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Los Alamos
NATIONAL LABORATORY

August 2022

2022 Climate Change Vulnerability Assessment and Resilience Plan

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Cover photo: Los Alamos welcome sign with the 2011 Las Conchas wildfire burning in the background.

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Executive Summary

Los Alamos National Laboratory (LANL or the Laboratory) produced this Vulnerability Assessment and Resilience Plan (VARP) following current U.S. Department of Energy (DOE) Guidance to assess and manage climate change–related risks to the Laboratory's assets and operations.

The VARP was led by the Pollution Prevention (P2) Program in the Environmental Protection and Compliance Division (EPC-DO) and covers the entirety of the 36-square-mile LANL site in Los Alamos, New Mexico. A Steering Committee, composed of representatives from the three main Laboratory Directorates and the National Nuclear Security Administration-Los Alamos Field Office (NA-LA), identified real property critical assets based on their Mission Dependency Index (MDI) scores. LANL used MDI scores of 70 and above, which are considered Mission Critical, to generate a list of 141 critical asset facilities.

Climate-related hazards were determined through a combination of a review of historical records, including LANL-specific sources, and a review of the literature. The Risk Assessment Tool, developed by DOE, was used to score hazard vulnerabilities for each critical asset. Those hazards projected to have high impacts to two or more critical assets were characterized as High Impact Hazards. Five High Impact Hazards were identified for LANL:

- increased frequency and intensity of extreme heat events;
- increased frequency, intensity, and duration of extreme precipitation events;
- thunderstorms (combined precipitation, wind, and lightning);
- increased flooding and erosion events; and
- increased wildfire frequency.

Using the calculations provided in the Risk Assessment Tool, LANL created a VARP Risk Matrix to help visualize the vulnerabilities of critical assets against climate change hazards. Using the 141 critical assets and 10 climate change hazards, the Risk Assessment Tool produced 1,410 individual VARP Risk Scores for LANL. The full Risk Matrix was too large to appear in the body of the report; it is included as Appendix E. LANL also developed a secondary Summary Risk Matrix showing average risk by asset type versus by individual critical asset. The Summary Risk Matrix is shown on the next page. Many of the risk scores appear in red—the High Risk category—both in the Summary and the full risk matrices. This result is likely a function of the algorithms that were part of the Risk Assessment Tool. The LANL VARP Planning Team generally agreed that this result did not mean that the Laboratory was in great danger from the hazards related to climate change; rather, these high scores indicated which hazards warranted the greatest degree of mitigation and which critical assets needed the most protection.

Four of the identified hazards received a risk score of "None" across all critical assets, indicating that they were either not vulnerable to the hazard or—in the case of drought—the impacts were secondary and were captured elsewhere. The hazard that presented the greatest risk across all critical assets was wildfire.

VARP Risk Score and Color Key	
High	>7
Medium	3.5–7
Low	<3.5
No	Zero Calculated Risk

LANL VARP Risk Matrix Summary Showing LANL's Average VARP Risk Scores* across Asset Types and Climate Change Hazards

		Hazards					
Asset Type	Count	Increased Heat Wave Events	Increased Precipitation Events	Increased Thunder-storms	Increased Flooding Events	Increased Wildfire Frequency	Increased Severe Wind Events
Specialized or mission-critical equipment	48	8.5	8.8	8.4	7.7	8.4	7.8
Energy Generation and Distribution Systems	30	7.5	7.5	7.5	7.5	7.8	5.7
Onsite Waste Processing	18	8.6	8.0	7.8	7.6	8.1	6.9
Site Buildings	25	7.2	8.2	7.8	7.4	7.7	7.2
Water and Wastewater Systems	18	6.4	7.9	7.9	6.8	7.6	6.8
IT and Telecommunication Systems	2	7.2	7.2	4.7	6.7	7.7	4.7

*Average VARP Risk Scores = Log$_{10}$ (Average Risk) + 3.5. Zero Calculated Risk is not shown.
IT = Information Technology

The team solicited ideas for Resilience Solutions from personnel across the Laboratory. A total of 48 projects were proposed for consideration. Each solution was evaluated against

- the hazard(s) that it addressed,
- its expected effectiveness,
- feasibility,
- cost and funding type, and
- the timeline for the proposed project.

The VARP team recommended 19 Resilience Solution projects for inclusion and tracking in the DOE Sustainability Dashboard.

(b) (5), nearly half of which currently has an identified funding source. The final portfolio of recommended Resilience Solutions addresses vulnerability mitigations for all asset types and climate change hazards with a VARP Risk Score of Medium or High. The final Portfolio of Resilience Solutions is included as Appendix F of this report.

Director's Foreword

VARP: Defending LANL's Mission and Operations from Climate Change

There is strong scientific consensus that anthropogenic activity is driving climate change and disrupting the Earth's natural cycles. Increasing frequency and severity of extreme weather events and shifts in long established weather patterns poses an existential threat to our communities, our nation, and our planet.

As individuals, as a Laboratory, and as a country, we all have a role to play in identifying and implementing ways to not only minimize the damage caused by climate change but also to become more resilient to potential disruptions.

In April 2022, I called on Laboratory employees to suggest ways to respond to this problem. Experts from across the site proposed ideas for delivering technical breakthroughs, advancing the frontiers of climate research, anticipating national security risks, and shoring up our operations. From their input, we developed the Laboratory's first Vulnerability Assessment and Resilience Plan (VARP). This strategic document focuses on understanding the relationship between critical assets—from equipment to our workforce itself—and their vulnerabilities to climate-related hazards. In short, the VARP leverages the Laboratory's broad expertise to evaluate climate change hazards and propose actions that may lead us into a better future.

This plan is only one of Los Alamos National Laboratory's many efforts to address climate change. By identifying a range of resilience solutions, the VARP will help our Laboratory protect our mission and our operations from the effects of climate change well into the future.

Thomas Mason

Thom Mason serves as the Director of Los Alamos National Laboratory

1 Introduction

President Joseph R. Biden issued Executive Order (EO) 14008, *Tackling the Climate Crisis at Home and Abroad*, in February 2021. The EO emphasizes that the federal government should lead by example and directs federal agencies to develop plans to increase the resilience of their facilities and operations in preparing for the impacts of climate change.

In response to this EO, the U.S. Department of Energy (DOE) published the Climate Adaptation and Resilience Plan (CARP), outlining “Priority Actions” for all DOE sites. Following issuance of the CARP, DOE published the Vulnerability Assessment and Resilience Plan (VARP) guidance document that describes the process for how sites should complete the vulnerability assessment and create a resilience plan.

The VARP for Los Alamos National Laboratory (LANL or the Laboratory) has been developed using a variety of resources, including the DOE Sustainability Performance Division Guidance (Version 1.2), the DOE Risk Assessment Tool, and the Submission Template. This VARP is tailored specifically to LANL and builds upon numerous related studies, initiatives, and programs undertaken at LANL and beyond.

1.1 Site Description and Overview

LANL is a multidisciplinary research institution engaged in strategic science on behalf of national security. Laboratory personnel apply scientific and technical expertise to solve complex nuclear security and energy challenges.

Triad National Security, LLC (Triad), operates the Laboratory under a Management and Operations (M&O) Prime Contract, administered by the National Nuclear Security Administration (NNSA), a semi-autonomous agency within the DOE, responsible for enhancing national security through the military application of nuclear science. Triad is a national security science organization comprising three members: Battelle Memorial Institute, the Texas A&M University System, and the University of California.

The Laboratory was established in 1943 as a secret location for the purpose of designing and building an atomic bomb during World War II. Almost all Laboratory infrastructure was built over a very short time to accommodate the scientists and many support staff at the site. It was expected to be a temporary settlement and not the permanent community it is today.

LANL is located in the arid, high desert of New Mexico on the Pajarito Plateau, which is part of the Jemez Mountains—the southernmost extension of the Rocky Mountains (Figure 1-1 and Figure 1-2). The Pajarito Plateau was formed by volcanic eruptions 1.2 to 1.6 million years ago. Built on a series of mesas separated by deep canyons, the Laboratory covers 36 square miles (the “site”) and spans elevations from 6,200 to 7,800 feet above mean sea level. The topography that provided the isolation and inaccessibility originally desired for a top-secret facility also encompasses diverse ecosystems that are challenged by both natural and human activities, as well as hazards related to climate change.

1 Introduction

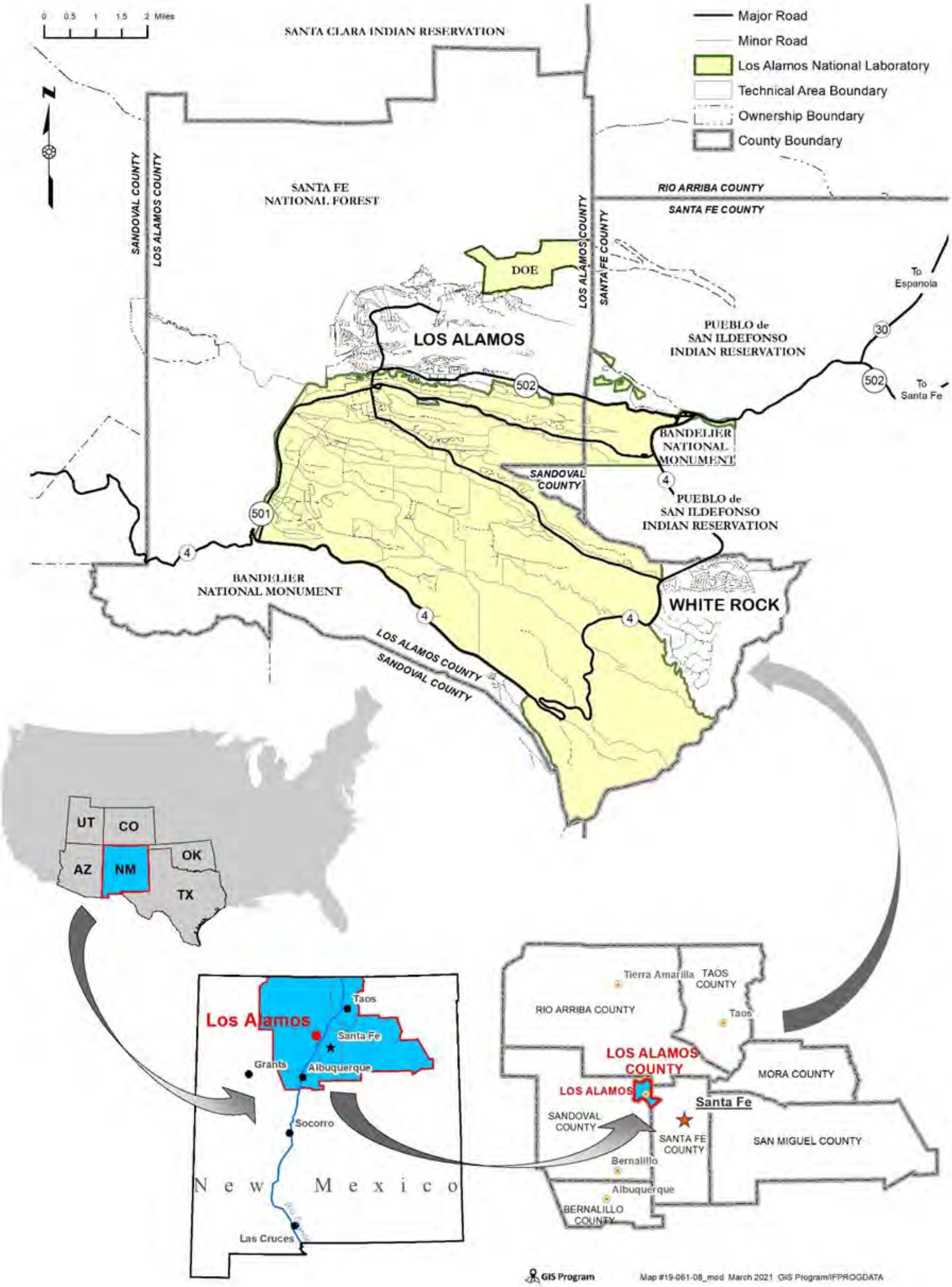

Figure 1-1. Location of Los Alamos National Laboratory within the United States

Figure 1-2. Aerial View of Laboratory Property

Today the Laboratory directly employs approximately 18,000 people and is still growing. The site contains more than 900 individual facilities, with 8.4 million gross square feet of building and $37.6 billion in replacement plant value. A sizable portion of the portfolio is nearing end of life. The average age of facilities is 44 years. More than 26 percent of the portfolio is 61 years or older, and 61 percent is more than 50 years old (Figure 1-3). The age and deteriorating condition of many of the facilities contribute to their vulnerability, including to climate hazards (Figure 1-4).

