TRANSPORTATION VULNERABILITY ASSESSMENT TECHNICAL MEMO

TO: Amit Armstrong (FHWA Western Federal Lands), LaJuanda Stands and Looks Back

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SUBJECT: Technical summary of the Rosebud Sioux Tribe climate change vulnerability assessment of the transportation network

DATE: **July 21, 2023**

EXECUTIVE SUMMARY

The Rosebud Sioux Tribe faces existing climate stress that will only be exacerbated by future climate change. These impacts affect the community as a whole and create concerns for the transportation systems of the Tribe. This vulnerability assessment for the Rosebud Sioux Tribe focuses on the impacts of climate hazards and extreme weather on the Tribe's transportation infrastructure, aiming to understand the extremes that climate change has caused and evaluate climate change considerations across the entire roadway system. The Federal Highway Administration Vulnerability Assessment and Adaptation Framework is used as the basis for the vulnerability assessment conducted for this project. This final report will supplement existing climate work that the Tribe has conducted, notably the Rosebud Sioux Tribe Climate Change Adaptation Plan.

This vulnerability assessment examines the impacts of extreme heat, freeze-thaw, precipitation, wildfire, storms, and tornadoes on the transportation network of the Rosebud Sioux Tribe. This examination relies on obtained climate data, including information from historic climate events and climate model projections. Modeled projections are used to show potential future scenarios related to extreme heat, freeze-thaw, and precipitation for mid-century and end-of-century thirty-year average periods, 2055 (average of 2040 to 2069) and 2085 (average of 2070 to 2099).

One of the primary concerns for the Rosebud Sioux transportation network is extreme heat, many pedestrians use the transportation network every day. Between 1976 and 2005, there was one day when the heat index exceeded 103°F, the National Weather Service's threshold for the Danger classification for Heat Index, in which heat disorders are likely with prolonged exposure or strenuous activity.[1] The number of days above this threshold is modeled to rise to between eight and 13 days in the 2050s and between 12 and 34 days in the 2080s. This is a significant increase in the historical data and creates a major public health concern.

Given the results of the study, the following set of recommendations has been created for the Rosebud Sioux Tribe to adapt their transportation network to the changing climate:

- Identify interventions to conduct in the short and medium term to reduce the impact of climate-related events on transportation infrastructure and its functionality.
- Integrate climate change considerations in the design of improvements and new infrastructure.

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[1] https://www.weather.gov/ama/heatindex

- Integrate climate change considerations into the preparation of future Transportation Plans (e.g., Long Range Transportation Plan).
- Develop a database of climate-related events and their impacts on roadway infrastructure.
- Support pedestrian infrastructure that promotes public health, such as shade structures and sidewalks.
- Maintain a list of at-risk assets and their priority for further study or improvements, as applicable.

1 PROJECT BACKGROUND

WSP supported the Federal Highway Administration (FHWA) to create a transportation-focused climate change vulnerability assessment for the Rosebud Sioux Tribe in South Dakota. This vulnerability assessment uses the FHWA Vulnerability Assessment and Adaptation Framework to assess the vulnerability and impact of transportation infrastructure to climate-related events.

Representatives from the Rosebud Sioux Tribe were involved in every step of the implementation of the Framework which deepened the understanding of the challenges faced by climate change and the identification of adaptation solutions to climate change. Additionally, nearby University professors and Bureau of Indian Affairs representatives assisted with further understanding of the transportation network and climate hazards. The Rosebud Sioux Tribe envisions that the outputs of the project will enable identifying priority assets and support risk-based decision-making to increase the resiliency of the transportation infrastructure.

The Rosebud Sioux Tribe is a federally recognized Indian Tribe with 21,245 enrolled members living on the reservation, a land area of 882,416 acres in south central South Dakota, bordered by the Pine Ridge Reservation, the White River, and Cherry County, Nebraska, shown in Figure 1.1. The land of the reservation is primarily semi-arid hills, and the main climate hazards that affect the area are extreme heat, extreme cold, increased soil erosion, storms, wildfires, and drought. In recent years, long-term groundwater level declines have been observed, increasing the reservation's vulnerability to drought. The Rosebud Sioux Tribe has completed other studies and projects to understand this threat to the Tribe's water resources, such as their 2017 Drought Vulnerability Assessment, 2020 Drought Adaptation Plan, and 2021 Climate Guidebook. The Tribe is also currently developing a Water Resiliency Manual, expected to be completed in late 2023.

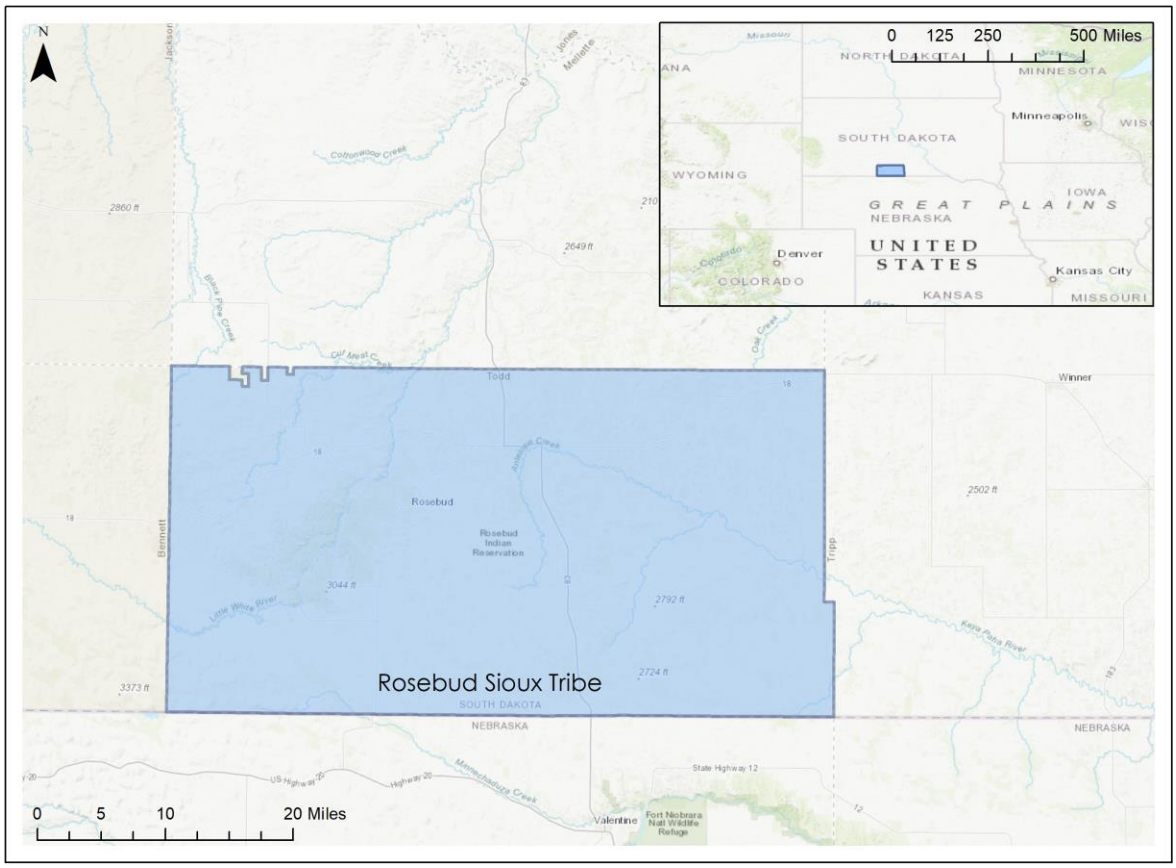


Figure 1.1. Location and territory boundaries of the Tribe

2 GLOSSARY

Adaptation: The process of adjustment to the actual or anticipated climate and its effects. In human systems, adaptation seeks to moderate harm or make use of beneficial opportunities. In natural systems, human intervention may facilitate adjustment to the expected climate and its effects.[2]

Climate change: Changes in average weather conditions that persist over long periods of time, usually 30-year periods or longer, encompassing increases and decreases in temperature and changes in trends such as shifts in precipitation.[3]

CMIP: Coupled Model Integration Project; a large compendium of Global Climate Models that are developed and run by institutions around the world to provide a larger sample size, accounting for potential biases in the different ways the code of the models is written.

Ensemble Average: The mean value of a subset of climate model projections. In this analysis, 12 models were analyzed, so the ensemble average values reflect the average of all 12 model projections.

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[2] United Nations Intergovernmental Panel on Climate Change Glossary. https://www.ipcc-data.org/guidelines/pages/glossary/glossary_c.html

[3] Investing in Transportation Resilience: A Framework for Informed Choices (2021)

Exposure: The presence of people, assets, and infrastructure in places where they could be adversely affected by hazards (e.g., a road that is in a floodplain).

GCM: General or Global Climate Model; numerical representations of the climate system based on the physical, chemical, and biological properties of its components. GCMs are developed and run by institutions around the world based on computer code that simulates the Earth system and its patterns and responses to different stimuli.

Hazard: Potentially damaging impacts resulting from natural causes (e.g., floods, wildfires, heat waves).

LOCA: Localized Constructed Analogs; a method of statistical downscaling to take the large outputs from GCMs (usually hundreds of miles large for each grid cell of information) and make them smaller (3.7 miles squared per grid cell) and more regionally informative based on localized factors like topography and weather.

Mitigation: Strategies and actions taken to reduce greenhouse gas emissions that contribute to climate change. This can be contrasted with adaptation, which is focused on actions taken to prevent or minimize the impacts rather than preventing climate change and impacts from occurring.

Representative Concentration Pathways: Scenarios that include time series of emissions and concentrations of the full scale of greenhouse gases and land use/land cover. The word "representative" means that each RCP provides one of several possible scenarios in the future. RCPs are labeled with different numbers, referring to the warming that would occur under that scenario (in watts per square meter of radiation).[4] RCP 4.5 refers to a scenario wherein peak fossil fuel dependency occurs in 2040 and declines in the centuries following, coupled with strong policy and social mitigation strategies to reduce emissions. RCP 8.5 assumes little to no action to mitigate emissions and continued dependency on fossil fuels throughout the remainder of the century.

Return period: Also known as "recurrence intervals" or "annual exceedance probabilities," return periods indicate the likelihood of an event, such as heavy precipitation, occurring or being exceeded based on the estimated average time between events over a long period of time. For example, a 100-year storm has a 1% likelihood of occurring each year.

Risk: The overall likelihood of exposure and loss due to hazards or threats, taking into account the vulnerability and economic and social consequences of the damage.[5]

Tornado: A violently rotating column of air with circulation reaching the ground. A tornado nearly always starts as a funnel cloud and may be accompanied by a loud roaring noise similar to that of a freight train. On a local scale, it is the most destructive of all atmospheric phenomena.[6]

Vulnerability: The predisposition to be adversely affected by something. Vulnerability can mean sensitivity or susceptibility to harm and lack of capacity to cope and adapt.[7]

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[4] United Nations Intergovernmental Panel on Climate Change Glossary. **https://www.ipcc-data.org/guidelines/pages/glossary/glossary_c.html**

[5] Investing in Transportation Resilience: A Framework for Informed Choices (2021)

[6] National Weather Service Glossary. **https://w1.weather.gov/glossary/index.php?word=TORNADO**

[7] United Nations Intergovernmental Panel on Climate Change Glossary. **https://www.ipcc-data.org/guidelines/pages/glossary/glossary_c.html**

3 FHWA VULNERABILITY ASSESSMENT AND ADAPTATION FRAMEWORK

This Tribal Transportation Climate Change Vulnerability Assessment for the Rosebud Sioux Tribe is part of a larger research project funded by FHWA, which will complete Tribal transportation network vulnerability assessments for seven tribes and a total of six assessments across the US. Each assessment will follow the FHWA's Vulnerability Assessment and Adaptation Framework, and at the end of the project, FHWA will compile the challenges and successes of using the pre-existing framework for Tribal transportation networks.

