoregon.edu/

The Tribal Climate Change Project contains publications and tribal climate change profiles that document how tribes across the United States are addressing climate change. The Tribal Climate Change Network also established the PNW Tribal Climate Change Network to foster communications between tribes and other entities about climate change policies and programs.

“Tribal Climate Change,” Northern Arizona University Institute for Tribal Environmental Professionals (ITEP)

Available at: http://www4.nau.edu/itep/climatechange/

ITEP’s Tribal Climate Change Program includes training, technical assistance, tools, and educational resources to assist tribes in addressing the impacts of climate change. This resource includes webinars, training programs, and newsletters.

“Risk Mapping, Assessment, and Planning (Risk MAP),” U.S. Department of Homeland Security Federal Emergency Management Agency

Available at: https://www.fema.gov/risk-mapping-assessment-and-planning-risk-map

FEMA’s Risk MAP tool contains high quality flood maps and tools and outreach support to assist a variety of stakeholders, including state and local officials, in mitigating flood risk.

“Preparedness Resources for Tribes,” U.S. Department of Homeland Security Federal Emergency Management Agency

Available at: https://www.fema.gov/preparedness-resources-tribes

FEMA’s list of preparedness resources includes training courses, funding programs, and tips for tribes to prepare for emergencies such as extreme weather events.

“Community Guidelines for Energy Emergencies,” U.S. Department of Energy Office of Electricity Delivery & Energy Reliability

Available at: http://energy.gov/oe/services/energy-assurance/emergency-preparedness/community-guidelines-energy-emergencies

DOE’s Office of Electricity Delivery and Energy Reliability publishes energy emergency guidelines for homeowners, business owners, and local leaders. These guidelines include tips for preparing for and responding to power outages, fuel shortages, and natural gas and utility disruptions.

"Climate Change and the U.S. Energy Sector: Regional Vulnerabilities and Resilience Solutions," U.S. Department of Energy Office of Energy Policy and Systems Analysis

DOE’s Office of Energy Policy and Systems Analysis published this report to support communities in their climate change preparedness and resilience planning activities. The report examines current and potential future impacts of climate change on the U.S. energy sector at the regional level, provides illustrative examples of resilience actions that have been taken, and identifies potential opportunities to deploy climate-resilient energy technologies and practices.

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