LANL's 2021 Campus Master Plan (CMP) projects approximately 2,400,000 gross square feet of new construction in the next 10 years, coupled with more than 1 million square feet in demolition of obsolete or excess facilities.

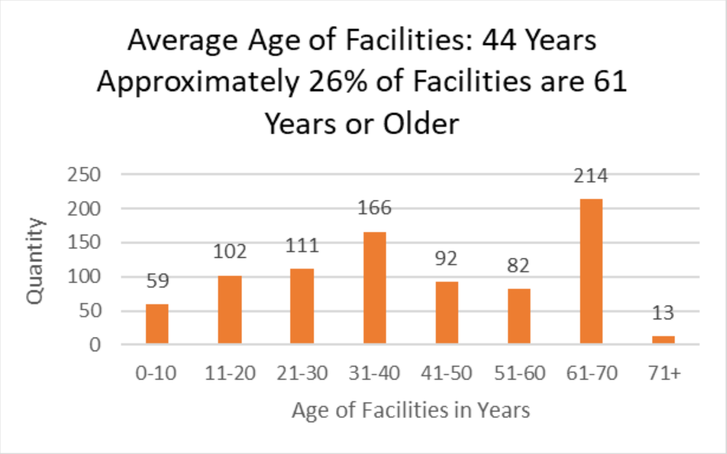

Figure 1-3. Age of Laboratory Facilities

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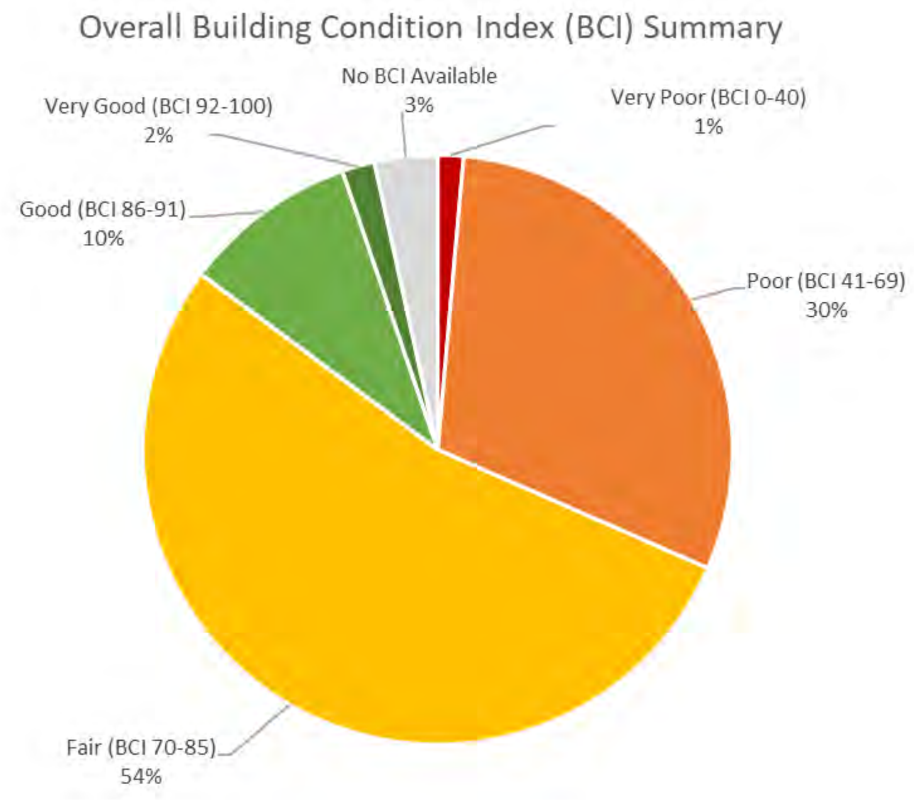

Figure 1-4. Building Condition Index

1.2 Scope and Approach

The VARP process (Figure 1-5) consists of two parts: the Vulnerability Assessment (Steps 2 through 6) and the Resilience Planning (Steps 7 and 8). The Vulnerability Assessment includes identification of mission-critical assets, identification of climate change hazards likely to impact the site (such as wildfire, drought, and wind), and creation of a risk matrix showing the relationships between critical assets and hazards, thereby exposing vulnerabilities. The Resilience Planning portion includes identifying and assessing potential resilience solutions and recommending mitigation strategies to address previously identified vulnerabilities.

LANL facilities, infrastructure, and personnel are located throughout the 36-square-mile site, as well as within more than 28 leased, offsite facilities. For the purposes of the VARP, only onsite locations are considered. Two remote sites are excluded from consideration under the VARP. Technical Area (TA)-57, Fenton Hill, is a small, remote research site located approximately 35 miles west of LANL on property owned by the U.S. Forest Service. Rendija Canyon, an 830-acre site located in Los Alamos townsite and used primarily for passive recreation, is scheduled to be transferred to Los Alamos County in 2023 and contains no LANL facilities.

The size of the LANL site and variations in elevation, ecosystems, and distribution of population, functions, and capabilities all present challenges to its assessment regarding different climate hazards; however, the site is considered as a whole in the VARP due to its cohesive missions, integrated operations, interrelated capabilities, and unified workforce.

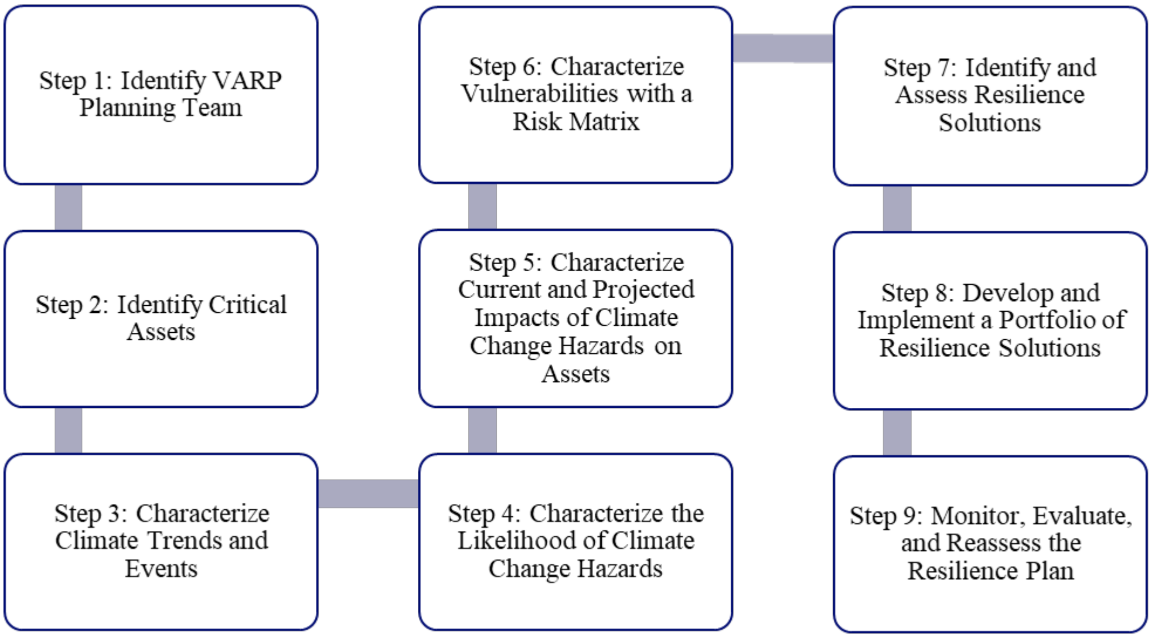

Figure 1-5. Process Flow Chart of the VARP from DOE Guidance

1.3 VARP Planning Team

The VARP represents a site-wide effort. The VARP Planning Team comprised a Steering Committee, advisors to the Steering Committee, and stakeholders from all Associate Laboratory Directorates (ALDs). The Steering Committee also included representatives from the three main Directorates at the Laboratory: Weapons; Operations; and Science, Technology, and Engineering (STE). Advisors provided information about topics that affected multiple groups and certain site-wide concerns. Stakeholders provided information about the vulnerabilities of specific facilities within their domains and helped define the individual facilities in the list of critical assets. The team was led by the Pollution Prevention (P2) Program in the Environmental Protection and Compliance Division (EPC-DO) within the Laboratory's Operations Directorate. In addition to LANL personnel, the NNSA Los Alamos Field Office (NA-LA) served on the Steering Committee, and representatives from Los Alamos County served as advisors.

The VARP Planning Team was assembled from across the entire Laboratory, with staff who represented the collective knowledge needed to meet the unique goals of the VARP. The Steering Committee acted as the primary drivers and decision-makers for the project. Subject matter experts were recruited as advisors to provide guidance to the Steering Committee on specific topics. The stakeholders represented all other ALDs to ensure that the VARP captured respective vulnerabilities and solutions site-wide. Laboratory staff in each group represent the following organizations within LANL:

Steering Committee

- Pollution Prevention Program
- Sustainability Program
- Forest Health Program
- Campus Master Planning

- Annual Site Environmental Report (ASER)
- ALD for Facilities and Operations
- ALD for Plutonium Infrastructure
- Los Alamos Field Office, NA-LA

Advisors to the Steering Committee

- Environmental Management Systems Team
- Earth and Environmental Sciences
- Meteorology
- Research and Development
- Environmental Justice
- Tribal Relations
- Los Alamos County

Stakeholders (ALDs)

- Business Services
- Capital Projects
- Chemistry, Earth, and Life Sciences
- Environment, Safety, Health, Quality, Safeguards and Security
- Global Security
- Physical Sciences
- Plutonium Infrastructure
- Simulation and Computation
- Weapons Engineering
- Weapons Physics
- Weapons Production

The following plans and policies were reviewed and updated to provide a starting point and foundation for the VARP.

- In 2015, LANL released a case study titled "Climate Change and Los Alamos National Laboratory: The Adaptation Challenge." This case study discussed how LANL has adapted to respond and prepare for extreme events such as wildfires, severe droughts, flooding, and wind—all exacerbated by climate change.
- In 2016, the Laboratory completed a Conceptual Model of Climate Change Impacts at LANL, wherein LANL-specific asset and climate stressors were identified, impacts of climate stressors on each asset were outlined, and the likelihood and severity of each climate stressor against each asset were determined. This information gave a baseline for the VARP in identifying climate change hazards and the likelihood of their occurrence, although the VARP is much more detailed.
- In 2017, LANL completed a preliminary risk assessment that included a broad scope of Laboratory vulnerabilities earmarked for further assessment in the next iteration of climate change preparedness. This preliminary risk assessment considered the impacts of climate and weather stressors on critical assets and identified where knowledge gaps existed.

The next sections of this report provide additional detail on project approach, roles, and responsibilities.

2 Critical Assets

LANL critical assets are those facilities, systems, programs, and other resources required to maintain core mission activities and capabilities. Identification of critical assets was based on the Laboratory's mission, which consists of four main components:

- Nuclear Security
- Mission-Focused Science, Technology, and Engineering
- Mission Operations
- Community Relations

The Laboratory promotes integration of all four areas, and its overarching mission is "to solve national security challenges through simultaneous excellence."

2.1 MDI Critical Assets

The Mission Dependency Index (MDI) was employed to identify the relative criticality of real property assets regarding mission. Originally developed by Naval Facilities Engineering Systems Command and the United States Coast Guard Office of Civil Engineering, MDI is now used by numerous federal, military, and other organizations, including DOE and NNSA. MDI is a metric that assigns a score to each separate facility to indicate its criticality and importance to mission. MDI calculates a score of 1 to 100 for all real property assets—applicable primarily to buildings and transportainers—to determine the facility's impact on mission. The score is based on a combination of consequences to mission: the difficulty to replace the facility if it were lost and its interdependency to other facilities. Higher MDI scores indicate greater impact to mission.

In designating critical assets for the VARP, LANL used MDI scores of 70 and above to generate a list of 141 critical asset facilities. Real property assets scoring less than 30 were considered Not Mission Dependent; assets scoring 30–70 were considered Mission Dependent, Not Critical; and assets scoring above 70 were considered Mission Critical. (See Appendix A[1] for a complete list of MDI scores.)