This assessment followed the first four steps of the FHWA framework also summarized in Figure 3.1:

1. **Define study objectives and scope** of the assessment to identify the assets to be included in the assessment, the hazards to be analyzed, and the level of detail of the study.
2. **Obtain asset data**, which includes revision of available information, identification of data collection needs, and characterization of the available information.
3. **Obtain climate data**, including information from historic relevant climate events and climate model projections where feasible, and a definition of climate intensity parameters (i.e., temperature, precipitation depth, etc.) to be generated.
4. **Assess the vulnerability** of transportation assets to hazards. For this step, there are three approaches: a stakeholder input approach, consisting of surveys and interviews with local stakeholders; an indicator-based approach, which enables ranking transportation asses based on available data; and an engineering-informed approach, with a higher level of detail, includes analysis of future climate conditions and identification of adaptation measures.
5. Identify, analyze, and prioritize adaptation options
6. Incorporate assessment results into decision-making
7. Monitor and revisit

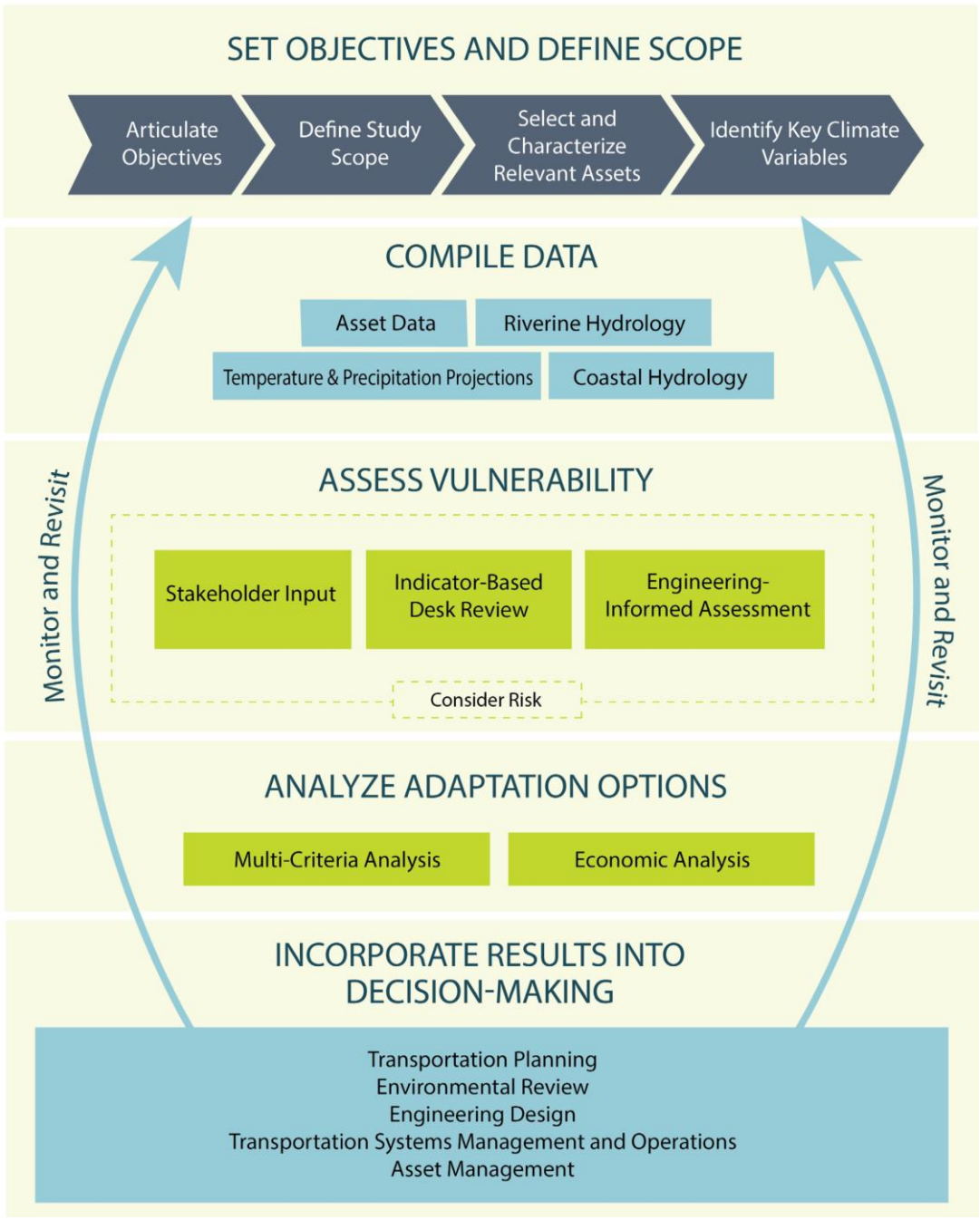


Figure 3.1. FHWA Vulnerability Assessment and Adaptation Framework

3.1 TRANSPORTATION NETWORK – ASSET DATA

The Rosebud Sioux Tribe transportation infrastructure assets are primarily owned by the Bureau of Indian Affairs, which oversees 312 miles of roads, but the Rosebud Sioux Tribe Transportation Program manages the tribal transportation infrastructure. They are directly funded and when possible, partner with the BIA for road maintenance endeavors While the roads within RST lands are owned by various public authorities, the Tribe takes a central role in managing the transportation system to meet the needs of their citizens. They work with the various public authorities to address transportation needs, and for TTP-funded projects, the public authority is afforded an opportunity to review and comment on the Tribe's PS&E packages for projects on their roads. The tribal roads account for less than 1 mile of the transportation network. The County and state also maintain roads within tribal boundaries.

In addition, road assets located within or that provide access to Tribal Lands are eligible for federal programs and services, including the Tribal Transportation Program, which provides funds to address the needs of transportation infrastructure for Tribes.[8]

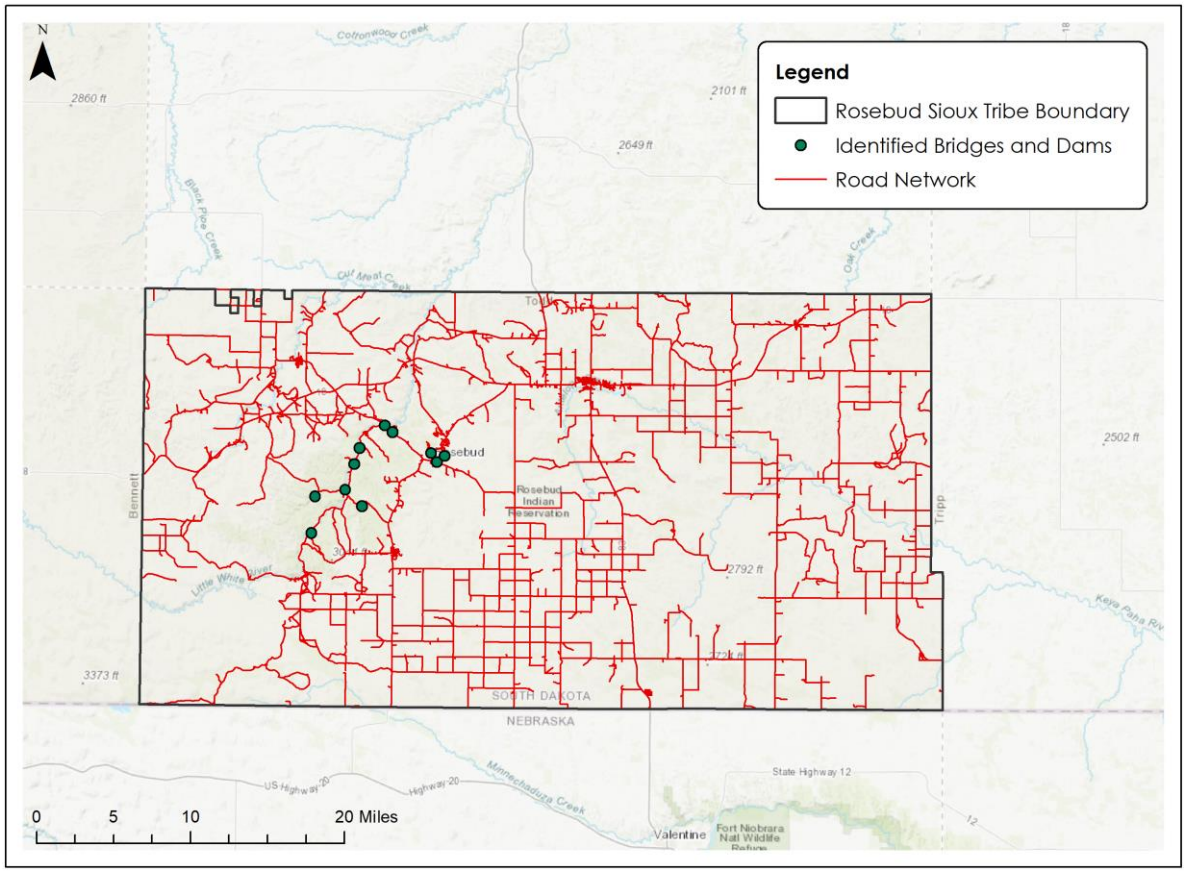


Figure 3.2 presents the spatial distribution of the roads that are assessed in this study as well as bridges and dams that are important to the Tribe. Images of the identified bridges and dams are presented in the Appendix.

[8] https://www.bia.gov/bia/ois/division-transportation/operations

Based on stakeholder input, some of the climate-related challenges currently faced by the Tribe related to the vulnerability of transportation infrastructure include riverine flooding, tornadoes, ice storms, extreme temperatures, drought, soil erosion, and wildfires. These events result in temporary road closures and increased maintenance needs that are likely to be exacerbated due to climate change.

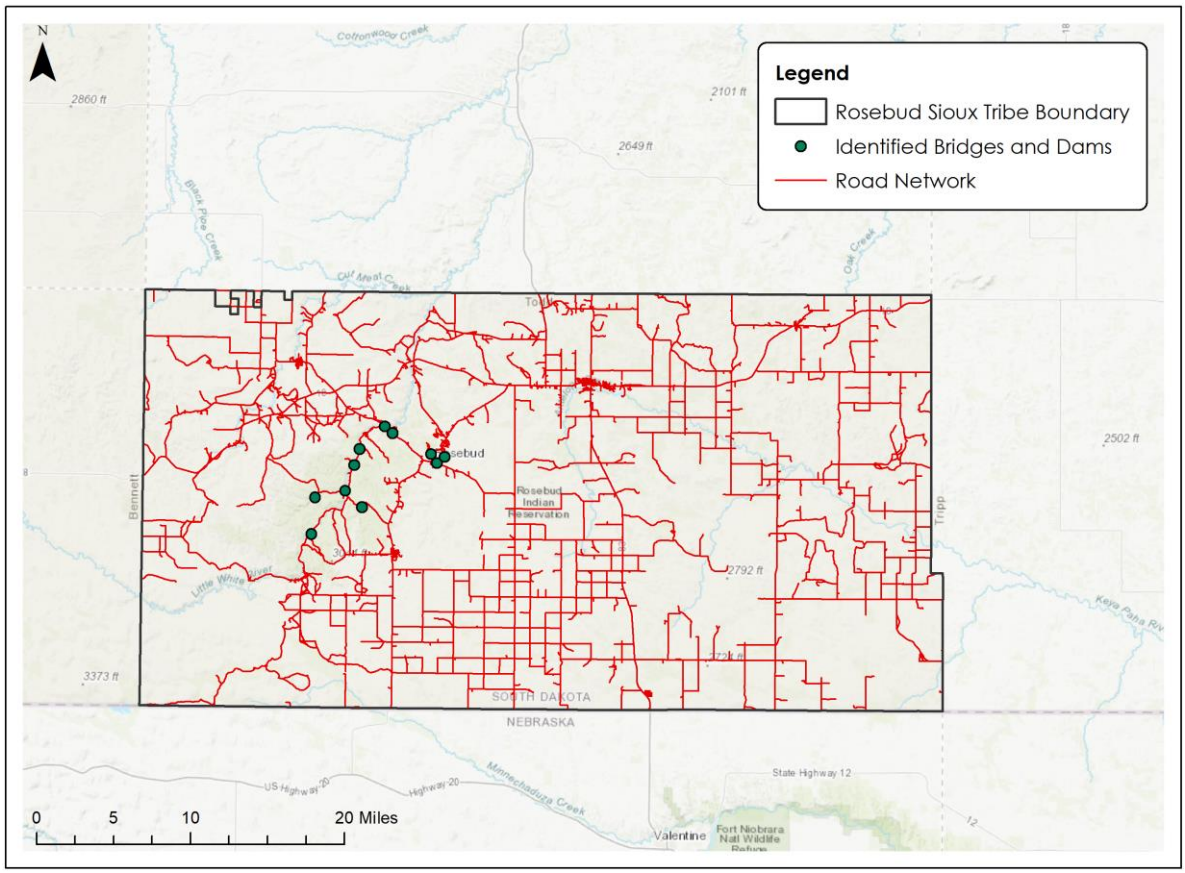


Figure 3.2. Roads assessed in this study

3.2 CLIMATE HAZARDS

The NOAA Storm Event database compiles nationwide historic information about storm events, including parameters such as event type, intensity, and impact.[9] Based on this, information was obtained and summarized for the counties including and surrounding the study area as presented in Figure 3.3. These include Todd County and the towns of Mission, Rosebud, Okreek, St. Francis, and Parmelee, amongst others. As presented, the most recurrent events in the study area include hail, thunderstorm winds, tornadoes, and winter storms. The Federal Emergency Management Agency (FEMA) National Risk Index illustrates the census tracts and counties most at risk for 18 different natural hazards. A community's score is represented by its percentile ranking among all other communities at the same level for Risk, Expected Annual Loss, Social Vulnerability and Community Resilience. For example, if a given Census tract's Risk Index percentile for a hazard type is 84.32 then its Risk Index value is greater than

[9] https://www.ncdc.noaa.gov/stormevents/

84.32% of all US Census tracts.[10] The results of selected Climate Hazards for the two census tracts in the study area are displayed below in Table 3.1.[11]

Table 3.1: FEMA National Risk Index results for select climate hazards in the study area

Climate Hazard	Hazard Type Risk Ratings for Census Tract 940100	Hazard Type Risk Ratings for Census Tract 940200
Cold Wave	99.8 (Very High)	99.9 (Very High)
Drought	83.7 (Relatively Low)	87.5 (Relatively Low)
Hail	91.0 (Relatively High)	96.9 (Relatively High)
Ice Storm	95.6 (Relatively High)	98.9 (Very High)
Landslide	99.0 (Relatively High)	93.6 (Relatively High)
Strong Wind	90.0 (Relatively High)	98.3 (Very High)
Tornado	81.5 (Relatively High)	97.1 (Very High)
Wildfire	97.1 (Relatively High)	99.3 (Very High)
Winter Weather	99.4 (Very High)	100.0 (Very High)

Based on this information and stakeholder consultation, this study analyzed the potential impact of some of these climate-related events on the transportation network in the study area, considering the effect of climate change. The following sections describe the climate data compiled for this study.