In accordance with DOE's Risk Assessment Tool, critical assets receive a Criticality Score based on their MDI score:

- Assets with MDI score 70–79 are considered Low Criticality
- Assets with MDI score 80–89 are considered Moderate Criticality
- Assets with MDI score 90–100 are considered High Criticality

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[1] Appendix A lists all 141 critical asset facilities and their MDI scores. All were evaluated individually for two main reasons. First, due to the size of the LANL site—nearly 40 square miles—and combined with the wide range of topographic and related environmental conditions, facilities were subject to disparate conditions and varied hazards. Second, there were many large and/or unique facilities, each of which represented its own potential risks. Where facilities could be categorized by type or functionality—such as office, light laboratory, or a combination office and lab—they were assembled into those groups for the purposes of the VARP.

2 Critical Assets

Due to the substantial number of LANL assets that scored 70 and above in the MDI, it was necessary to further categorize and sort the 141 critical assets into more manageable groups for the VARP. DOE's Risk Assessment Tool lists 11 asset types used to categorize all critical assets:

- Site Buildings
- Specialized or Mission-Critical Equipment
- Onsite Waste Disposal Facility
- Energy Generation and Distribution Systems
- IT and Telecommunication Systems
- Water and Wastewater Systems
- Transportation and Fleet Infrastructure
- Supply Chains for Critical Materials
- Site Workforce
- Site Ecology and Land Preservation
- Other

Stakeholders for the VARP assigned one of the 11 asset types to each of the 141 critical assets. Table 2-1 shows examples for each Asset type as well as the number of critical assets and total square footage of each Asset type. Figure 2-1 shows the location and distribution of real property critical assets at LANL.

Asset types 1–6 were considered in the MDI as real property assets and are part of the Risk Assessment Tool. Asset type 7 was included in the MDI; however, none of the Type 7 assets scored high enough to be considered Mission Critical. Asset type 8 was not considered in the MDI, and a narrative that discusses its criticality is included later in this section. Asset types 9–11 are not considered in the MDI and are therefore assessed separately as non-MDI critical assets.

VARP Stakeholders reviewed the list and recommended adding multiple facilities that were important but did not score higher than 70 in the MDI. These facilities and their MDI scores are highlighted in Appendix B but are not officially listed as critical assets; however, the VARP team included them in an informal risk assessment to ensure that they did not present high risk potential. Such assets—and others not ranking above 70 in the MDI—will be considered in subsequent VARPs. Similarly, secondary utilities, including transformers, electrical cables, poles, towers, natural gas piping, distribution transformers, and transmission lines, are not included but may be considered in future VARPs.

Table 2-1. Critical Site Assets and Infrastructure System Types

(b) (7)(E), (b) (7)(F)

(b) (7)(E), (b) (7)(F)

[redacted]

*See Acronyms and Abbreviations in Section 10.

(b) (7)(E), (b) (7)(F)

[redacted]

Figure 2-1. Location and distribution of real property critical assets at LANL

2.2 Non-MDI Critical Assets

A subcommittee of the Steering Committee considered critical assets other than the real property assets identified in the MDI. These assets were defined as tangible or intangible assets that, if impacted by climate change, would directly or indirectly negatively impact LANL's mission today or in the future, local communities, or the preservation of cultural or ecological resources for future generation.

Table 2-2 lists the non-MDI-rated critical assets considered in the VARP:

Table 2-2. Non-MDI Critical Assets

(b) (7)(E), (b) (7)(F) [redacted]

The non-real property critical assets identified in the VARP are critical to the Laboratory’s ability to fulfill its mission. These non-MDI critical assets fall under three main categories and are further sorted as shown in Table 2-2. Appendix C provides descriptions of the assets and what is known about their vulnerability to climate change hazards. A summary of recommendations from subject matter experts regarding mitigation or the need for further investigation of climate change impacts is also included in Appendix C.

The VARP also recognizes the potential for supply chain disruptions because of climate change hazards—especially the possibility of impacts to transportation, which can disrupt delivery of mission-critical supplies. (b) (7)(E), (b) (7)(F) [redacted] (b) (7)(E), (b) (7)(F) [redacted] (b) (7)(E), (b) (7)(F) [redacted]. Climate hazards could also disrupt LANL’s ability to deliver materials, including pits and radioisotopes to NNSA, other federal agencies, and private industry. Alternative procurement and delivery strategies will be addressed in future VARPs.

3 Historical Hazard Events and Impacts

In the last 22 years, LANL has experienced several extreme weather events, including wildfires, extreme precipitation, extreme temperatures, and damaging windstorms. Mandatory evacuations of the Los Alamos townsite and the Laboratory were implemented during the Cerro Grande wildfire for 2 weeks and the Las Conchas wildfire for 10 days. Due to the historic and unprecedented severity of the two fires, the VARP includes extreme weather events dating to the earlier of the two fires in 2000. These events have impacted the Laboratory in lost productivity, facility and environmental damages, and repair costs. A summary of the events and their financial impact on the Laboratory are included in Table 3-1. These extreme events are expected to increase in both intensity and frequency in the future due to climate change; therefore, it is essential that the costs of these events are recorded and the data used to anticipate future costs to LANL.

Table 3-1. Summary of Historical Extreme Events

Event Type and Date(s)	Description of Event	Financial Impact (estimated $ and/or work hours)
Cerro Grande Wildfire May 2000	• 7,500 acres of LANL property burned • 14-day shutdown of Lab • 45 Lab buildings lost, 67 damaged, and 237 faced impacted operational readiness	• $331 million in damages to the Lab • 11 working days in lost productivity
Record Cold Event February 2011	• 2 weeks of extreme cold temperatures • Frozen pipes, infrastructure, and equipment caused work stoppages and damaged facilities	• Significant costs in damages to the Lab • Several working days in lost productivity and cleanup
Las Conchas Megafire June 2011	• 1 acre of operational LANL property burned • 9-day shutdown of Lab	• $15.7 million in damages to the Lab • 9 working days in lost productivity
1,000 Year Rain Event September 2013	• 450% of average rainfall, leading to ground saturation • 130 sites experienced damages	• $17.4 million in damages to the Lab
Above Average Snowfall December 2018–January 2019	• 30–36 inches of snowfall • 2-day closure of Lab • Total precipitation 175% above average for December and January	• $290 thousand for snow cleanup • 5,000 labor hours for snow cleanup efforts • 2 working days in lost productivity
Bomb Cyclone March 2019	• High winds with gusts up to 63.3 mph • More than 3,000 trees uprooted across the Lab • Extensive damage to facilities and security fencing, power outages, and road closures	• $250 thousand for tree cleanup efforts • $70.6 thousand for security fencing replacements
High Wind Event December 2021	• High winds with gusts up to 80 mph • 300 trees uprooted across the Lab • Fallen trees damaged facilities and power lines	• $25 thousand for tree cleanup efforts

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Event Type and Date(s)	Description of Event	Financial Impact (estimated $ and/or work hours)
Cerro Pelado Wildfire April–June 2022	• Fire started on Earth Day 4/22 • Shifted to maximum telework 5/9 (“set” phase) • Returned to “ready” phase 5/17 • Fire fully contained on 6/15	• TBD

3.1 Cerro Grande Wildfire – May 2000

This wildfire began as a controlled burn on May 4, 2000, originally intended to remove fuel from 900 acres to prevent fires in the Bandelier National Forest and support ecosystem restoration. Due to high winds and dry conditions, this controlled burn developed into the largest and most destructive wildfire in New Mexico’s history at the time. Figure 3-1 shows the Cerro Grande wildfire as seen from space. The communities of Los Alamos and White Rock were evacuated, and the Laboratory was shut down May 8–22. The fire burned more than 43,000 acres, including 7,500 acres of LANL property. Community members lost their homes, and the Laboratory suffered damage to facilities. A total of 45 Laboratory buildings were lost in the fire, with another 67 Laboratory structures damaged. These buildings were mainly trailers and small storage sheds but included many of the historic Manhattan Project buildings. The fire also impacted the operational readiness of 237 facilities. The Cerro Grande fire is one of the most expensive wildfires in New Mexico history to date (Segarra 2022) with more than $1 billion in total damages. The Laboratory alone suffered $331 million in damages to facilities and property. Additionally, due to evacuations and Laboratory closure, there were 11 full working days in lost productivity.

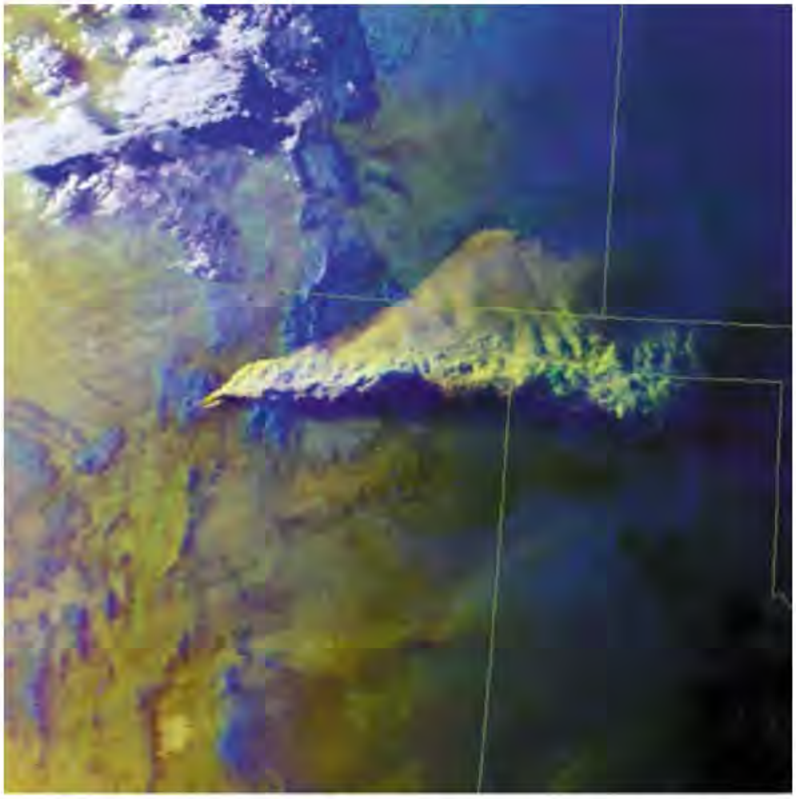


Figure 3-1. Cerro Grande Wildfire as seen from space, May 2000

The Cerro Grande wildfire demonstrated the extreme danger and damage of wildfires in proximity to the Laboratory. This event resulted in changes to some of the protocols for wildfire prevention and management. The controlled burn was started at the beginning of fire season while the region was experiencing a persistent drought. Additional steps taken to improve resiliency against wildfires include the identification and management of critical areas to maintain lower fuel levels of about 50 to 150 trees per acre, protection of cultural resources with fire mitigation methods, and improvements in communication between federal, state, and local agencies for better coordination in fire inspection programs (Fowler et al. 2015).

3.2 Record Cold – February 2011

On February 1, 2011, extreme cold weather moved into New Mexico when a jet stream dipped lower than normal, bringing Arctic (Fleck 2011) air to more temperate areas of North America. Extreme low temperatures lasted nearly 2 weeks, with multiple days of subzero temperatures. This weather impacted much of New Mexico and parts of Texas (Hardiman 2011). The main Los Alamos Meteorological Tower registered its lowest temperature on record, −16°F, on February 3. The cold temperatures caused electricity and natural gas demand to increase, and gas production in multiple states, including in northern New Mexico, experienced shutdowns. Fortunately, Laboratory gas supplies remained intact; however, LANL experienced extensive failed or damaged infrastructure and equipment, including burst water pipes, causing work stoppages. Some server rooms overheated when the cooling system, designed to stop operation at temperatures below zero, shut down. Other servers were manually shut down to reduce power load on the system.

The extreme cold event resulted in significant monetary costs to the Laboratory, including hours in lost productivity due to work stoppages and repair. Specific values are not quantified because this event occurred more than 10 years ago and did not have the same severe financial, physical, cultural, and historical impacts as the Cerro Grande and Las Conchas wildfires. However, “recent Polar Vortex events across the U.S. followed this same weather pattern and indicate an ongoing vulnerability” (Fowler et al. 2015).

3.3 Las Conchas Megafire – June 2011

The Las Conchas wildfire was started on June 26, 2011, in the Santa Fe National Forest, when a tree fell on a power pole. Intense winds grew the fire to 61,000 acres in the first day. The National Park Service reported that this fire burned nearly an acre per second in the first 13 hours (The Las Conchas Fire). The Los Alamos townsite and the Laboratory were closed and evacuated on June 27. The fire burned a total of 154,000 acres. Las Conchas was also the first megafire in New Mexico, defined by the U.S. Interagency Fire Center as a wildfire that burns more than 100,000 acres of land (Megafire). To date, it is the third largest wildfire in New Mexico history. Figure 3-2 shows a National Aeronautics and Space Administration (NASA) image of the Las Conchas wildfire from space. The fire greatly impacted the ecosystem by destroying vegetation and creating a waxy semi-impermeable layer over the soil. These impacts contributed to an increased risk of flooding, which occurred in the region in August, following the fire. One acre of operational Laboratory land was burned. Although no buildings were damaged in the fire, the Laboratory incurred $15.7 million in damages and 9 full working days of lost productivity. Fortunately, resilience solutions developed and implemented after the Cerro Grande wildfire in 2000 prevented even greater damage. To prepare the area for flash floods, the Laboratory installed barriers to divert water to holding areas, sealed wells, moved waste drums, and established sampling stations to test runoff water. These mitigation methods were proven successful in reducing damage from precipitation events that followed the Las Conchas Megafire (Fowler et al. 2015).

Figure 3-2. A NASA picture of Las Conchas Megafire, June 2011

3.4 1,000-Year Rain Event – September 2013

During September 10–18, 2013, Los Alamos experienced a 1,000-year precipitation event, recording a total rainfall of 7.67 inches during these dates (Bruggeman and Dewart 2016). “The heaviest precipitation during the event occurred on 13 September measuring 3.52 inches at TA-06, which broke the record for highest daily precipitation from 5 October 1911 that recorded 3.48 inches” (Bruggeman and Dewart 2016). Some local mountain locations recorded 18 inches of rain in the same 24 hours. This event was 434 percent of the average monthly rainfall and led to ground saturation and flooding. Despite the flood mitigation efforts put in place following the Las Conchas wildfire, 130 Laboratory sites were damaged. Additionally, “the floods created 1,000 meters of channels and eroded the stream banks of the Pueblo Canyon wetland, which is an important contaminated sediment stabilization system on the LANL site” (Fowler et al. 2015). The possible contamination of runoff in canyons required re-sampling in those locations. “The resulting 1000-year rain event caused $17.4 million in damage to environmental restoration infrastructure, monitoring gages, roadways and storm water control structures on LANL property alone” (Fowler et al. 2015).

3.5 Above-Average Snow Event – December 2018 & January 2019

zat the end of December 2018. LANL was closed from December 25 through January 1 for the usual winter closure, but the closure was extended to allow for cleanup from the snowstorm. Cleanup efforts comprised more than 5,000 labor hours and required the Laboratory to be closed for an additional 2 full days. The total of precipitation and snowfall was approximately 171 percent above average for December and January. The cost for snow cleanup was $290,000 and 2 working days in lost productivity.

3.6 Bomb Cyclone – March 2019

This high-wind event, named “Winter Storm Ulmer,” occurred on March 13, 2019. Lab meteorologist David Alan Bruggeman said the storm developed so quickly and with such intensity that it was referred to as a bomb cyclone. A bomb cyclone is defined as “a storm that drops 24 millibars (mb) of pressure at its center in 24 hours” (Wind, Snow, Trees, Closure). Although snow did accompany the storm, the quantity of precipitation was not abnormal; however, the high winds limited visibility and “caused snow drifts of up to 6 feet in some areas” (Wind, Snow, Trees, Closure). The storm produced high winds, with gusts up to 63.3 mph, which is tied for the fourth highest wind gust measured by the TA-06 tower since its installation in 1990. These high winds, combined with soft soil from snowmelt, caused more than 3,000 trees to be uprooted across the Laboratory and surrounding areas (Wind, Snow, Trees, Closure). The falling trees caused extensive damage to facilities and security fencing, power outages, and road closures. Labor and tree cleanup processes cost the Laboratory $250,000, and fencing replacements cost another $70,600. Additionally, LANL lost productivity due to power outages and damages to facilities, although the total lost labor hours were not recorded. Figure 3-3 shows the heavy snow outside of the National Security Sciences Building (NSSB) during Winter Storm Ulmer.

Figure 3-3. Winter Storm Ulmer, “Bomb Cyclone,” March 2019

3.7 High Wind Event – December 2021

On December 15, 2021, Los Alamos and surrounding areas experienced a blizzard. This storm presented 40 mph sustained winds and gusts up to 80 mph—the second highest wind gusts ever recorded in Los Alamos (An Inside Look at the Dec. 15 Weather Event). These high winds resulted in a total of 300 trees uprooted across the Laboratory, damaging facilities and power lines. Due to the timing of the storm, the Laboratory could not close for the day, but employees were encouraged to work from home if possible. Power outages occurred in “all facilities west of TA-03 and down N.M. Route 4 to TA-33” (Lab Recovery from Power Outage a Team Effort with County). Power was restored by noon the following day. “The power outage, which began around 7 a.m. . . . affected a couple thousand employees” (Lab Recovery from Power Outage a Team Effort with County). The storm caused nearby Taos County to declare a state of emergency due to damages from high winds that “blew off roofs, knocked mobile homes off their foundation, and left people without gas or power” (Gonzales and Giron 2021). “Power outages were reported in the Jemez Mountains and on the Navajo Nation for at least 10,000 homes” (Fjeld 2021). Tree cleanup cost the Laboratory $25,000, and an unknown number of hours were lost in productivity.

3.8 Cerro Pelado Wildfire – April–June 2022

During the writing of this report, on the annual Earth Day celebration, April 22, another wildfire began southwest of the Laboratory in the Jemez Mountains. While the cause of the fire continued to be investigated, the National Weather Service issued a red flag warning for most of New Mexico. This warning is issued when weather conditions, including high winds and low humidity, are considered ideal for wildfire ignition and spread. On the day this fire started, winds gusted up to 60 mph.

The Cerro Pelado wildfire was one of many fires during the 2022 wildfire season in New Mexico. The 2022 wildfire season saw 638,714 acres burned as of June 22, 2022. This burn area is significantly more than the average acreage burned during 1990–2021, which is recorded at 153,131 acres burned. Figure 3-4 shows a large plume of smoke from the Cerro Pelado wildfire behind the NSSB. Fortunately, the Laboratory had spent considerable time preparing for large wildfires since the Cerro Grande fire in 2000. Adaptive measures already in place were proven effective in 2022, when quick actions helped protect the Laboratory and surrounding communities from the Cerro Pelado fire. One adaptive measure was the creation of firebreaks, which are areas with limited vegetation and other flammable materials that help slow or stop the progression of fires. Some firebreaks, like rivers and canyons, occur naturally. LANL crews created firebreaks by reducing vegetation to prevent the rapid spread of fire. Powerline corridors typically have firebreaks to reduce fire risk in case of electrical equipment failure. Removing brush and dead vegetation is a year-round effort that the Laboratory uses to maintain appropriate vegetation levels in many areas. Crew members thin Laboratory forested or woodland areas manually or by using the four masticating machines that grind up biomasses into a mulch (Why the Lab was Prepared for Cerro Pelado). Adaptive measures first started following the Cerro Grande fire in 2000 and were further developed after the Las Conchas fire. The Laboratory’s Wildland Fire team has actively managed Laboratory property for many years, removing approximately 3,500 tons of forest fuels in the last 3.5 years (Behind the Scenes at Cerro Pelado 2022).

Figure 3-4. Smoke from the Cerro Pelado Wildfire, April 2022

The Cerro Pelado wildfire was fully contained on June 15, 2022, having burned a total of 45,605 acres. The Laboratory shifted to maximum telework on May 9, and no evacuations were ordered for the Laboratory or for the town of Los Alamos. Given the recent occurrence of this event, the financial impact of this wildfire on the Laboratory is currently unknown; however, it is predicted that this fire will have less of an impact than either the Las Conchas or Cerro Grande wildfires because the Cerro Pelado wildfire did not directly impact Laboratory property.

4 Climate Change Projections for Hazards Affecting the Site

Several sources informed Step 4 - Identifying Climate Change Hazards. Review of recent historical hazard events, as discussed in Step 3, served as a baseline for developing insight into climate change hazard trends and projections. The next step was to expand upon these events through a literature review of local climate patterns. The National Climate Assessment (NCA4), particularly the Climate Science Special Report (CSSR), was a valuable information source that supported the identification of individual hazards at the Laboratory. LANL-specific reports, as well as data from LANL weather stations, provided information on historical trends. Although the NCA4 and CSSR served as the primary source of confidence levels for future climate projections, tools such as the Climate Explorer, U.S. Climate Resilience Toolkit, and the National Oceanographic and Atmospheric Administration’s (NOAA’s) 2022 State Climate Summaries served heavily to evaluate the likelihood of the different climate change hazards. The last step in defining LANL-specific climate change hazards was to separate gradual long-term changes from changes in the frequency, intensity, and duration of extreme events because each scenario has the potential to impact assets in significantly different ways.

Using a combination of these tools, it was possible to develop assessments of the current frequency of each climate change hazard and to determine how future climate projections would impact that frequency. The resulting values were entered into LANL’s Risk Assessment Tool to calculate the current and projected hazard likelihood. Those hazards that represented continuous change rather than occurrence as single events and were already occurring were assigned the highest frequency likelihood.

See Appendix D for the full table of climate change hazards, including secondary and projected impacts.

The ten main climate change hazards pertaining to LANL are discussed in the following subsections.

4.1 Increased Average Temperature

One of the most significant measured hazards associated with climate change is an increase in average temperature. In addition to the direct effects of hotter temperatures, warmer winters and a lower winter snowpack can impact water availability and groundwater recharge. Faster snow melt also increases flood risk. Changing growing seasons have substantial implications for the biology and ecology of the region. Increased temperature has the potential to increase energy and water demands. Additionally, conducting work under higher temperatures has major implications for the outdoor workforce in terms of health, safety, and productivity (Parsons et al. 2021).

Climate Change–Driven Patterns to Date

Average annual temperature in New Mexico has risen more than 2°F since the start of the twentieth century (Kunkel 2022). Average annual temperature has risen historically and is projected to continue to rise (very high confidence) (Vose et al. 2017). In Los Alamos County, the annual average temperature has been above the 1901–1960 baseline since 1998 (NOAA Climate Explorer). The 5-year running average temperature at Los Alamos National Laboratory has increased since 1924 (Hansen et al. 2020). Figure 4-1 shows the average annual temperature for Los Alamos County from 1895 to 2021.

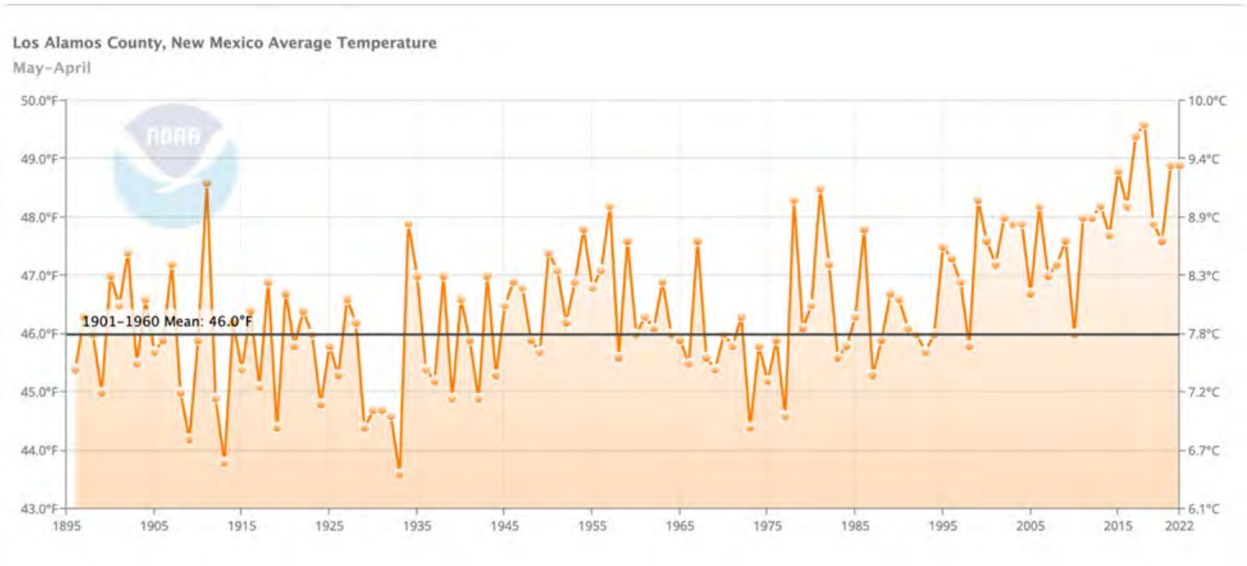


Figure 4-1. Average Annual Temperature for Los Alamos County 1895–2021 (NOAA Climate Explorer)

Projections

Based on both the historical record for the area and climate projections, long-term trends show an increasing average temperature for the area. Average daily maximum temperature for Los Alamos County is projected to increase an average of 12.5°F (60.5°F to 73°F) under RCP 8.5 and 7.0°F (60.5°F to 67.5°F) under Representative Concentration Pathway (RCP) 4.5 from the 1961–1990 baseline by the year 2100 (NOAA Climate Explorer). Daily minimum temperatures are projected to increase an average of 11.5°F (33.5°F to 45.0°F) under RCP 8.5 and 6.5°F (33.5°F to 40.0°F) under RCP 4.5 from the 1961–1990 observed average by 2100. (NOAA Climate Explorer). Increase in daily minimum temperature is shown in Figure 4-2.