[10] https://hazards.fema.gov/nri/understanding-scores-ratings
[11] https://hazards.fema.gov/nri/map

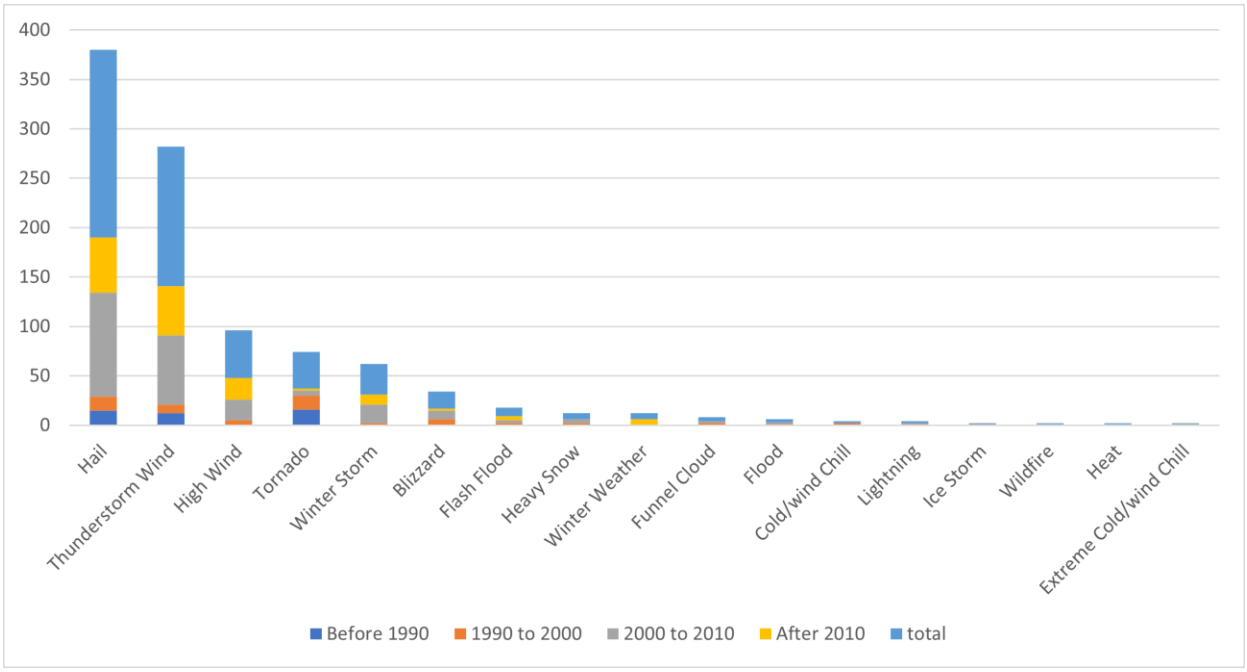


Figure 3.3. Climate events reported in the surroundings of the study area. Source: NOAA Storm Events Database

Climate data is represented in scenarios that describe the spatial distribution of an intensity parameter (i.e., precipitation depth, temperature) in a study area. As a result of climate change, extreme weather events are occurring with a higher frequency for which it is recommended to include these potential effects in decision-making and infrastructure management procedures.

Different generations of models were used for the temperature and precipitation analyses as relative humidity projections have not yet been released from the most recent generation of downscaled data. The climate data is represented in future time period averages as follows:

- Historical: 1976-2005
- Mid-century (2050s): 2040-2069
- End-of-century (2080s): 2070-2099

There is uncertainty on how parameters such as population growth, policies, and climate-forcing emissions will vary in the future (FHWA, 2017). To consider this, two types of scenarios are presented in this study: one based on historic information, and the other based on climate projection emission pathways, which will be further described in the following sections. For this project in particular, the specific modeled climate hazards analyzed are extreme heat, freeze-thaw, and precipitation and the climate hazards that are analyzed by looking at the historical data include wildfire, storms, and tornadoes.

3.2.1 TEMPERATURE RELATED HAZARDS

Observed daily maximum temperature, minimum temperature, and relative humidity values were taken from the UK Met Office Hadley Centre Integrated Surface Database (HadISD) global sub-daily weather dataset.[12] The specific weather station used was the Valentine, NE Miller Field (725670-24032) nearby to the Rosebud Sioux reservation.

Future climate projections of daily maximum and minimum dry-bulb temperature and daily minimum relative humidity were taken from climate models from the fifth Coupled Model Integration Project (CMIP5), downscaled using the Localized Constructed Analogs (LOCA) method. Projections were obtained for both RCP 4.5 and RCP 8.5 through the end of the 21st century. To correct for local factors that may lead to differences between the climate projections and localized climate, a delta bias correction was applied using the observed weather station data. This process includes a comparison between what a climate model projects for past conditions (in this case, 1976-2005) and what was observed in the past. Based on the difference, a ratio is added (for temperature) or multiplied (for precipitation) by the future values to ensure that the biases of the models do not carry heavily into the future projected conditions. For each 30-year time period in each emissions scenario, the ensemble mean, 5th percentile, and 95th percentile were calculated for each of the indices. The 5th and 95th percentile measure the value that delineates the top and bottom 5 percent of measured values.

For temperature, 32 downscaled Global Climate Models (GCMs) were available from the LOCA dataset. As heat index calculations account for both dry bulb temperature and relative humidity, only the 24 models included in the relative humidity dataset were used.

FREEZE THAW

As shown in Table 3.2, days where the minimum temperature is below the bottom threshold (15.8 °F) and the maximum temperature is above the upper threshold (32 °F, freezing temperature), otherwise known as freeze/thaw days, are projected to decrease. These thresholds were established based on guidance provided by the USDOT Transportation Climate Change Sensitivity Matrix: because water freezes at a lower temperature when trapped inside concrete pores due to the chemical composition of the aggregate used in concrete, the freeze-thaw cycle defined as that which can do structural damage to concrete is 15.8 °F to 32 °F.[13] This may have beneficial effects for infrastructure as water is not freezing (and therefore expanding) and then thawing out (therefore contracting) within pavements, which can cause cracking.

Freeze/thaw days are the number of days that have a minimum temperature below the bottom threshold and a maximum temperature above the top threshold. Observed values for daily temperatures were gathered from the Livneh dataset, which provides gridded historical data and is commonly used with the LOCA projections.[14] Climate projections for daily precipitation were gathered from the LOCA dataset.

[12] https://www.metoffice.gov.uk/hadobs/hadisd/
[13] https://ctr.utexas.edu/wp-content/uploads/pubs/1405_1.pdf
[14] Pierce, D. W., Kalansky, J.F., & Cayan, D.R. (2018). *Climate, Drought, and Sea Level Rise Scenarios for California's Fourth Climate Change Assessment: A Report for California's Fourth Climate Change Assessment.* https://www.energy.ca.gov/sites/default/files/2019-11/Projections_CCCA4-CEC-2018-006_ADA.pdf

The climate projections were processed to produce estimates for multiple metrics, including the number of annual days below -7.6°F, minimum annual temperature, and freeze/thaw days, or days where the minimum temperature is below 15.8°F and the maximum temperature is above 32°F (freezing).

As the climate data used in this analysis is based on predictive models, hindcasting using a delta (change) method was performed to improve the accuracy of the projected data. To produce these results, the difference between the modeled past and the modeled future was calculated as a percentage of change and multiplied by the observational dataset's values to obtain a future projection value. Since the temperature events analyzed in this report are extreme values, this bias correction is a necessary step as LOCA data can underestimate extreme daily temperatures.

This data provides information on model ensemble averages from the 12 climate models analyzed. While this provides useful information on the average condition for each of these metrics in the future projected time periods, it does not fully represent possible extreme conditions. Further analysis based on regional climate models is recommended for future studies.

As shown in Table 3.2, minimum temperatures are projected to increase. Warmer minimum temperatures mean that recuperation from periods of extreme heat will be more challenging for humans, animals, and ecosystems. Rising minimum temperatures can affect infrastructure as well. The binding material in pavement is rated down to -7.6°F, so when the temperature dips to -7.6°F or lower, the pavement can degrade. Minimum daily temperatures are estimated to increase by 8°F on the reservation, which may have a positive effect on pavements. Freeze/thaw days, or days that have a minimum temperature below 15.8°F and a maximum temperature above 32°F, are projected to decrease as well, which may have beneficial effects for infrastructure as water is not freezing (and expanding) and thawing (and contracting) in pavements.

Figure 3.4 and Figure 3.5 map the number of freeze thaw days that are projected to occur over the area under RCP 8.5 in 2055 and 2085. The number of days is projected to decline over time, with the northeast corner of the study area experiencing the higher number of days.

Table 3.2: Freeze/thaw projections. Units: days:

Baseline			2050s				2080s			
Units: days per year	**1976-2005**	**5-95th percentile**	**Medium Scenario (RCP 4.5)**	**5-95th percentile**	**High Scenario (RCP 8.5)**	**5-95th percentile**	**Medium Scenario (RCP 4.5)**	**5-95th percentile**	**High Scenario (RCP 8.5)**	**5-95th percentile**
Freeze/Thaw Days	26	*18-35*	20	*15-34*	18	*11-23*	18	*14-23*	14	*6-21*
Days below -7.6°F	9.3-	*1-24*	3	*0-6*	2	*0-7*	2	*0-6*	0	*0-3*

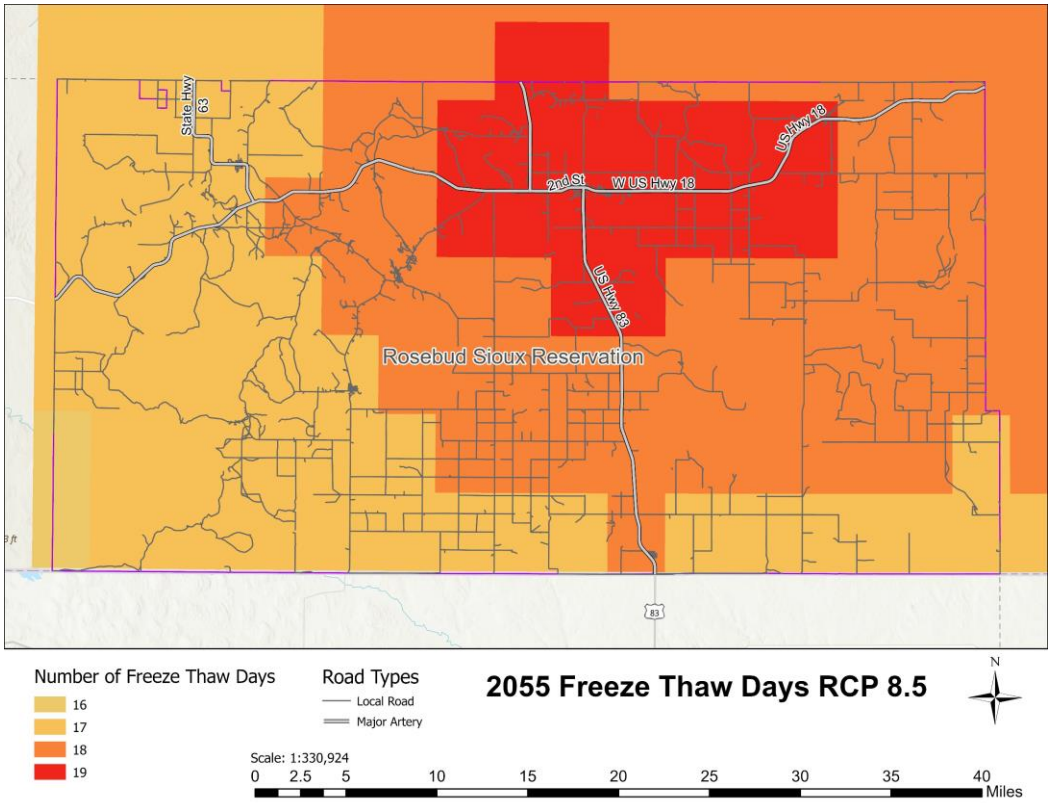


Figure 3.4: 2055 Freeze Thaw Days RCP 8.5

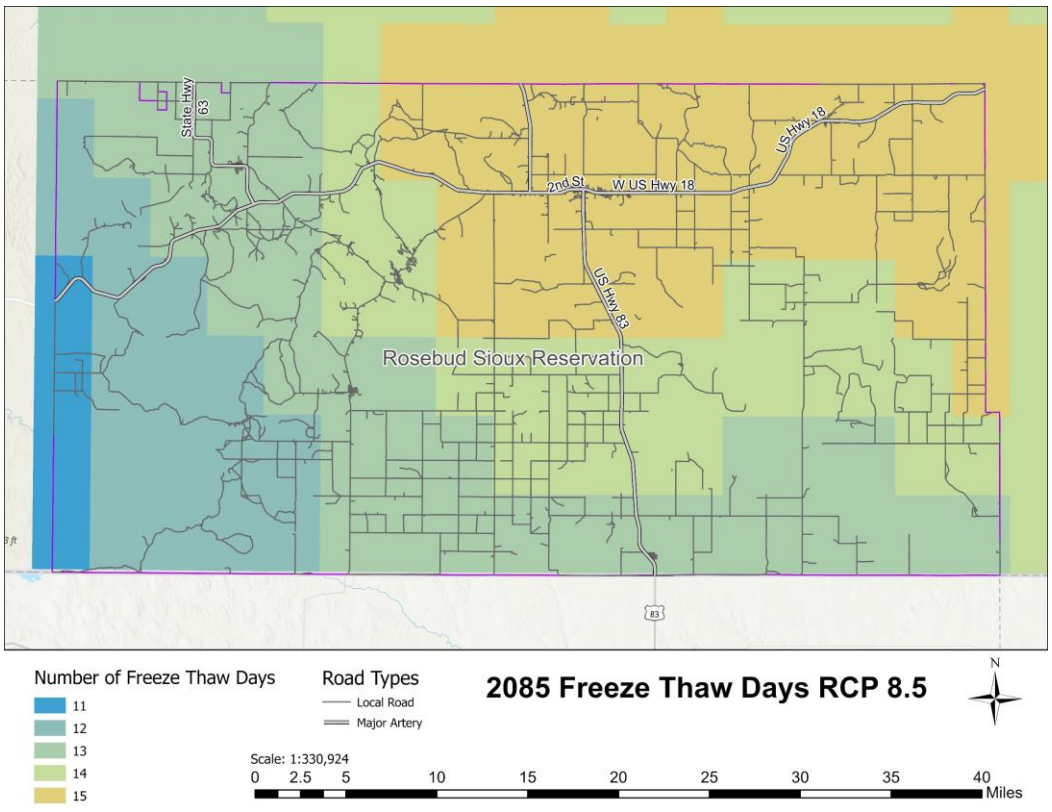


Figure 3.5: 2085 Freeze Thaw Days RCP 8.5

EXTREME HEAT

Extreme heat can have significant impacts on both the built environment and public health. Extreme heat events can cause discomfort and a multitude of health issues to humans and animals, particularly when combined with humidity. Hot and humid air makes it challenging to cool off by sweating. A conventional thermometer measures the dry-bulb temperature (also known as dry heat) and the National Weather Service's heat index reflects the 'feels-like' temperature, the combination of heat and humidity. Under humid conditions, the heat index can be significantly higher than the dry-bulb temperature (see Figure 3.6).