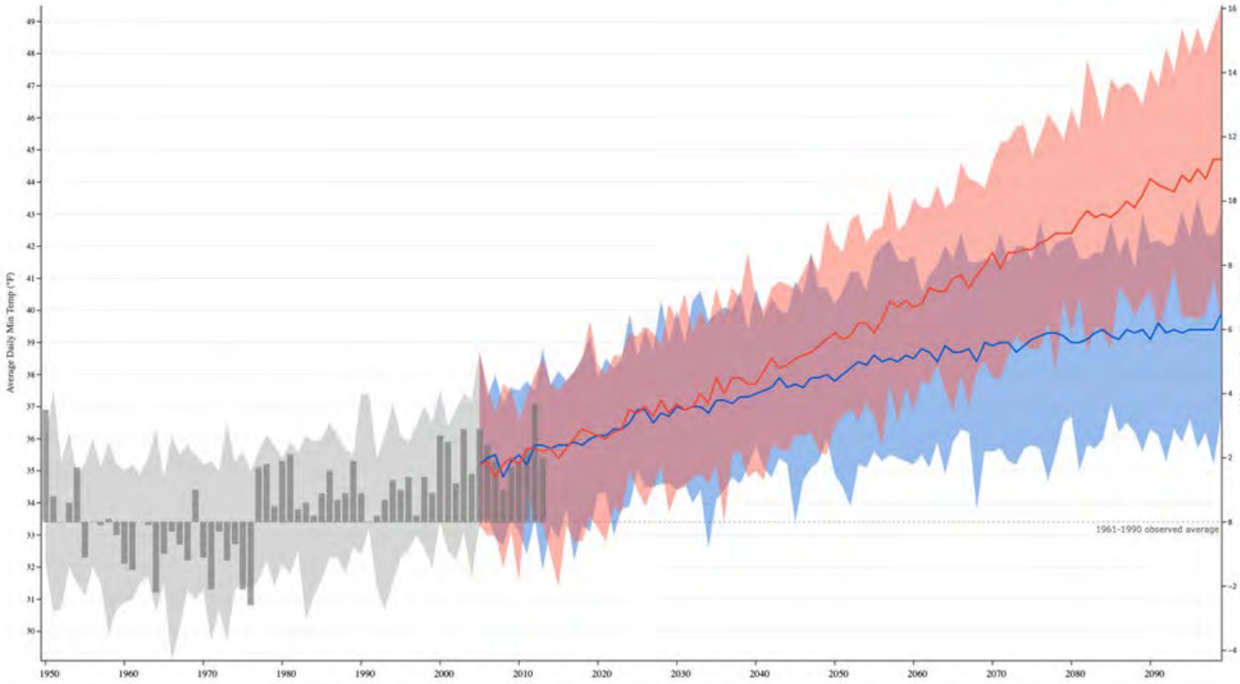


Figure 4-2. Average daily minimum temperature for Los Alamos County, historical and predicted. Daily minimums are projected to increase an average of 11.5°F (~33.5°F to 45.0°F) under RCP 8.5 and 6.5°F (~33.5°F to 40.0°F) under RCP 4.5 from the 1961–1990 observed average by 2100. (NOAA Climate Explorer).

4.2 Increased Frequency and Intensity of Extreme Heat Events

Temperature is predicted to become more variable within the overall increasing trend. The greater variability can lead to more frequent, longer, and more intense extreme heat events. As with increasing average temperature, extreme heat events have the potential to increase wildfire likelihood, contribute to local ecological mortality, and increase demands on water and energy.

Climate Change–Driven Patterns to Date

In New Mexico, the number of extremely hot days paired with warm nights has increased over the past 100 years (Kunkel 2020). Heatwaves in Western North America show a significantly increasing trend from 1950 to 2017 (Perkins-Kirkpatrick and Lewis 2020). The number of cooling degree-days per year at LANL has been increasing since 1990, whereas the number of heating degree-days has been decreasing (Hansen et al. 2021). Figure 4-3 shows Los Alamos cooling degree-days per year.

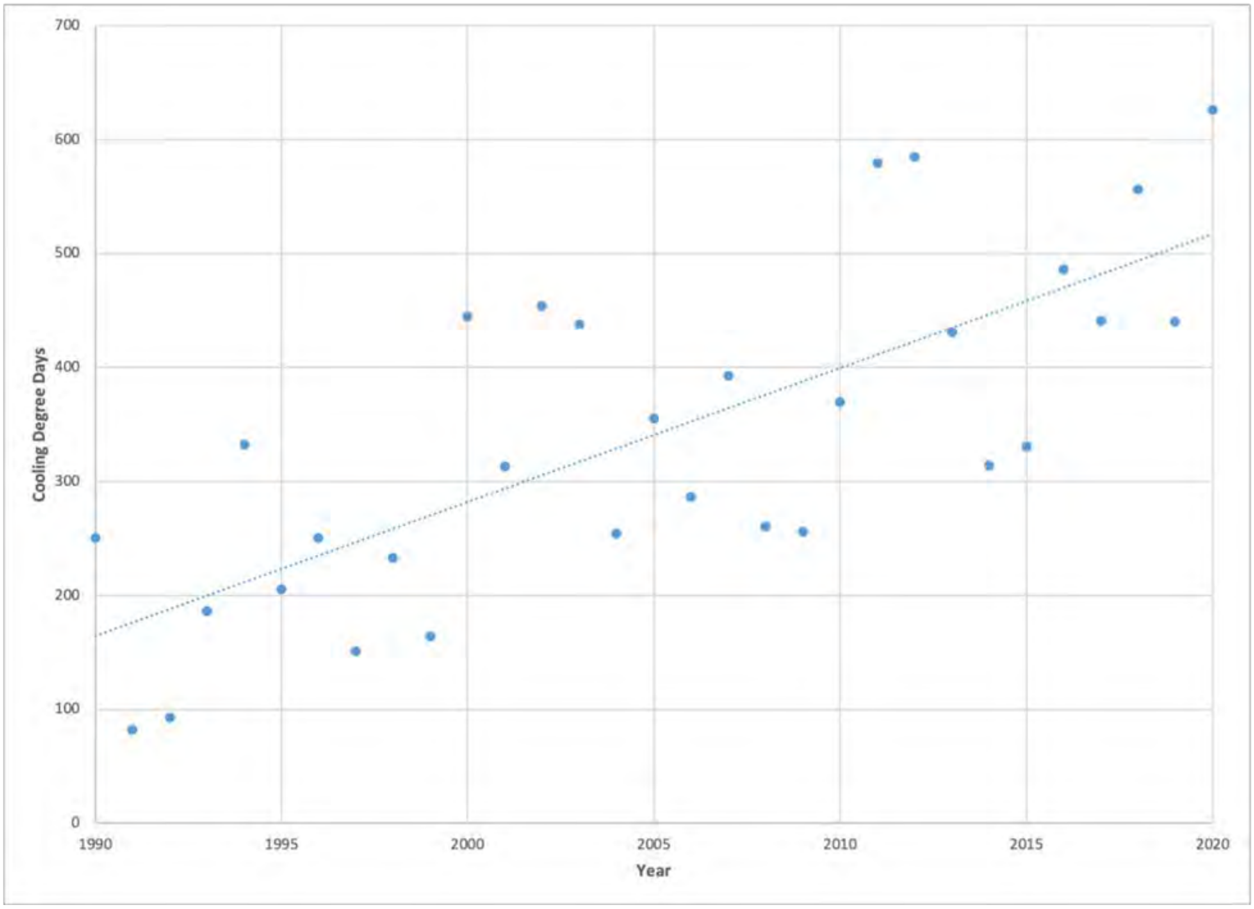


Figure 4-3. Los Alamos cooling degree-days per year. The dashed line represents the trend line for cooling degree-days, which shows that cooling degree-days have increased, resulting in more energy needed to cool buildings (Hansen et al. 2021).

Projections:

Extreme heat events, as well as extreme precipitation, thunderstorms, flooding, and wind events, are anticipated to increase with climate change (Bennett et al. 2021, Field et al. 2012, and Garfin et al. 2014), with impacts to infrastructure, ecology, human health, and fire intensity and re-occurrence. Extreme temperatures are projected to increase even more than average temperatures (very high confidence) (Vose et al. 2017).

Measures of threshold exceedances are often used to examine how climate change could be impacting society, because temperature extremes, in particular, can have far-reaching effects (Guirguis et al. 2018). The number of days per year in Los Alamos County that exceed 90°F is projected to increase from a historical level around 5 days per year to approximately 75 days per year by the end of the century under a higher emissions scenario (NOAA Climate Explorer). Figure 4-4 shows Los Alamos County total number of days per year with a maximum temperature above 90°F, historical and projected.

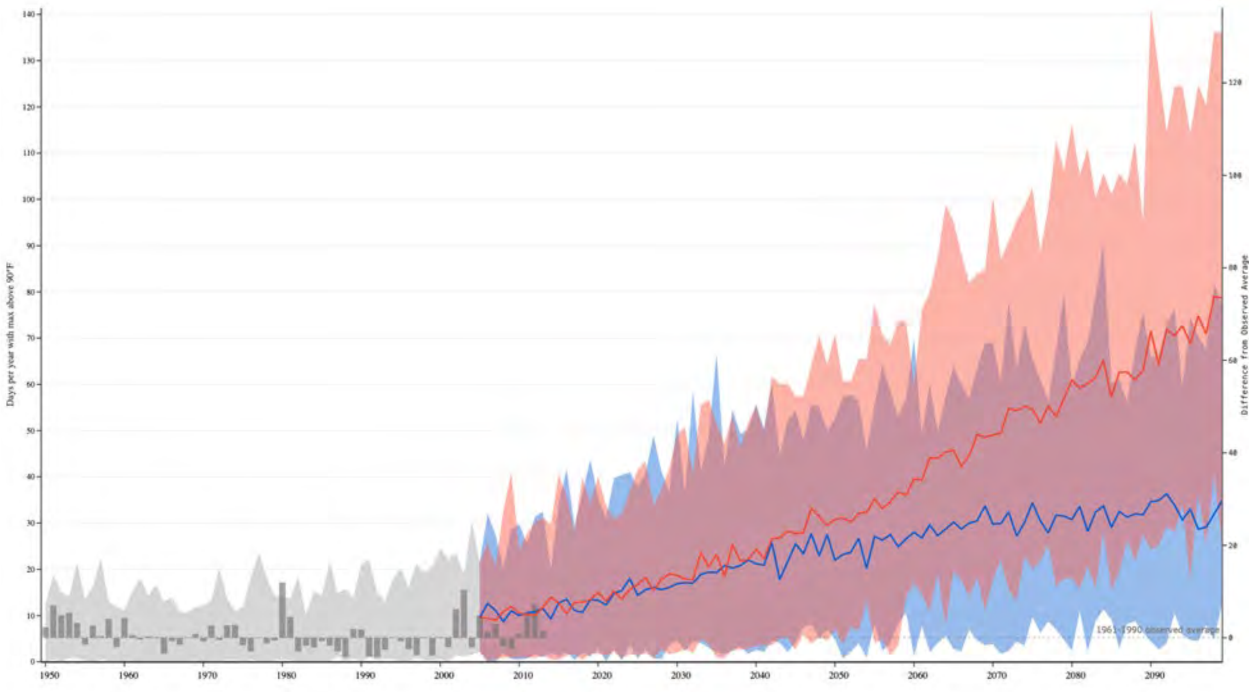


Figure 4-4. Los Alamos County total number of days per year with a maximum temperature above 90°F, historical and projected. Number of days is predicted to increase from approximately 5 per year to approximately 75 (RCP 8.5) or 30 (RCP 4.5). (NOAA Climate Explorer).