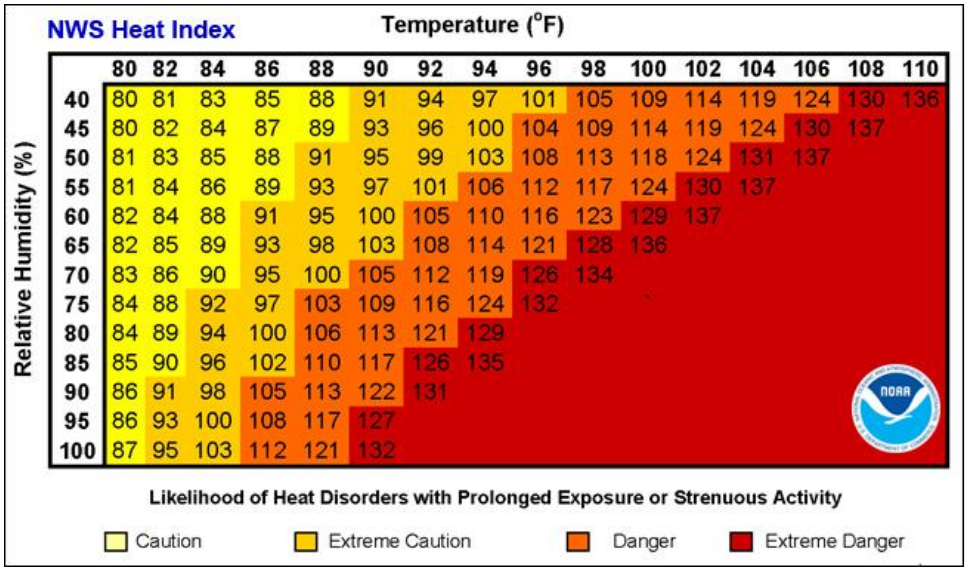


Figure 3.6. National Weather Service heat index table. Source: NWS

Extreme heat events disproportionately impact vulnerable populations such as those who cannot afford air conditioning or cooling technology and are therefore exposed to high temperatures for extended amounts of time. During extreme heat events, particularly when combined with high humidity levels, people can experience health-related illnesses like fatigue, heat cramping, and heat stroke (see Figure 3.7).

Classification	Heat Index	Effect on the body
Caution	80°F - 90°F	Fatigue possible with prolonged exposure and/or physical activity
Extreme Caution	90°F - 103°F	Heat stroke, heat cramps, or heat exhaustion possible with prolonged exposure and/or physical activity
Danger	103°F - 124°F	Heat cramps or heat exhaustion likely, and heat stroke possible with prolonged exposure and/or physical activity
Extreme Danger	125°F or higher	Heat stroke highly likely

Figure 3.7. Public health impacts of heat index. Source: NWS

These events can be exacerbated by power outages caused by an overload of electricity demand for powering air conditioners. Extreme heat can also damage infrastructure. For example, equipment in power rooms for mechanical equipment can be damaged in high-temperature operating conditions.

Damages to pavement and concrete on roads and bridges from extreme heat can include the rutting and shoving of asphalt surfaces, increased hardening of asphalt binder, concrete curling and warping, subgrade shrinking, and blow ups due to slab expansion.[15]

To address these concerns, future paving and bridge projects could use asphalt and concrete that is rated for higher temperatures.

[15] U.S. Department of Transport (Federal Highway Administration), 2015, Climate Change Adaptation For Pavements, Tech Brief (FHWA-HIF-15-015), https://www.fhwa.dot.gov/pavement/sustainability/hif15015.pdf

Table 3.3. Heat index day projections based on the National Weather Service heat index categories. Units: days per year

	Baseline		2050s				2080s			
Units: days per year	1976-2005	5-95th percentile	Medium Scenario (RCP 4.5)	5-95th percentile	High Scenario (RCP 8.5)	5-95th percentile	Medium Scenario (RCP 4.5)	5-95th percentile	High Scenario (RCP 8.5)	5-95th percentile
Caution (80-90°F)	64	*46-78*	58	*53-66*	57	*48-66*	58	*50-65*	51	*43-62*
Extreme Caution (90-103°F)	30	*14-47*	53	*39-63*	58	*47-67*	57	*44-68*	60	*53-72*
Danger (103-125°F)	1	*0-3*	8	*3-13*	13	*6-20*	12	*4-18*	34	*14-53*
Extreme Danger (> 125°F)	0	*0-0*	0	*0-0*	0	*0-0*	0	*0-0*	0	*0-1*

As shown in Table 3.3, the number of days with a high heat index is projected to increase. As temperatures rise, there is an estimated decrease in the number of days in the first category (Caution: 80-90°F), but a sharper increase in the following two categories of extreme caution (90-103°F) and danger (103-125°F) moving into the remainder of the century. Heat index temperatures rising above 125°F are an uncommon occurrence and are therefore not projected to happen regularly in an average year. However, it is important to note that these projections show an average year, not an extreme one. For example, if a weekly temperature forecast is an average of 80°F, not all the days that week will be exactly 80°F. There will likely be days both below and above that threshold, and this does not account for the most extreme of events. These 'ensemble mean' (averaged) projections show the middle-of-the-road value over a set of years, and further protections against a year that experiences above-average heat may be necessary.

Table 3.4. Extreme heat projections.

Baseline			2050s				2080s			
Units: days per year	1976-2005	5-95th percentile	Medium Scenario (RCP 4.5)	5-95th percentile	High Scenario (RCP 8.5)	5-95th percentile	Medium Scenario (RCP 4.5)	5-95th percentile	High Scenario (RCP 8.5)	5-95th percentile
Days above 90°F	38	*17-57*	67	*50-82*	75	*60-88*	73	*54-92*	97	*76-118*
Days above 95°F	20	*6-38*	43	*27-56*	51	*34-65*	79	*31-67*	75	*49-99*
Days above 100°F	6	*0-16*	20	*10-28*	26	*14-36*	24	*12-37*	48	*22-71*
Days above 105°F	1	*0-3*	6	*2-11*	10	*4-17*	9	*3-16*	24	*7-41*

Heat index values were calculated using the LOCA and weather station temperature and minimum relative humidity data with the National Weather Service's heat index equations (see Equation 1). Minimum relative humidity and maximum temperature were used to calculate the maximum heat index for each day since the lowest daily relative humidity levels correlate with the highest daily temperature values.

Equation 1. National Weather Service Heat Index Equations. Source: National Weather Service

$$HI = -42.379 + 2.04901523*T + 10.14333127*RH - .22475541*T*RH - .00683783*T*T - .05481717*RH*RH + .00122874*T*T*RH + .00085282*T*RH*RH - .00000199*T*T*RH*RH$$

$$ADJUSTMENT = [(13-RH)/4]*SQRT\{[17-ABS(T-95.)]/17\}$$

$$ADJUSTMENT = [(RH-85)/10] * [(87-T)/5]$$

T: air temperature (°F)

RH: relative humidity (%)

For days with a heat index below 80, Equation 2 was used.

Equation 2. Steadman heat index equation. Source: NWS

$$HI = 0.5 * \{T + 61.0 + [(T-68.0)*1.2] + (RH*0.094)\}$$

HI: Heat Index (°F)

T: air temperature (°F)

RH: relative humidity (%)

The projected number of days of extreme caution and dangerous Heat Index under the National Weather Service Heat Index categorization for 2055 and 2085 are shown below in Figure 3.8, Figure 3.9, Figure 3.10, and Figure 3.11. As the maps show, the northeast portion of the study area has more days over 103 °F Heat Index, showing that that region of the study area is more prone to the dangerous public health effects of extreme heat, especially when walking is a prevalent form of transportation.