4.3 Changes to Total Average Annual Precipitation

Total average annual precipitation could decrease, which, coupled with increased temperatures, could impact water availability and groundwater recharge and lead to shifts in the local ecology and eventually longer-term shifts in landscape structure.

Climate Change–Driven Patterns to Date

Annual precipitation has decreased in the Southwest (medium confidence) (Easterling et al. 2017). A long-term drought has been measured at LANL beginning in 1998, with precipitation under 15 inches per year between 2000 and 2003 and between 2011 and 2012. Several years between 2003 and 2012 recorded as little as 10 inches of annual precipitation (Hansen et al 2020). Figure 4-5 shows annual precipitation totals for Los Alamos from 1924 to 2020.

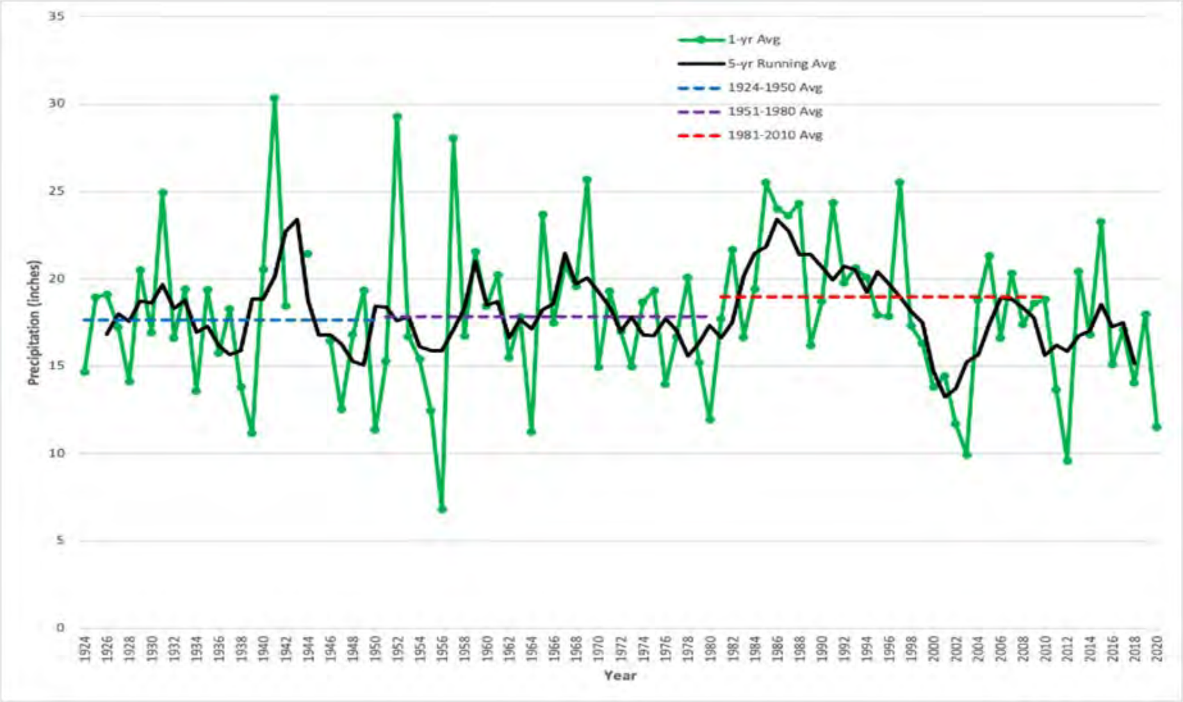


Figure 4-5. Annual precipitation totals for Los Alamos. The dashed lines represent long-term climatological average total precipitation, the black line represents the 5-year running average precipitation, and the green line represents the 1-year total precipitation. Significant drought since the 1990s has resulted in below-average precipitation in many recent years (Hansen et al. 2021).

Projections

Projected changes to total precipitation vary depending on the model considered. Outputs from the NOAA Climate Explorer tool demonstrate a slight decrease under RCP 4.5 and a larger decrease under RCP 8.5 (~10–15 percent) by 2100. Other studies find that total future precipitation is predicted to decrease (Garfin et al. 2014). Figure 4-6 shows Los Alamos County total annual precipitation, historical and projected.

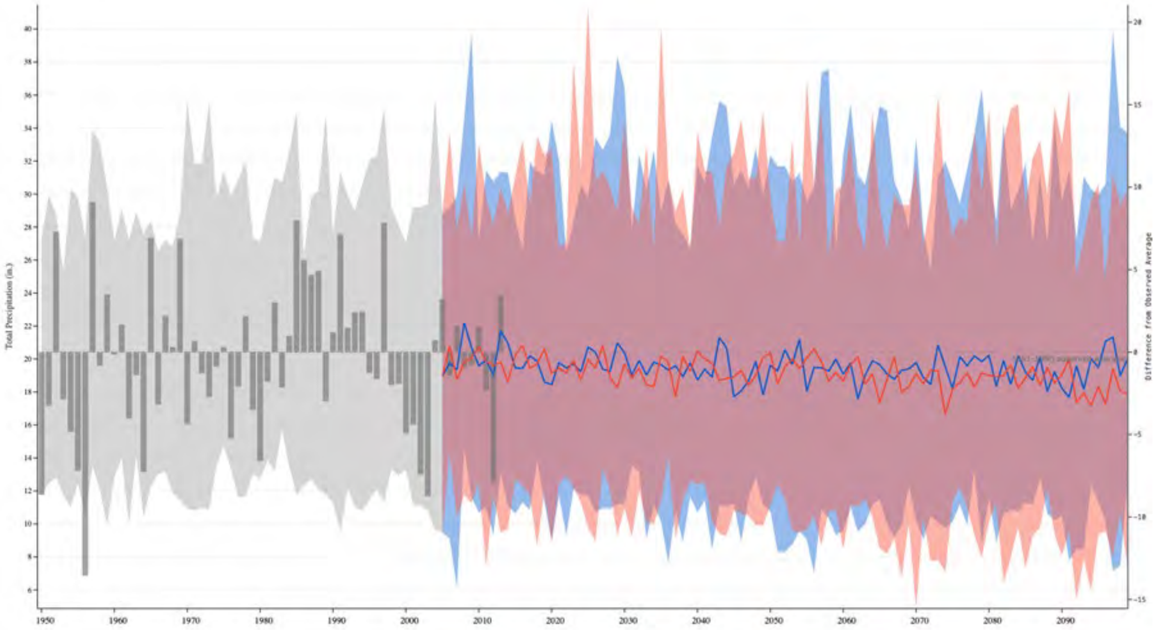


Figure 4-6. Los Alamos County, total annual precipitation, historical and projected. Slight decrease is predicted under RCP 4.5; larger decrease is predicted under RCP 8.5 (~10–15 percent) by 2100. (NOAA Climate Explorer).

4.4 Increased Frequency, Intensity, and Duration of Extreme Precipitation Events

Changes in climate are driving increasing variability in patterns of precipitation. These changes include variations in the seasonality and potentially the concentration of precipitation into more frequent and intense extreme events. These events, in turn, have implications regarding water availability and quality, local ecology and mortality, flooding, and erosion. Extreme precipitation events can put stress on worker safety and emergency response, as well as on facilities.

Climate Change–Driven Patterns to Date

Nationally, since the 2010s, the number of 2-day precipitation events that exceeded the 5-year recurrence period has increased more than 40 percent since the 1901–1960 average (Easterling et al. 2017). The North American Monsoon has recently demonstrated greater instability due to climate change (Pascale et al. 2017). Figure 4-7 shows the number of days per year with precipitation greater than 0.5 inches.

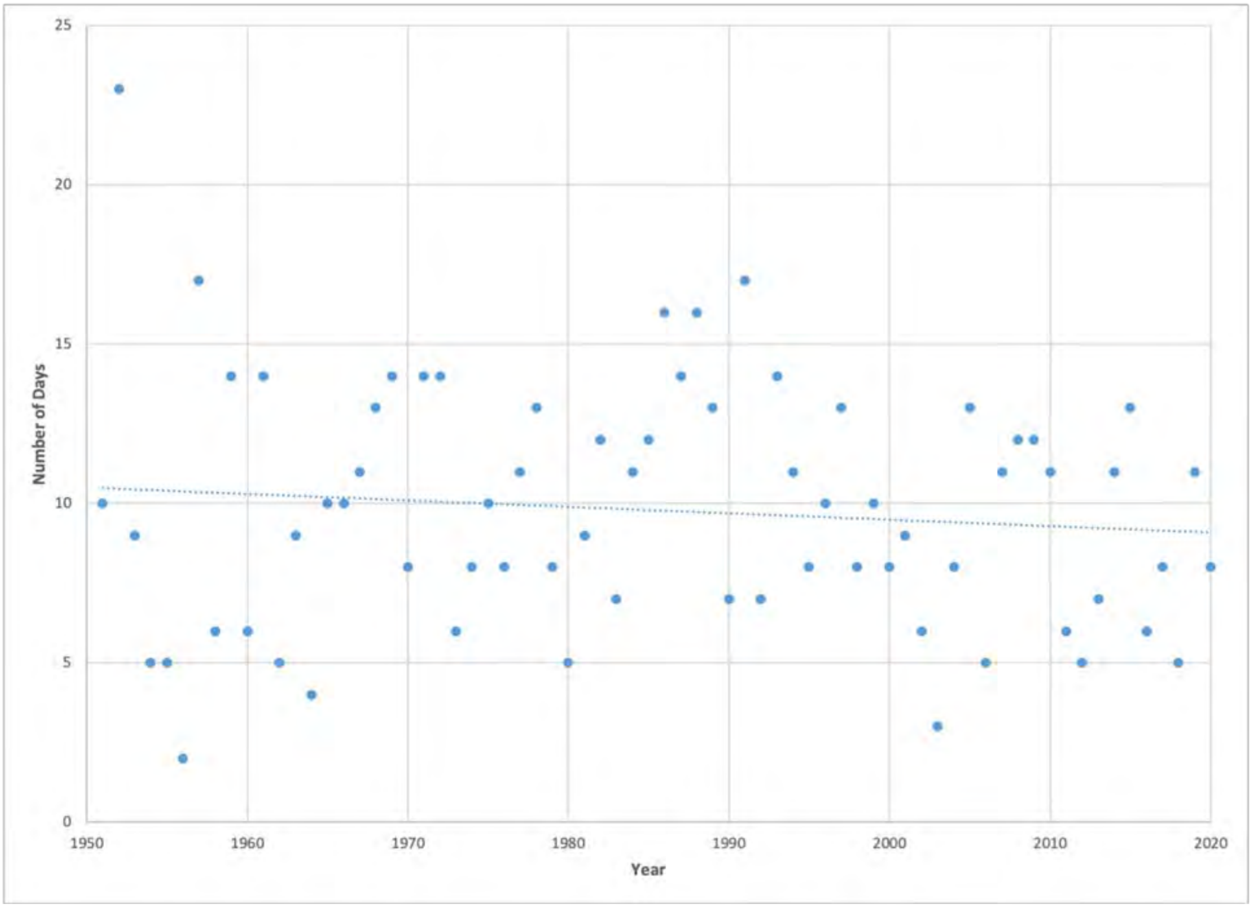


Figure 4-7. Number of days per year with precipitation greater than 0.5 inches. The dashed line represents the trend line for days with precipitation in excess of than 0.5 inches. The slight decreasing trend since 1950 is not statistically significant.

Projections

Frequency and intensity of heavy precipitation events are expected to increase across the United States. The southwest is predicted to receive less precipitation in the winter and spring (high confidence and medium confidence, respectively) (Hansen et al. 2021). Extreme events—both extreme wet and extreme dry events—are predicted to increase in the future (Milly et al. 2002). The Southwest is projected (2061–2100) to have up to a 15 percent increase in rainfall events above the 95th percentile of 1975–2014 levels. Heavy precipitation days (>10mm) are projected to increase approximately 10 percent (Akinsanola et al. 2020). Figure 4-8 shows the number of days with zero precipitation, historical and predicted, for Los Alamos County.