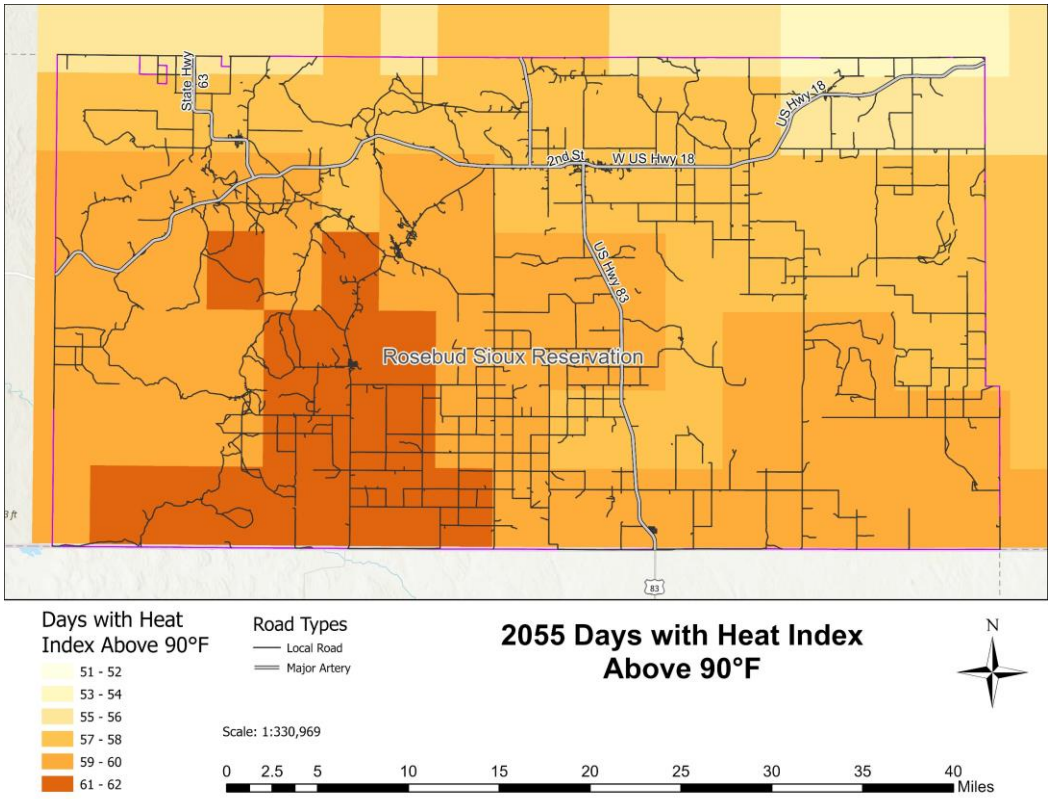


Figure 3.8: Days with Heat Index between 90° F and 103° F in 2055

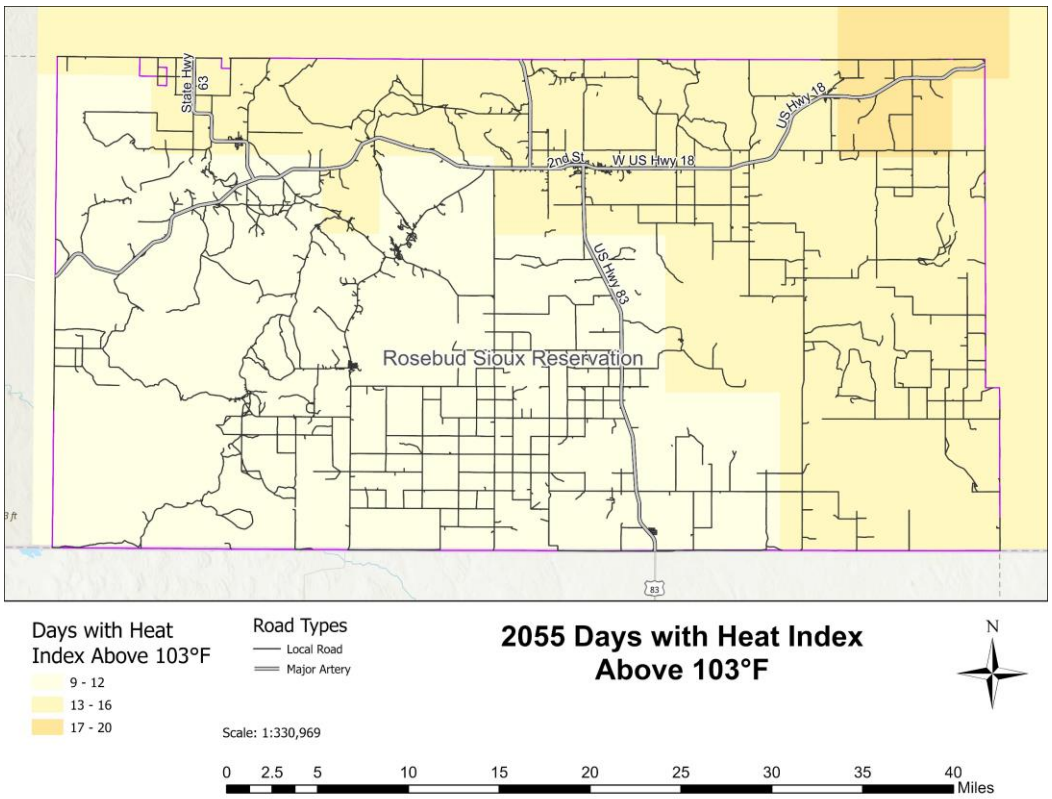


Figure 3.9: Days with Heat Index above 103° F in 2055

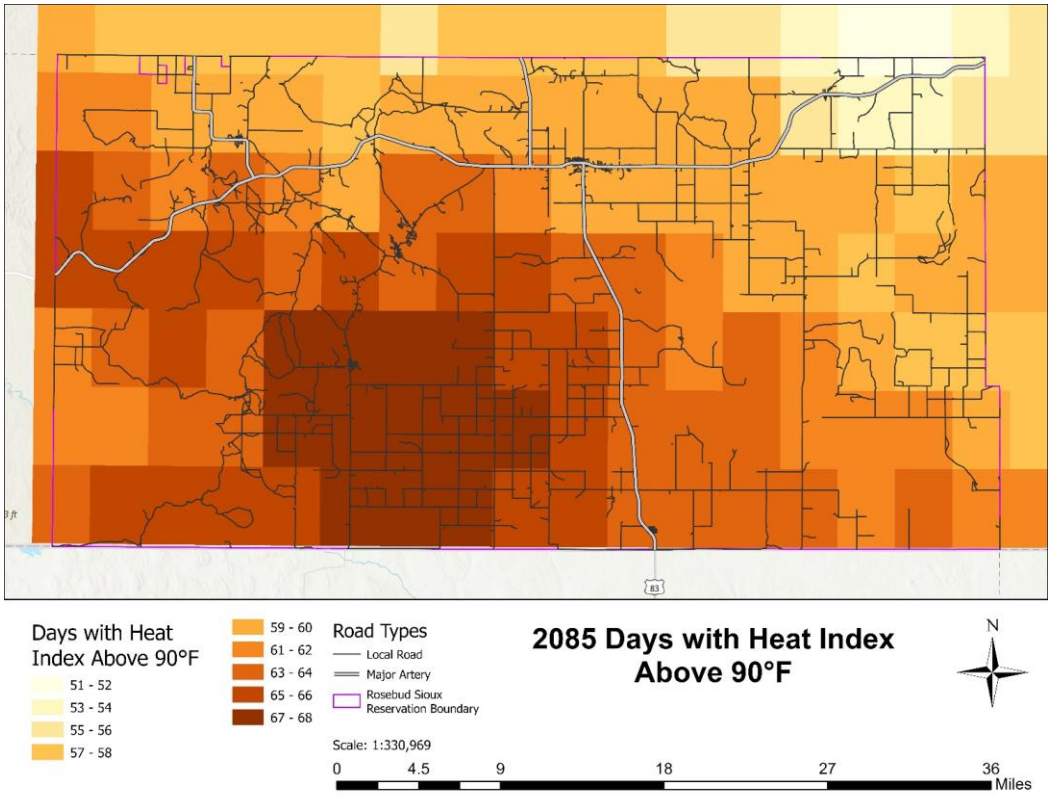


Figure 3.10: Days with Heat Index between 90° F and 103° F in 2085

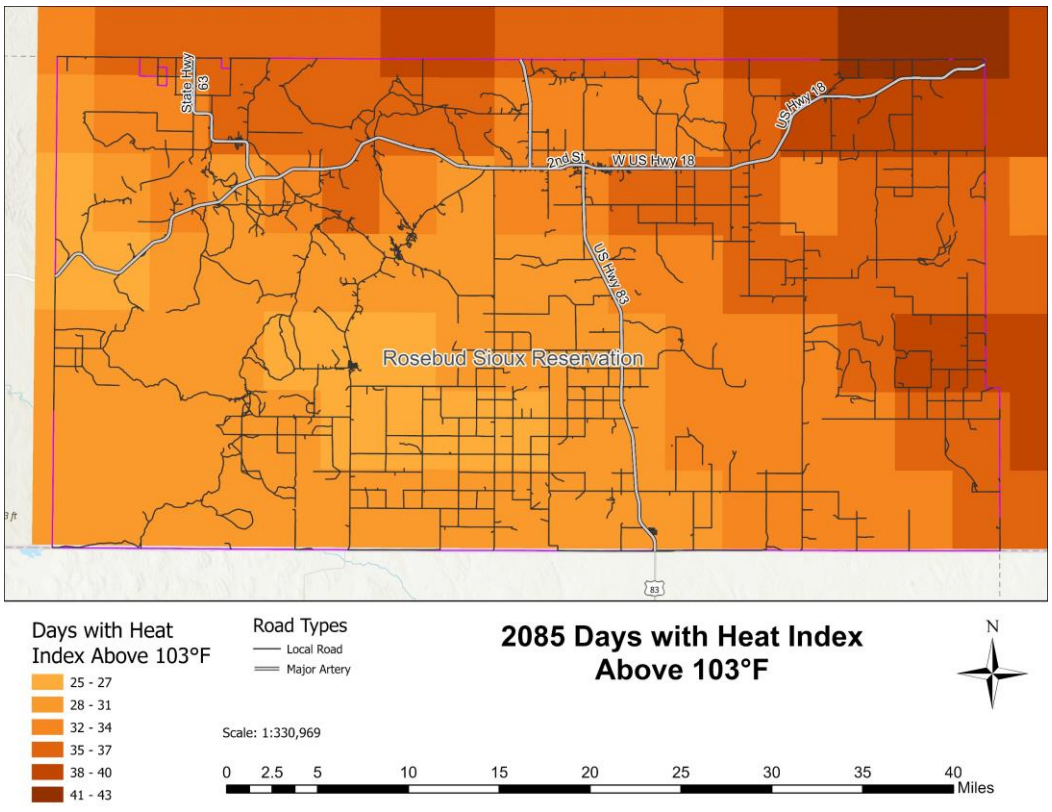


Figure 3.11: Days with Heat Index above 103° F in 2085

3.2.2 PRECIPITATION

Extreme precipitation events can cause localized flooding and damage to infrastructure. The intensity, duration, and frequency of extreme precipitation events are increasing as climate change progresses and is projected to continue doing so throughout the remainder of the century. Projected values are shown in Table 3.5 below. On average, the values slightly increase for each scenario and each return period. For example, the baseline for a 100-year event is 4.9 inches. This is projected to increase by approximately half an inch (10-14%) by the 2080s under both emissions scenarios. Compared to the historical baseline, a 2-year event is likely to increase by 9% from 2.3 inches to 2.5 inches for all scenarios and the 200-year event is expected to rise from 5.5 to between 6.1 (11%) and 6.2 (13%) inches for all scenarios. A precipitation-related area of concern for the Rosebud Sioux Tribe is the flood risk for the bridges, dams, and lakes within the tribal lands. During a site visit, images were collected of assets at risk of flooding, located in the Appendix. If the dams were to be overtopped or damaged, flooding could occur and cut off sections of the transportation network. A predicted increase in the intensity, duration, and frequency of extreme precipitation events will require increased maintenance for these assets as well as upgrades to undersized culverts and bridges, improvements to drainage infrastructure, and increased flood monitoring.

Table 3.5. Extreme precipitation annual exceedance probabilities for 24-hour precipitation events. Units: inches.

Baseline			2050s				2080s			
Units: inches	Historical	5-95th percentile	Medium Scenario (SSP2-4.5)	5-95th percentile	High Scenario (SSP5-8.5)	5-95th percentile	Medium Scenario (SSP2-4.5)	5-95th percentile	High Scenario (SSP5- 8.5)	5-95th percentile
2-year	**2.3**	*1.9-2.7*	**2.5**	*2.1-3.2*	**2.5**	*2.1-3.1*	**2.5**	*2.2-2.9*	**2.5**	*2.2-2.9*
5-year	**2.8**	*2.3-3.3*	**3.1**	*2.5-3.8*	**3.1**	*2.6-3.8*	**3.1**	*2.6-3.7*	**3.1**	*2.6-3.6*
10-year	**3.2**	*2.7-3.9*	**3.7**	*2.8-4.3*	**3.6**	*3.0-4.4*	**3.6**	*2.9-4.3*	**3.6**	*3.0-4.1*
25-year	**3.9**	*3.1-4.8*	**4.4**	*3.4-5.2*	**4.3**	*3.6-5.3*	**4.3**	*3.5-5.2*	**4.4**	*3.6-4.9*
50-year	**4.4**	*3.5-5.5*	**5.0**	*3.8-5.9*	**4.9**	*4.1-6.0*	**4.9**	*4.0-5.9*	**5.0**	*4.1-5.5*
100-year	**4.9**	*3.8-6.2*	**5.6**	*4.3-6.6*	**5.4**	*4.5-6.7*	**5.5**	*4.5-6.6*	**5.6**	*4.6-6.2*
200-year	**5.5**	*4.1-7.1*	**6.2**	*4.8-7.3*	**6.1**	*5.1-7.5*	**6.1**	*5.0-7.4*	**6.2**	*5.1-6.9*

Observed values for 24-hour precipitation return period estimates were gathered from the NOAA Atlas-14 dataset which contains gridded estimates based on weather station data along with upper and lower confidence limits. Daily precipitation projections were gathered from the recently released updated version of the LOCA dataset used in the temperature projections, LOCA2. This new dataset is based on the updated sixth generation of CMIP (CMIP6) and contains 23 models that provide data for scenarios similar to those used in the temperature analysis. Some biases that underestimated extreme precipitation values in the previous iteration of the LOCA dataset were corrected in LOCA2.[16]

For consistency within the analysis, we used Shared Socioeconomic Pathway (SSP) 2-4.5 and SSP5-8.5. SSP2-4.5.[17] The moderate scenario (SSP2-4.5) approximately correlates to RCP4.5 and assumes intermediate GHG emissions begin to fall around 2050 and reach net zero by 2100. SSP 5-8.5, the high scenario that approximately correlates to RCP 8.5, assumes very high GHG emissions that triple by the 2070s.

The climate projections were processed to produce 24-hour estimates for annual average exceedance probabilities for mid-century and end-of-century. As the climate data used in this analysis is based on predictive models, a delta change method was applied to the data to improve the accuracy of the projections. To produce these results, the difference between the modeled past and the modeled future was calculated as a percentage of change and multiplied by the observational dataset's values to obtain a future projection value. This delta correction was applied using the approach outlined in the report prepared by Kilgore et al. in 2019 for the FHWA.[18] Ratios were calculated for the 2-year, 5-year, and 10-year return periods. All return periods above the 10-year event (25-, 50-, 100-, and 200-year events) used the ratio calculated for the 10-year event due to the uncertainty inherent in extreme value projections with a low probability and the limited ability of high-resolution climate datasets to represent precipitation extremes.

The NOAA Atlas-14 observational data, while comprehensive and well-vetted, is outdated. Further analysis should be conducted based on updated current conditions of annual exceedance probabilities for heavy precipitation events.

The modeled precipitation is shown in three maps below: Figure 3.12: Baseline 100-year Storm Precipitation, Figure 3.13: 2055 100-year Storm Precipitation, and Figure 3.14: 2085 100-year Storm Precipitation. These maps show minor geographic variation in rainfall, with the Southeast corner of the study area experiencing more rain in the baseline and in future projections. Rainfall is expected to increase for the region overall.

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[16] Pierce, D.W., Cayan, D.R., Feldman, D.R., & Risser, M.D. (2023). Future Increases in North American Extreme Precipitation in CMIP6 downscaled with LOCA. *Journal of Hydrometeorology*. doi:10.1175/JHM-D-22-0194.1, in press.

[17] Shared Socioeconomic Pathway (SSP): projected socioeconomic scenarios that describe plausible major global developments that together would lead in the future to different challenges for mitigation and adaptation to climate change

[18] Kilgore, R. et al. (2019). *Applying Climate Change Information to Hydrologic and Coastal Design of Transportation Infrastructure*. NCHRP Project 15-61.

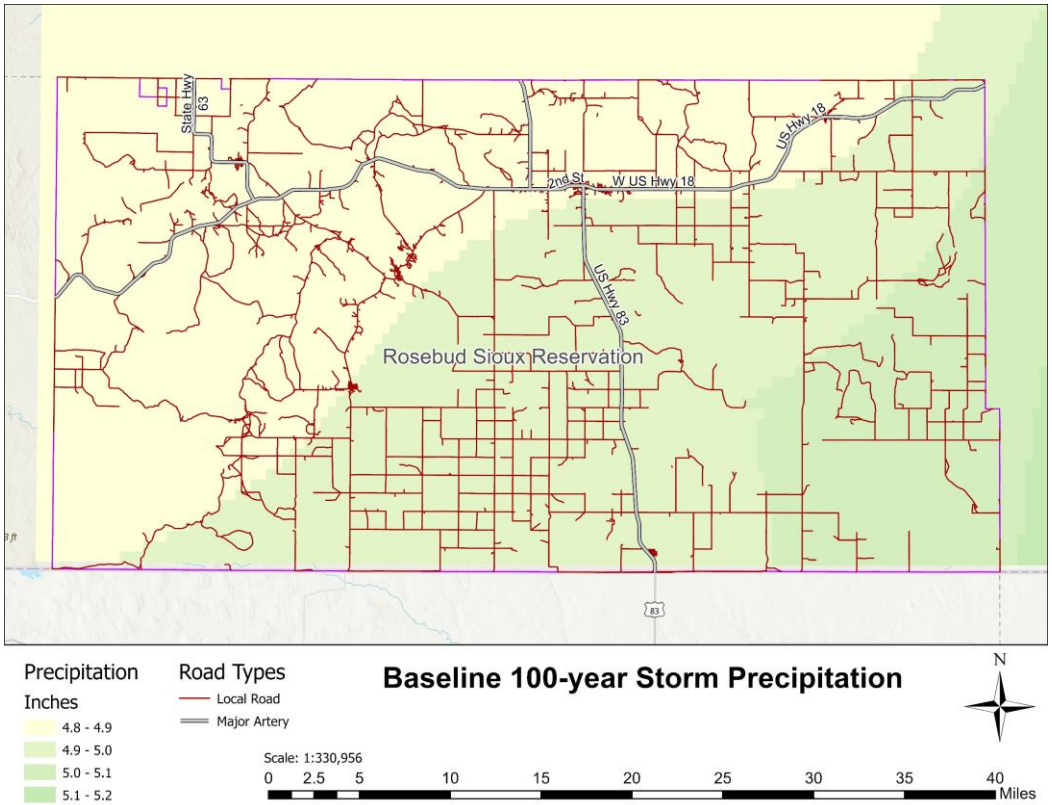


Figure 3.12: Baseline 100-year Storm Precipitation

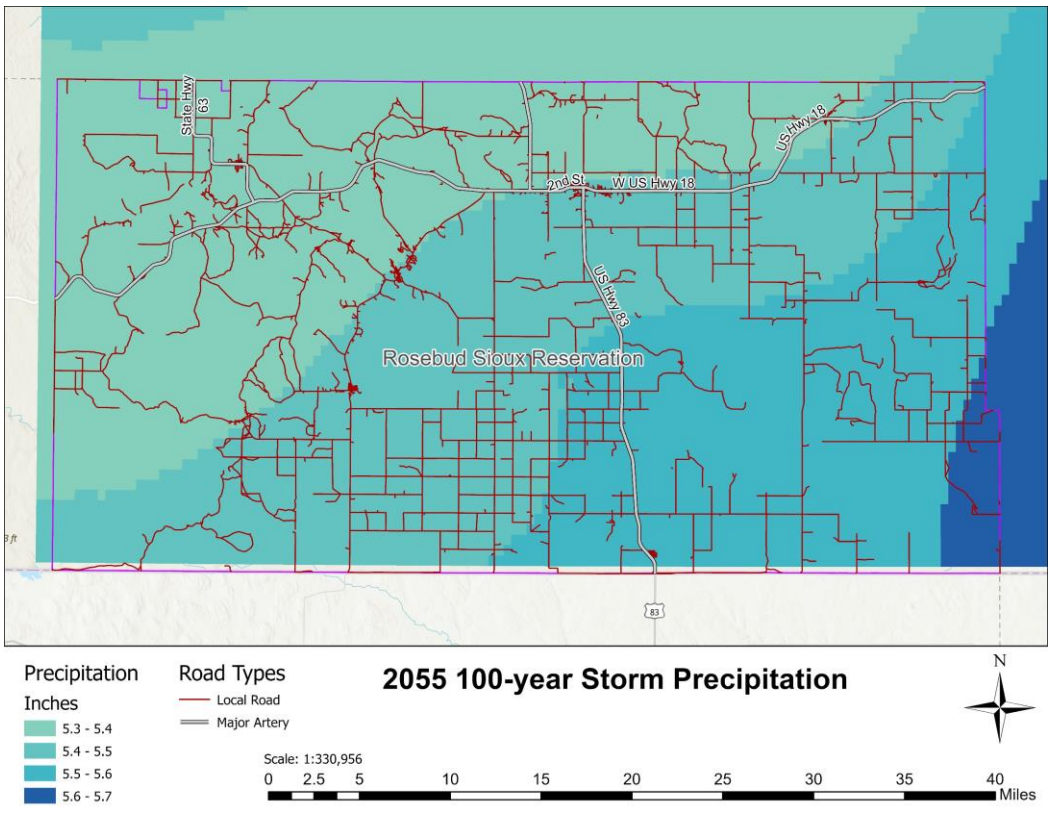


Figure 3.13: 2055 100-year Storm Precipitation

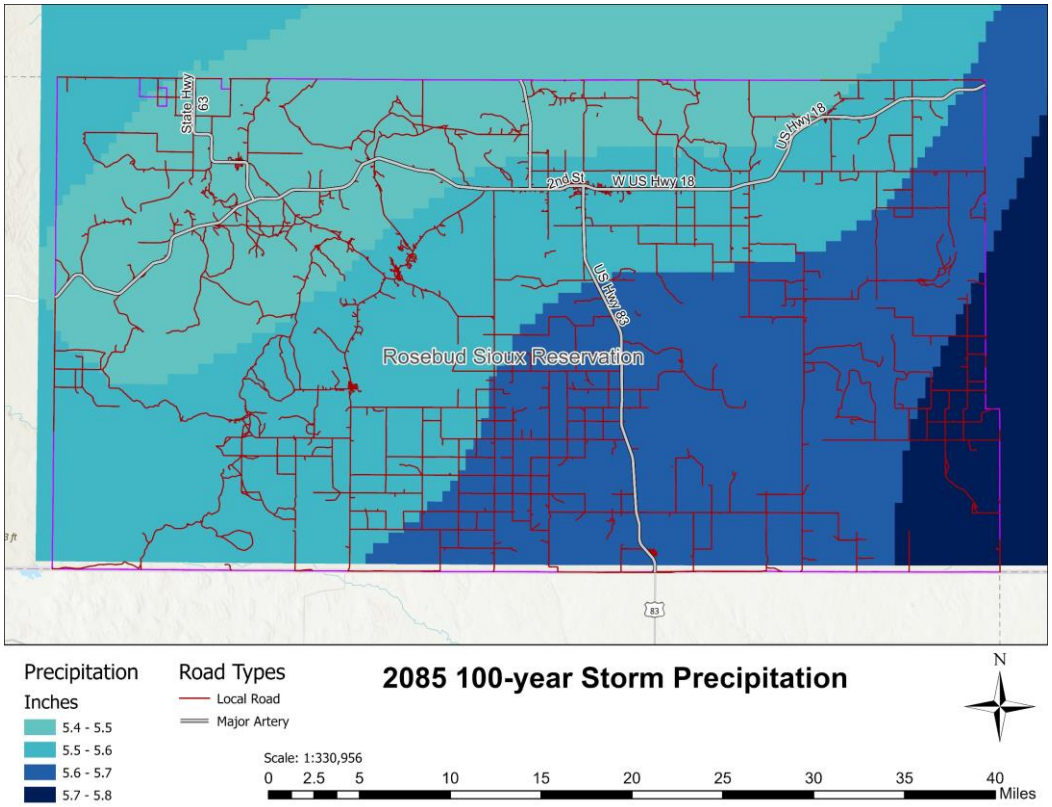


Figure 3.14: 2085 100-year Storm Precipitation

3.2.3 WILDFIRE

The FEMA National Risk Index provides an index for wildfire as a risk, and the study area has scores ranging from 97.1 to 99.3, combined with other risk components to yield a relatively moderate to relatively high expected annual loss, a very high social vulnerability, and a very low community resilience.[19] The scores for the surrounding regions are shown below in Figure 3.15. The Tribe experienced a large wildfire in June that burned over 12 square miles. Fortunately, the fire was contained before any structures were destroyed, but the fire did cause damage and threatened homes on the edge of the Grass Mountain community. Wildfires can have an immense impact on transportation infrastructure, disrupting road and pedestrian networks. Intense heat from fires can weaken asphalt, concrete, and bridge structures, leading to road closures and potentially hazardous conditions for drivers. Smoke and reduced visibility can impede navigation and cause public health concerns for pedestrians. Additionally, fires can damage power lines, disrupting traffic signals and public transportation systems. The aftermath of wildfires, such as landslides and debris flows, can further compromise transportation routes. Collaborative efforts between emergency services, transportation departments, and the local community are crucial to quickly assess and repair

[19] https://hazards.fema.gov/nri/map

the damage, restoring the vital transportation lifelines that communities rely on. A functioning transportation system is vital to effectively respond to wildfires.[20]

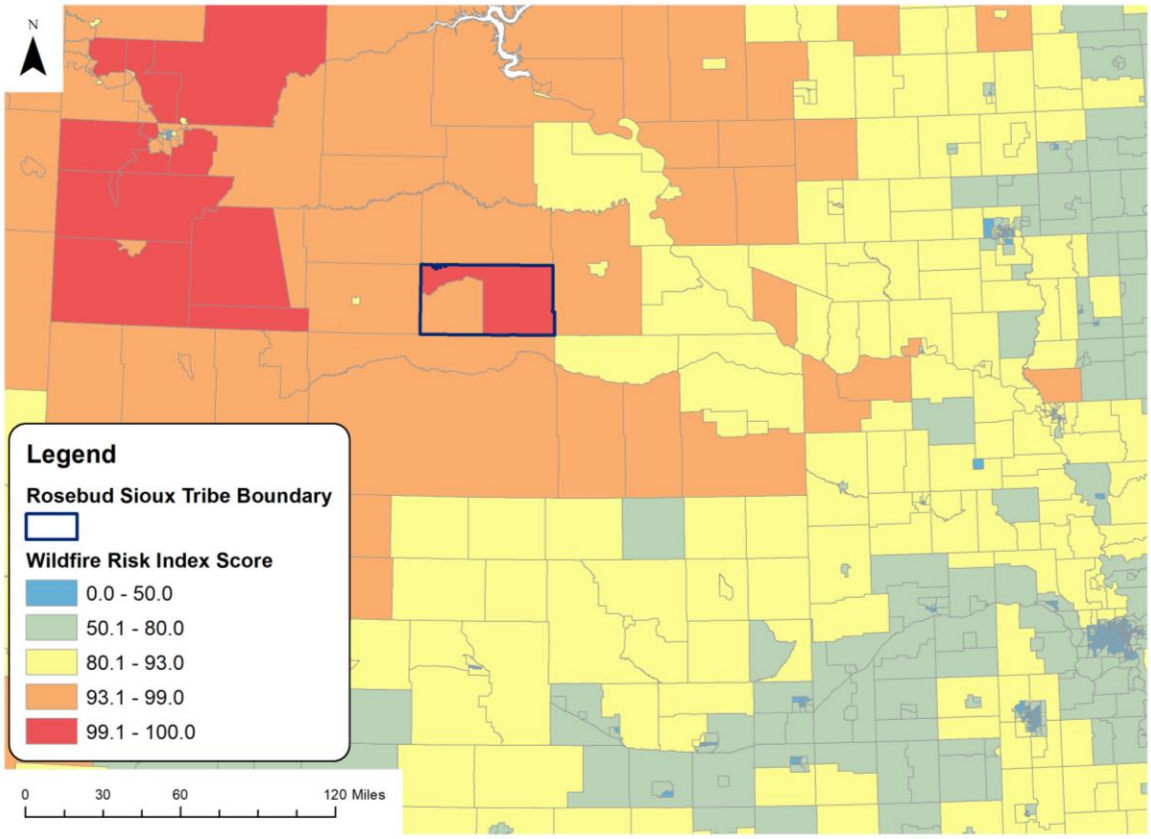


Figure 3.15: FEMA National Risk Index Wildfire Score Census Tracts

3.2.4 STORMS AND TORNADOES

Tornadoes, violently rotating columns of air that descend from a thunderstorm to the ground, pose a hazard in South Dakota. South Dakota lies on the outskirts of the area where tornadoes most commonly occur in the United States, often referred to as Tornado Alley. All tornadoes pose hazards to humans, but most infrastructure can withstand tornadoes between EF0 and EF2 on the Enhanced Fujita (EF) scale, which is used to rate tornado severity (see Figure 3.16). How climate change will affect the frequency, intensity, and development of tornadoes, derechos, thunderstorms, and winter weather events is uncertain as they occur over short time periods and over small areas of land, making it difficult to detect and predict trends. However, according to the Fourth National Climate Assessment (2018), thunderstorm-related weather hazards have increased more than any other type of extreme weather since 1980 in the United States, and there is some indication that conditions conducive to severe thunderstorms will likely

[20] Andrew M. Fraser, Mikhail V. Chester & B. Shane Underwood (2022) Wildfire risk, post-fire debris flows, and transportation infrastructure vulnerability, Sustainable and Resilient Infrastructure, 7:3, 188-200, DOI: 10.1080/23789689.2020.1737785

increase, likely within the Midwest and Southern Great Plains.[21] This is an active area of scientific research and is still being studied.

EF Rating	Wind Speeds	Expected Damage	
EF-0	65-85 mph	'Minor' damage: shingles blown off or parts of a roof peeled off, damage to gutters/siding, branches broken off trees, shallow rooted trees toppled.	 
EF-1	86-110 mph	'Moderate' damage: more significant roof damage, windows broken, exterior doors damaged or lost, mobile homes overturned or badly damaged.	 
EF-2	111-135 mph	'Considerable' damage: roofs torn off well constructed homes, homes shifted off their foundation, mobile homes completely destroyed, large trees snapped or uprooted, cars can be tossed.	 
EF-3	136-165 mph	'Severe' damage: entire stories of well constructed homes destroyed, significant damage done to large buildings, homes with weak foundations can be blown away, trees begin to lose their bark.	 
EF-4	166-200 mph	'Extreme' damage: Well constructed homes are leveled, cars are thrown significant distances, top story exterior walls of masonry buildings would likely collapse.	 
EF-5	> 200 mph	'Massive/incredible' damage: Well constructed homes are swept away, steel-reinforced concrete structures are critically damaged, high-rise buildings sustain severe structural damage, trees are usually completely debarked, stripped of branches and snapped.	 