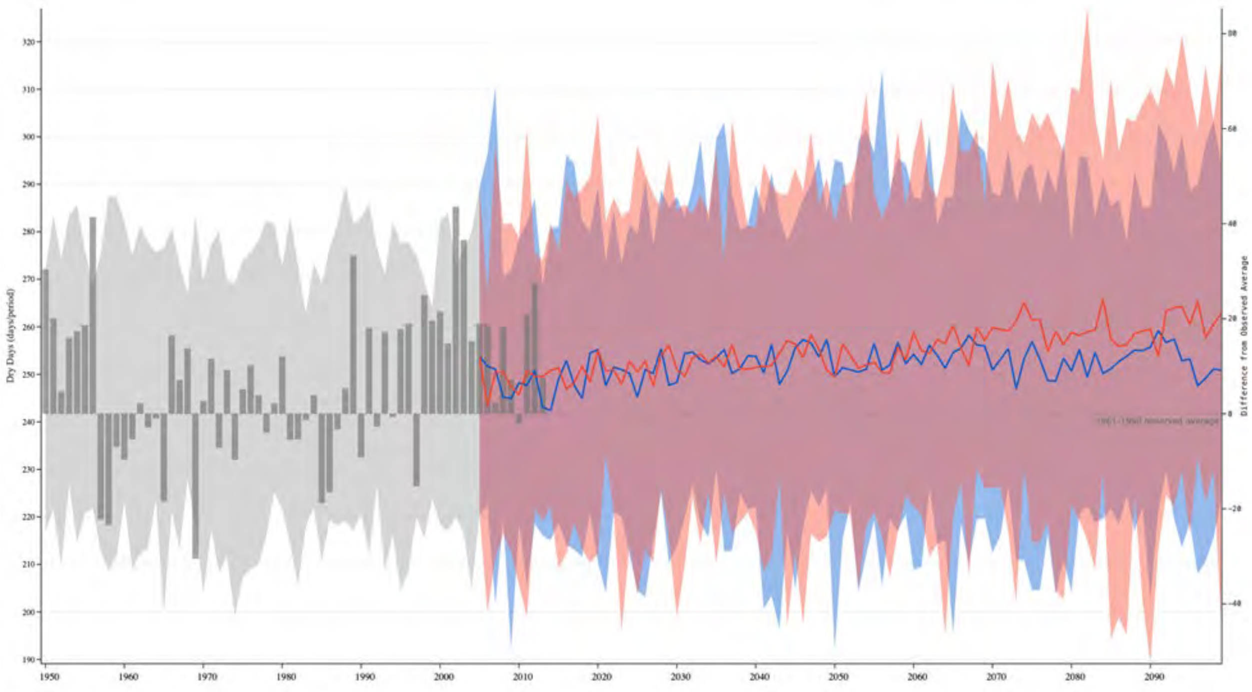


Figure 4-8. Los Alamos County, number of days with zero precipitation, historical and predicted. The number of dry days is predicted to increase more dramatically than the total precipitation is predicted to decrease, indicating the potential for greater variability. (NOAA Climate Explorer).

4.5 Decreased Water Availability

Temperature and precipitation drivers can interact and lead to decreased water availability (Bennett et al. 2021). Less available water has potential impacts on local site ecology and mortality and potentially on utilities and water use if water resources were ever to be at risk.

Climate Change–Driven Patterns to Date

Summer soil moisture in Southwestern North America has been below average for 18 out of 22 years since 2000 (Williams et al. 2022). Figure 4-9 shows annual average snowfall in Los Alamos.

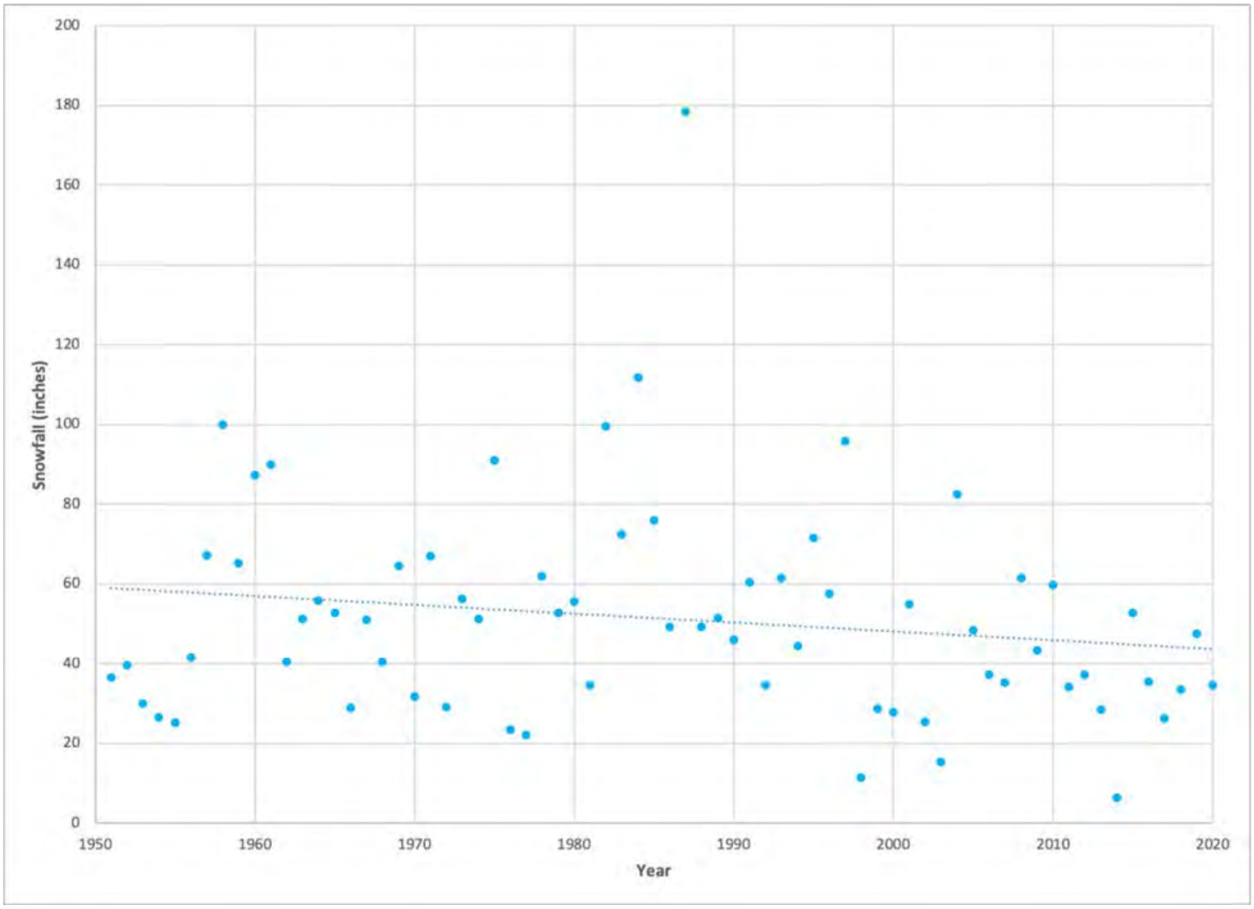


Figure 4-9. Annual average snowfall in Los Alamos. The dashed line represents the trend line for snowfall, which shows a decrease in annual snowfall (Hansen et al. 2021).

Projections

Snowpack accumulation is projected to decrease, and the summer monsoon will become more variable (Kunkel 2022). Large declines in snowpack are projected for the western United States (high confidence) (Easterline et al. 2017). The Southwest can expect decreased water availability; a reduced snowpack combined with an earlier snowmelt; and reduced, more variable stream flows by the end of the twenty-first century (USBR 2013 and Stephens 2018).

Locally, the native Chama and Jemez inflows will decrease by approximately one-third by 2100, with peak flow shifting from May to April (USBR 2013). Additionally, when surface water shortages on the San Juan-Chama diversion were examined, under climate change impacts alone, half of the six Earth System Models (ESMs) show that shortage sharing agreements will need to be implemented in 13 to 21 out of 30 years (2070–2099), with average shortages ranging from 16 to 70 percent.

When models consider both the impact of climate predictions (RCP 8.5) on water inputs and increasing social demand (full usage of water rights), water availability consistently comes up short. With both pressures in place, annual stream flows in the San Juan River basin are projected to be 33 percent lower than historical values (Bennett et al. 2019).

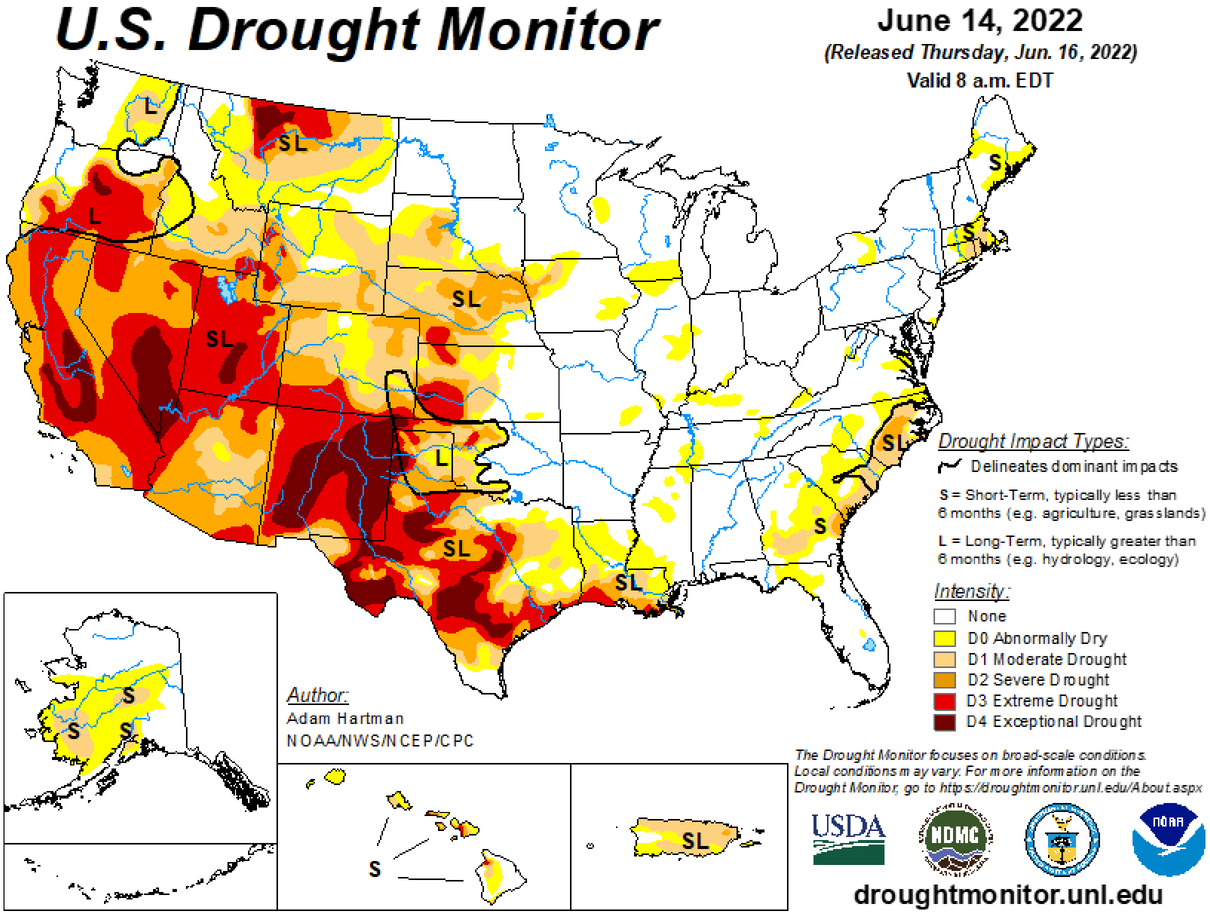
Conversely, deep groundwater aquifers that provide water resources to LANL and Los Alamos County are not anticipated to be at risk due to climate change impact (Bennett and Vesselinov 2017).