Figure 3.16. Damage associated with each ranking of tornadoes on the Enhanced Fujita (EF) scale. Source: NOAA

Tracks of the tornadoes that have occurred in the area surrounding the reservation can be seen in Figure 3.17. The only EF5 tornado that has occurred in South Dakota (the strongest tornado possible on the EF scale) occurred just east of the reservation in 1965. This tornado, commonly known as the Tripp County Tornado, destroyed farms and property but did not result in any casualties and only caused one injury. Cumulatively, since 1950, there have been nearly 1900 tornadoes in South Dakota that have caused over $250 million in property damage, nearly 500 injuries, and approximately 20 fatalities.[22]

Storms and tornadoes can wreak havoc on transportation infrastructure, causing widespread disruptions and damage. Strong winds can down trees and power lines onto roads, making them impassable and hazardous. Flooding

[21] https://nca2018.globalchange.gov/chapter/2/

[22] Argus Leader. (2023). *A history of twisters: Tornadoes in South Dakota since 1950.* https://data.argusleader.com/tornado-archive/

from heavy rain can wash out roads and bridges, erode embankments, and weaken pavement, rendering transportation routes unsafe or completely unusable. Tornadoes, with their intense winds, can tear apart buildings and structures, including transportation facilities. Debris from storms and tornadoes can scatter across roads, requiring extensive cleanup efforts before normal traffic can resume. Repairing and rebuilding transportation infrastructure after these events often demands swift and coordinated action from transportation agencies and emergency services to ensure the safety and functionality of these crucial networks.[23]

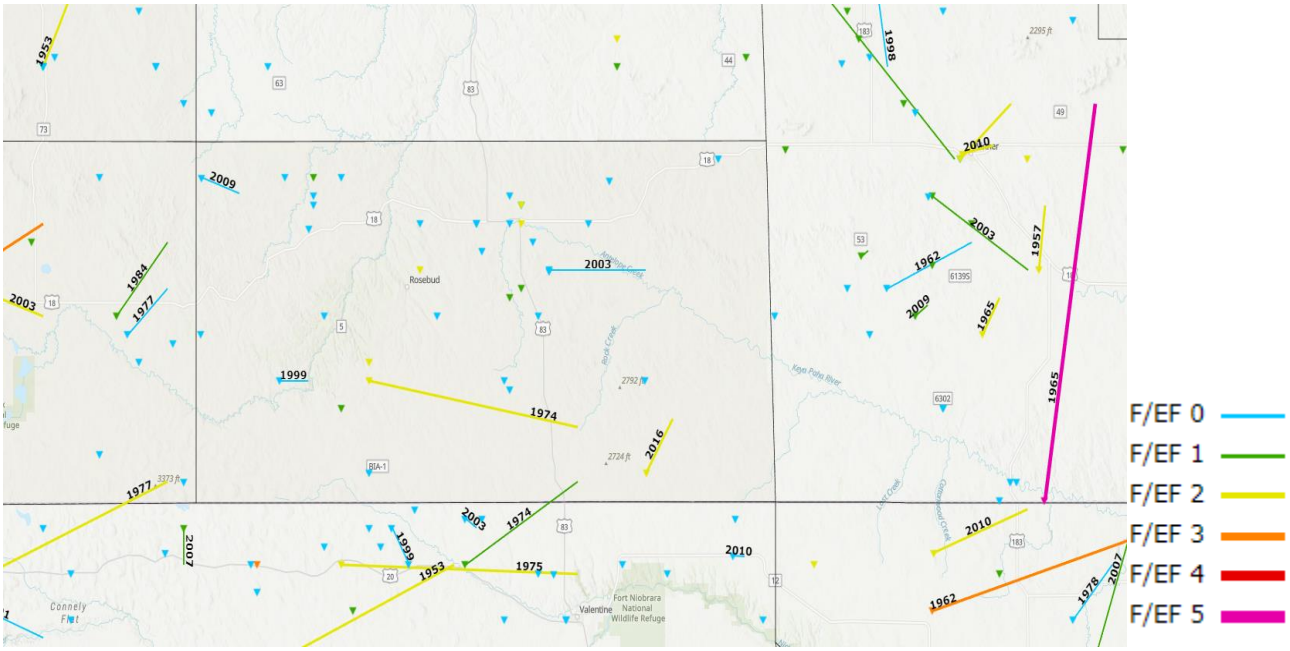


Figure 3.17. Tornadoes tracks surrounding the Rosebud Sioux reservation from 1950-2022. Source: Purdue Midwestern Regional Climate Center (MRCC) Tornado Tracks

3.3 VULNERABILITY ASSESSMENT

3.3.1 VULNERABILITY CATEGORIZATION OF ROAD ASSETS

Within the study area, the models show that freeze-thaw and precipitation are projected to impact the entire study area and the study area will be impacted with little spatial disparity. In this case, all transportation assets would be similarly affected by those impacts. Wildfire, storms, and tornadoes show a similar spatial scenario, where the entire transportation network will see similar risk. However, for extreme heat, there is a spatial disparity for which a categorization of risk applies. Because of these climate risks, the categorization of vulnerability will be determined

[23] https://public.wmo.int/en/bulletin/weather-and-climate-change-implications-surface-transportation-usa

by the heat index exposure and the type of roadway. This is especially relevant in the Rosebud Sioux Tribe, as many members of the Tribe walk as their primary mode of transportation. The National Weather Service's heat index provides classifications of risk that show how likely heat disorders are with prolonged exposure or strenuous activity. The categories are caution, extreme caution, danger, and extreme danger. For the road vulnerability classification, the assessment used days where the danger classification is reached, above 103°F heat index.

The second component of the vulnerability classification process was determining which roads on the roadway system should be evaluated. The 2022 US Census Bureau TIGER/Line road database was used as the roadway network. This road database classifies the roads by type: Local Neighborhood Road, Rural Road, City Street; Secondary Road; Private Road for service vehicles; Vehicular Trail; Alley; and Internal U.S. Census Bureau use. The count of total road classifications within the study area is summarized in Figure 3.18.

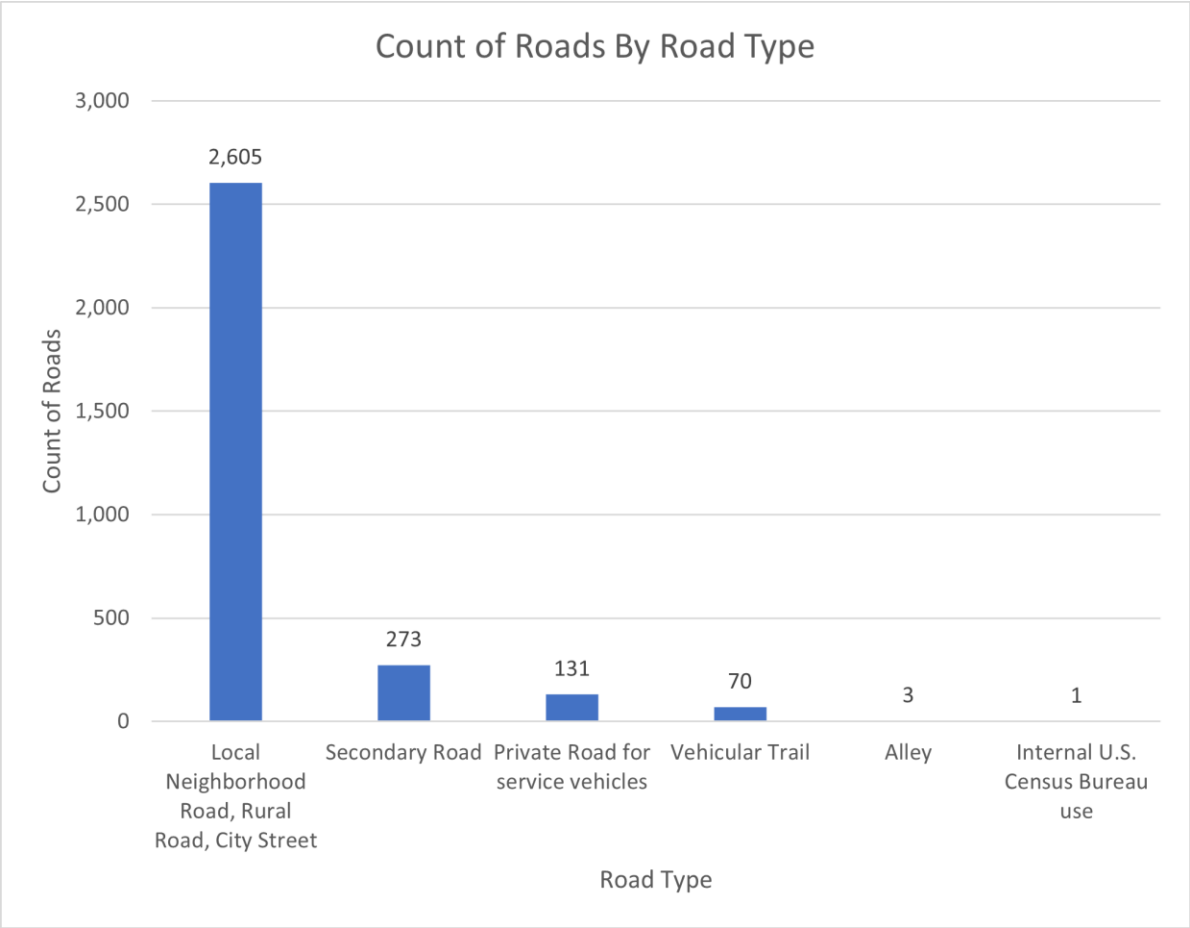


Figure 3.18: Counts of Road by Classification

That roadway network was overlaid with the heat index maps to find the roads that are exposed to a Heat Index over 103°F for both the 2055 and 2085 projections. The count of total roads exposed to extreme heat for those two years are summarized in Figure 3.19. To find which roads are most exposed, the mean days over 103°F was calculated, and roads that exceeded that value were considered most exposed. The mapped roadway network of most exposed roads is shown in Figure 3.20. The mapped exposure emphasizes major arterial roads and highlights the year in which the road would be exposed. The roads tend to be more exposed in the North and Northeastern parts of the reservation.

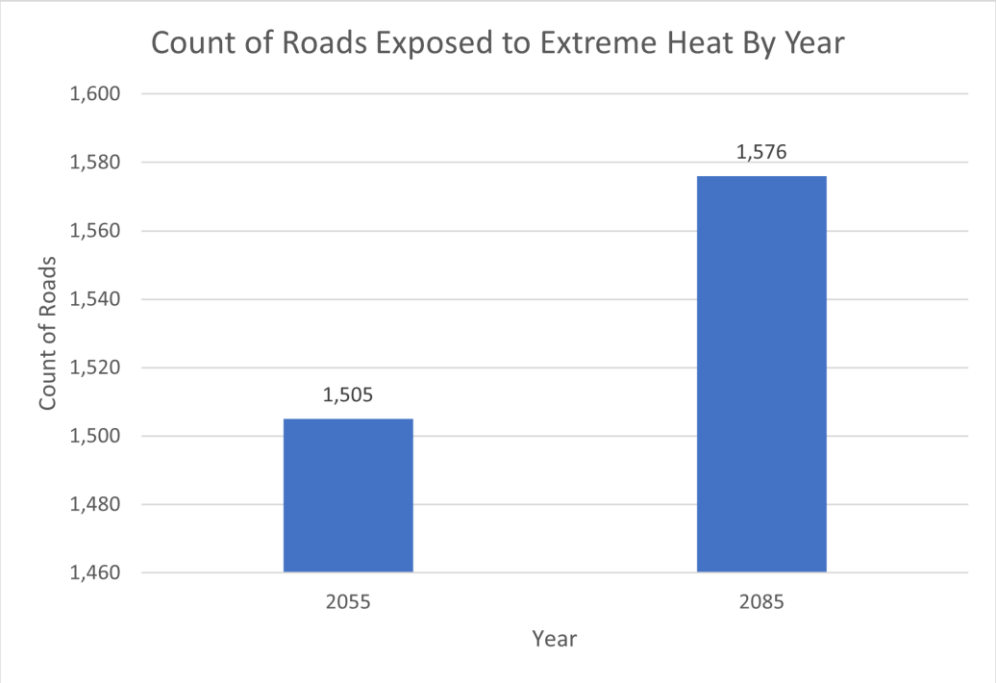


Figure 3.19: Count of Roads Exposed to Extreme Heat by Year

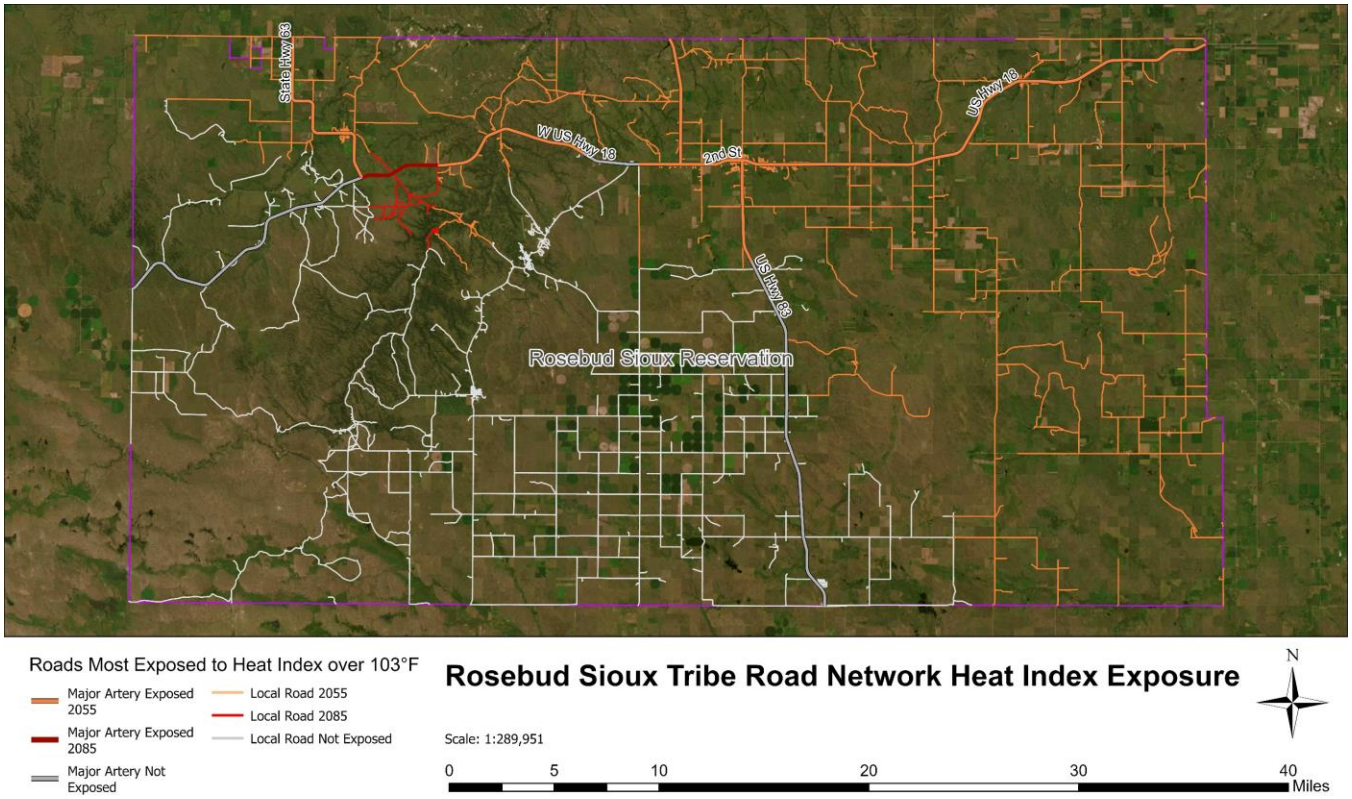


Figure 3.20: Road Heat Index Exposure Classification

3.4 RECOMMENDATIONS AND NEXT STEPS

Based on the results of this study and the identified limitations, below are compiled a set of recommendations and priorities to further strengthen decision-making processes for transportation infrastructure for the Rosebud Sioux Tribe:

- Based on updated information, climate data, and results of the prioritization done in the heat vulnerability analysis, it is recommended to identify interventions to conduct in the short- and medium-term to reduce the impact of climate-related events on transportation infrastructure and its functionality.
- Integrate climate change considerations in the design of improvements and new infrastructure. These include increased drainage capacities in areas with recurrent flooding problems and improved pedestrian safety like shade structures to withstand exposure to extreme temperatures.
- Integrate climate change considerations in preparation of future Transportation Plans (e.g., Long Range Transportation Plans).
- Develop a database to compile information on the impact of climate-related events in the road infrastructure including the event type, description of the impact in terms of damages to the infrastructure or infrastructure functionality loss (i.e., road closure) and duration, costs of infrastructure repair, and debris clean-up.
- Support pedestrian infrastructure that improves public health, such as shade structures and sidewalks.
- Maintain a list of at-risk assets and their priority for further study or improvements, as applicable.
- Detailed flood hazard modeling should be conducted to adequately define current and future risk and vulnerability that is asset- and area-specific.

4 GRANT OPPORTUNITIES

As climate change poses greater threats to Tribal governments, funding opportunities to increase community and infrastructure resilience is imperative in ensuring the safety and wellbeing of Tribes. Luckily there are increasingly more federal and state grant opportunities available for Tribes to prepare for climate change and improve their transportation networks. The following sections outline federal and state-specific funding opportunities which may help the Rosebud Sioux Tribe address climate change impacts. This is not a comprehensive list.

4.1 BUREAU OF INDIAN AFFAIRS

Tribal Climate Resilience Program: The Department of the Interior is investing about $43.2 million annually in funding Tribal communities to address the impacts of climate change. All federally recognized Tribes are eligible for these funds. The program is guaranteed through 2026. Funding is provided to support Tribal climate resilience planning and strategy implementation, and ocean and coastal management planning. **Categories of available funding** for climate adaptation planning and implementation include, but are not limited to, the following:

- Category 6: Capacity Building for Scoping Efforts ($65,000 maximum per award) – This category of funding supports staff time to conduct a needs assessment for the Tribe's response to climate change, especially for impacts to Tribal Treaty and Trust resources and economies. This could involve developing next steps for regional resilience efforts. Staff time could be used to develop a proposal for the next year of Category 2 funding.

- Category 2: Adaptation Planning ($250,000 maximum per award) – These awards fund vulnerability assessments, other data analysis, and climate adaptation plans. They cannot be used for existing projects.
- Category 3: Travel Support for Adaptation Planning ($15,000 maximum) – Awards funds for travel needed for adaptation planning project support.
- Category 10: Implementation of Climate Adaptation Strategies ($2,000,000 maximum) – Used to support "shovel-ready" adaptation activities which have a completed plan in place and are identified in Tribal planning documents (e.g., Climate Adaptation Plans, resource management plans, hazard mitigation plans).

(New) **Voluntary Community-Driven Relocation Program**: Announced in November 2022 and will assist Tribes that are severely affected by climate and environmental threats to relocate.

4.2 DEPARTMENT OF TRANSPORTATION

For more information on dedicated tribal programs and Tribe eligible competitive grant programs from US DOT, view: **Transportation Funding Opportunities for Tribal Nations**

Multimodal Project Discretionary Grant (MPDG): The MPDG is a consolidated federal grant opportunity that allows one application for funding for the following three programs.

- **Infrastructure for Rebuilding America (INFRA)**: A $7.25 billion program that awards grants for nationally or regionally important freight and highway projects that improve the safety, resiliency, economic benefits, efficiency, of freight/highway projects.
- **National Infrastructure Project Assistance (Mega)**: Mega program awards $1 billion annually and funds large and complex projects which will generate national or regional economic, mobility, or safety benefits and are difficult to receive funding from other sources.
- **Rural Surface Transportation Grant (Rural)**: The Rural grant awards $300-500 million annually to support projects that which improve and expand rural transportation infrastructure. The maximum award of the Rural grant is $25 million.

Promoting Resilient Operations for Transformative, Efficient, and Cost-Saving Transportation (PROTECT): A $1.4 billion program that supports resilience improvement projects, such as for developing plans, community resilience, identifying or improving evacuation routes, and protecting at-risk infrastructure. TTP funds can be used to meet matching requirements.

Charging and Fueling Infrastructure: A $2.5 billion program funded through 2026 that supports the deployment of publicly accessible electric vehicle charging and hydrogen, propane, and natural gas fueling infrastructure on alternative fuel corridors. Funds can also be used for operating assistance for first five years of infrastructure operations. TTP funds can be used to meet grant matching requirements.

Tribal Transportation Facility Bridge Program (TTFBP): The TTFBP has two sources of funding.

- **Bridge Formula Program (BFP)**: The purpose of the BFP awards $165 million annually to support replacement, rehabilitation, preservation, protection, and construction of Tribal transportation facility bridges.
- **Bridge Investment Program**: A $12.5 billion program funded through 2026 that funds the planning and improvement of National Bridge Inventory bridge conditions, safety, efficiency, and

reliability. Funding can also be used for culverts to improve flood control. There may be an opportunity to apply for Bridge Investment Program funds for bridge/culvert retrofits or replacements that incorporate considerations of future precipitation and river flows, to make tribal transportation assets more resilient. TTP funds can be used to match grant amounts.

Nationally Significant Federal Lands and Tribal Projects Program: The Federal Highway Administration within the Department of Transportation administers the Nationally Significant Federal Lands and Tribal Projects (NSFLTP) Program as part of the Fixing America's Surface Transportation Act (FAST Act)[30]. Applicable project types include those that "construct, reconstruct, or rehabilitate transportation facilities within, adjacent to, or providing access to, Federal and Tribal lands."[31] The NSFLTP Program funds construction projects of at least $25M value and requires a 10% cost match from non-USDOT sources. Eligible entities include those eligible under the Federal Lands Access Program, the Federal Lands Transportation Program, the Tribal Transportation Program, and the Federal Lands Planning Program, though the eligibility requirements note that a State, county or local government can only apply if sponsored by an eligible Federal land management agency or federally recognized Tribe.

FHWA Culvert Replacement Program: "The National Culvert Removal, Replacement, and Restoration Grant Program (Culvert Aquatic Organism Passage (AOP) Program) is an annual competitive grant program that awards grants to eligible entities for projects for the replacement, removal, and repair of culverts or weirs that meaningfully improve or restore fish passage for anadromous fish." Tribes are eligible applicants. While the focus of the program is on fish passage, funds could potentially be used to support stormwater projects that increase the capacity of drainage infrastructure.

FHWA Tribal Technical Assistance Program: "Provides transportation training and technical assistance to tribal communities, building skills and expertise to ensure the safety and maintenance of Tribal roads." Tribal Technical Assistance Program Centers will help Tribal communities secure funds from the $3 billion put aside for the Tribal Transportation Program by the Bipartisan Infrastructure Law.

Rebuilding American Infrastructure with Sustainability and Equity (RAISE): A $1.5 billion grant to help State projects and local level projects for municipalities, Tribes, and counties as well as other critical passenger and freight transportation infrastructure projects. 50% of the RAISE grants will be allocated to rural projects and the rest will be awarded to urban projects. The minimum grant award for rural and urban projects are $1 million and $5 million, respectively.

Federal Lands Access Program (FLAP): This program is designed to improve transportation facilities that are located within/adjacent to Federal Lands or provide access to them. On average, FLAP awards $297 million annually. Applicants should coordination with and confirm support from a Federal Land Management Agency (FLMA) such as the National Park Service (NPS), U.S. Fish and Wildlife Service (FWS), and U.S. Forest Service (USFS).

FHWA Federal-aid Funding Programs:

- **Federal-aid Essentials for Local Public Agencies**: Helping local public agencies access local programs, resources, and assistance.
- **Highway Safety Improvement Program (HSIP)**: The HSIP program is a Federal-aid program to reduce traffic fatalities and injuries on public roads, including roads on tribal lands and those that are not State-owned.

- **Transportation Alternatives (TA) Program**: The purpose of the TA program is to support strengthening the intermodal transportation system by expanding travel choice, improving local economies, and quality of life while protecting the environment.

4.3 FEDERAL EMERGENCY MANAGEMENT AGENCY

Building Resilient Infrastructure and Communities (BRIC): Discretionary grants for infrastructure projects, planning and design, and technical assistance to improve pre-disaster community resilience and reduce disaster suffering, mitigate loss of life, and decrease disaster costs. Replaces FEMA's Pre-Disaster Mitigation Grant Program. An additional $1 billion will go to the program through the Bipartisan Infrastructure Law.

Flood Mitigation Assistance: Provides $3.5 billion. Funding can be used for projects that reduce or eliminate the risk of repetitive flood damage to buildings insured by the National Flood Insurance Program.

5 APPENDIX

The following figures show the locations identified by the tribe as potential areas at-risk of climate impacts. They are mapped below and followed by images of the locations. These locations include dams, lakes, rivers, and bridges.

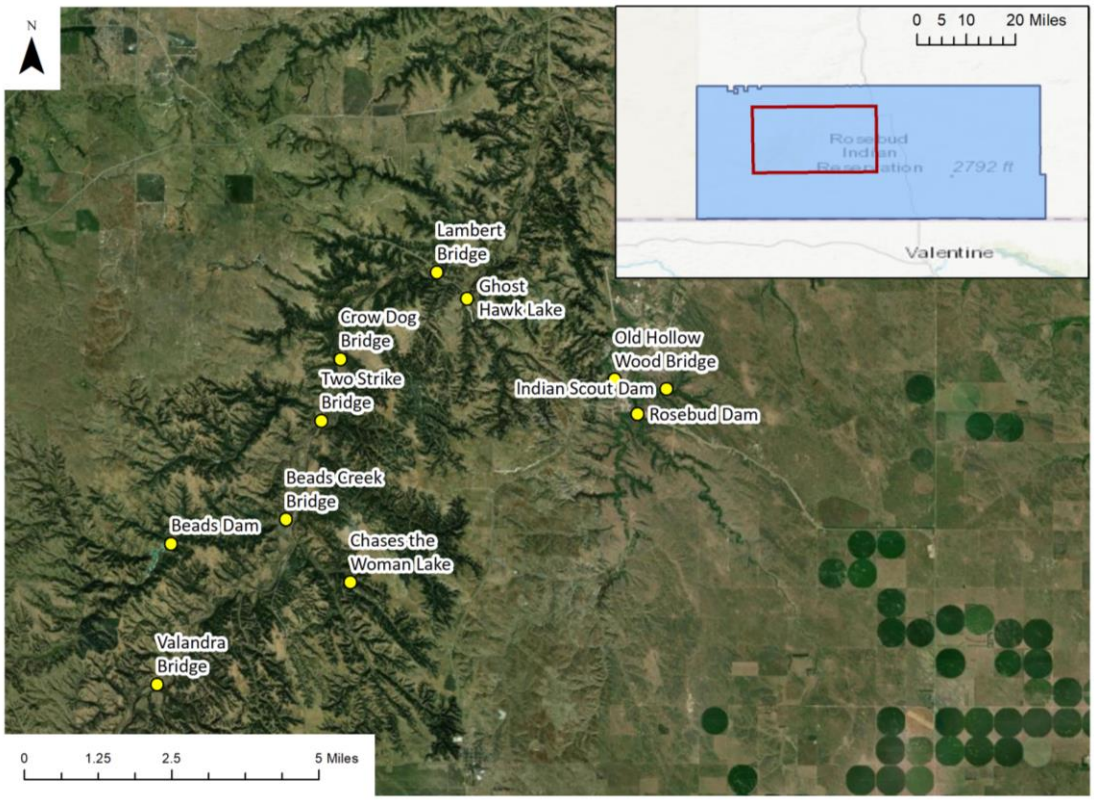


Figure 5.1: Locations of visited areas of potential climate risk



Figure 5.2: Beads Creek Bridge



Figure 5.3: Beads Lake



Figure 5.4: Chases the Woman Lake



Figure 5.5: Ghost Hawk Dam



Figure 5.6: Old Hollow Wood Bridge



Figure 5.7: Indian Scout Dam



Figure 5.8: Little White River



Figure 5.9: Rosebud Dam