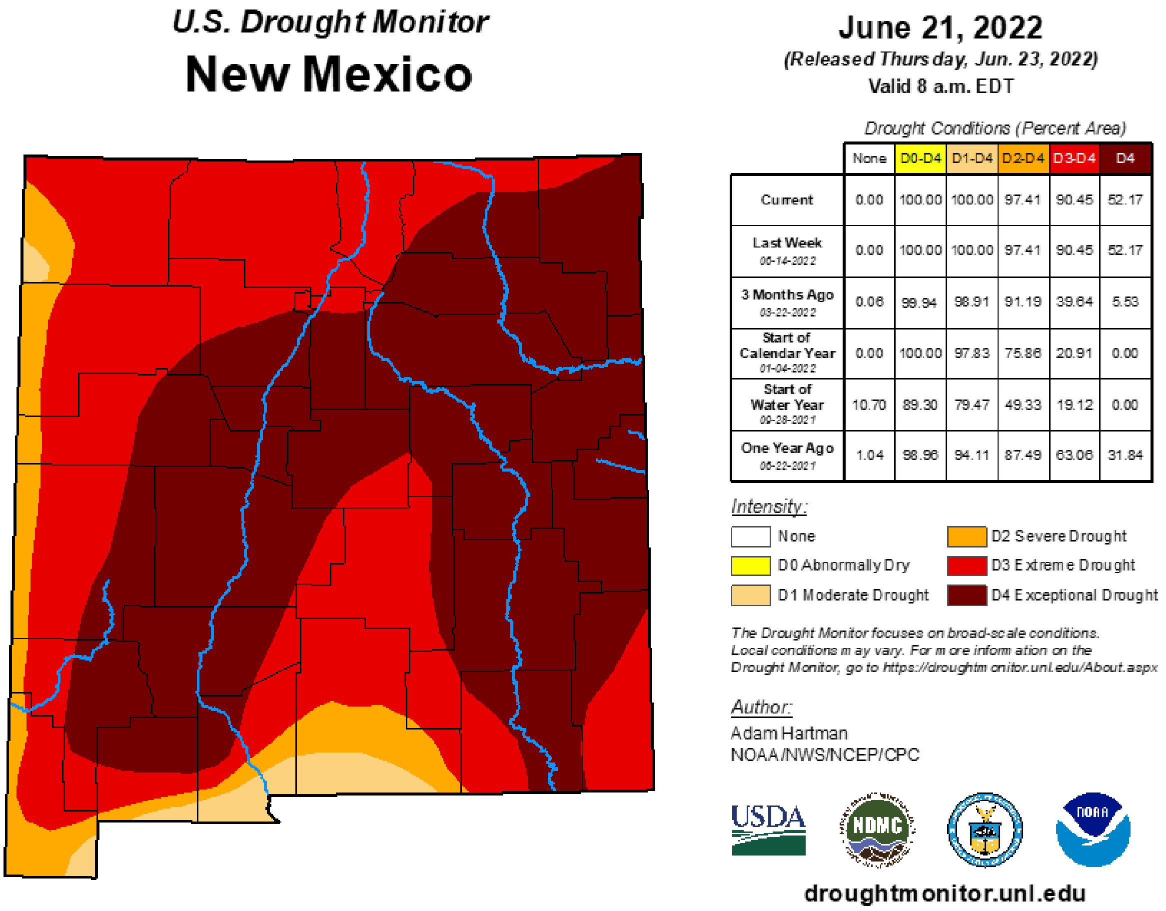
4.6 Increased Frequency, Intensity, and Duration of Extreme Drought Events

Combined lack of precipitation, lower water availability, and increased temperatures can all exacerbate drought conditions, leading to more frequent, intense, and longer lasting droughts. Droughts can have wide-ranging effects on water and energy use, as well as on workforce health and site ecology.

Climate Change–Driven Patterns to Date

Southwestern North America is currently experiencing its driest period (2000–2022) since at least 800 CE (Common Era; Williams et al. 2022), and New Mexico and Los Alamos County are currently experiencing an exceptional drought (U.S. Drought Monitor). A driving force of these drought conditions is surface moisture deficits caused by increased evapotranspiration brought on by higher temperatures (high confidence) (Wehner et al. 2017). Average precipitation for southwestern North America from 2000 to 2021 was 8.3 percent lower than the 1950–1999 average, whereas average temperature was 0.91°C above average for the same period (Williams et al. 2022). Figure 4-10 shows drought conditions for the United States and New Mexico during June 2022.





	None	D0-D4	D1-D4	D2-D4	D3-D4	D4
Current	0.00	100.00	100.00	97.41	90.45	52.17
Last Week 06-14-2022	0.00	100.00	100.00	97.41	90.45	52.17
3 Months Ago 03-22-2022	0.06	99.94	98.91	91.19	39.64	5.53
Start of Calendar Year 01-04-2022	0.00	100.00	97.83	75.86	20.91	0.00
Start of Water Year 09-28-2021	10.70	89.30	79.47	49.33	19.12	0.00
One Year Ago 06-22-2021	1.04	98.96	94.11	87.49	63.06	31.84

Figure 4-10. Current drought conditions for the United States and New Mexico

Projections

Drought intensity is projected to increase (state summary). An increase in regional temperature alone—under RCP 8.5—predicts a megadrought risk above 99 percent by the end of the century (Ault et al. 2016). Current surface moisture deficits linked to higher temperatures are also projected to increase (medium confidence) (Wehner et al. 2017). Additional projections indicate substantial reductions in western snowpack (high confidence), further demonstrating the possibility of chronic, long-term drought (very-high confidence) (Wehner et al. 2017). Reduced snowfall accumulations in much warmer future climates are virtually certain, as frozen precipitation is replaced by rain (Easterline et al. 2017 and Wehner et al. 2017).

4.7 Thunderstorm: Combined Precipitation, Wind, and Lightning

As climate-influenced extreme events, thunderstorms have the potential to be particularly destructive as they combine heavy winds, precipitation, and lightning. Precipitation in the forms of rain and hail can stress facilities and lead to flooding, whereas the combination of lightning and heavy winds increases the risk of wildfire. These combined risks have the potential to stress utilities, water, and energy use; compromise workforce safety and emergency services; and damage site ecology and cultural resources.

Climate Change–Driven Patterns to Date

Flash floods associated with thunderstorms occur throughout the Southwest, mainly during the months of the North American monsoon (Hirschboeck 1987, Maddox, Canova, and Hoxit 1980, and Garfin et al. 2014). The frequency of storm events reported in Los Alamos County has increased over the past 20 years (NOAA Storm Events Database).

Projections

Nationally, climate models consistently support an increase in frequency and severity of thunderstorms in areas currently prone to storms (low confidence in details). Overall, thunderstorms could increase as much as 100 percent in parts of the continental U.S. by 2099, with the number of severe storm weather days specifically in the southwest predicted to increase (Trapp et al., 2007).

4.8 Increased Flooding and Erosion Events

Interactions of wildfire, drought, and additional extreme precipitation events increase the chances of flooding and erosion events. These events, in turn, impact water availability and quality, local ecology, and erosion, especially in burn scars. Like the impacts of thunderstorms, floods can impact utilities, facilities, workforce, and emergency response, as well as site ecology and cultural resources. The risks are highest in areas that have experienced vegetation change due to water availability or wildfire.

Climate Change–Driven Patterns to Date

Flooding can occur in the aftermath of an extreme precipitation event or when tied to other climate change hazards, such as precipitation following a wildfire or drought. A complex process couples earlier rain on snow events, leading to heavy runoff (Vose et al. 2017). Sustained droughts followed by intense precipitation could cause complex interactions and mobilize accumulated sediment (Qiu 2021). Flooding can lead to increased erosion events, which can transport substantial amounts of sediment across the landscape. For example, in the 2013 flooding events that occurred after the Las Conchas fire, large amounts of sediment were removed from the landscape (Romero et al. 2018), resulting in the largest erosion event New Mexico had experienced in 1,000 years (Garfin et al. 2014).

Projections

Along with increased wildfire frequency, sediment flows after fires are predicted to double for one-third of all watersheds in the Southwest under a higher emissions scenario (Garfin et al. 2014). Flooding events can have varying outcomes, based on location and other factors. Based on 10 coupled Atmosphere/Ocean General Circulation Models from the Coupled Model Intercomparison Project, maximum daily surface runoff + baseflow (surface water) in parts of the southwest could increase 7–49 percent during 2021–2050 relative to 1976–2000) (Pagan et al. 2016). Partly because of shifts from snow to rain and lower total snowpacks with increasing temperatures, snowmelt-driven spring floods are expected to diminish in both frequency and intensity (Garfin et al. 2014). At the same time, rain-on-snow events and mid-winter precipitation events—along with warmer winters—could increase, leading to more flooding (Garfin et al. 2014 and Bennett et al. 2021). Rain events are more likely to cause flooding (Davenport et al. 2020).

4.9 Increased Wildfire Frequency

As the region gets hotter and drier, the risk of wildfire increases. Local wildfires have wide and severe impacts regarding tree mortality and changes to local ecology, as well as the potential for destruction of property and facilities. Increased financial resources for emergency response could be required.

Climate Change–Driven Patterns to Date

Temperature increases and vapor-pressure deficits have increased forest fire activity in the western United States by increasing the aridity of forest fuels and doubling forest fire–prone areas from 1984 to 2015 (Wehner et al. 2017). Figure 4-11 shows the cumulative forest area burned by wildfires, with and without climate change, between 1984 and 2015.

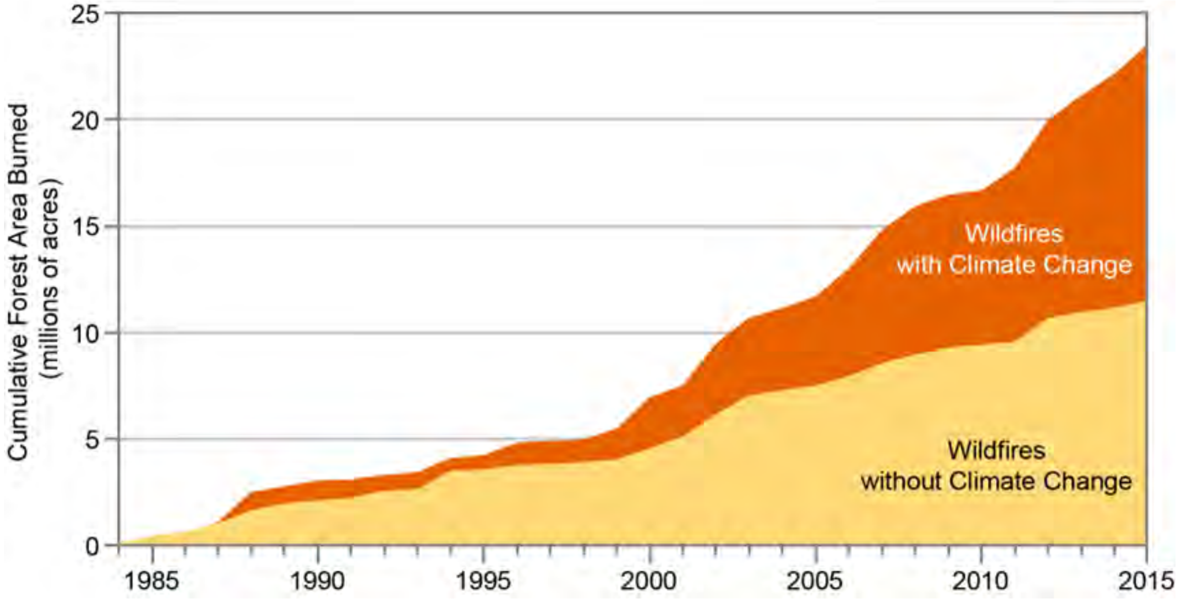


Figure 4-11. The cumulative forest area burned by wildfires has greatly increased between 1984 and 2015, with analyses estimating that the area burned by wildfire across the western United States over that period was twice what would have burned had climate change not occurred. (Adapted from Abatzoglou and Williams 2016 and Gonzales et al. 2018).

Projections

Wildfire frequency and severity are projected to increase (Kunkel 2022). Incidences of large forest fires have increased in the western United States since the 1980s (high confidence) and are projected to increase further (medium confidence) (Wehner et al. 2017). Incidences of very large forest fires are projected to increase by mid-century under both RCP 4.5 and RCP 8.5 (Wehner et al. 2017).

4.10 Increased Severe Windstorm Events

As temperatures increase with climate change, more heat in the atmosphere can lead to increased windspeeds (USGS). Incidents of severe windstorms are predicted to increase. Windstorm events directly increase tree mortality, impact air quality, and compromise worker safety. Longer term impacts can include changes to site ecology and damage to facilities.

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Climate Change–Driven Patterns to Date

The annual average wind speed measured at the Laboratory's meteorological tower of record at TA-06 has increased approximately 20 percent over the past 25 years. Over that same time, monthly average wind speed during spring months (windiest months) shows an increase by approximately 1 meter per second (Hansen et al. 2020). As of 2016, peak spring gusts, as measured by LANL weather stations, averaged 26–33 miles per hour across the Pajarito Plateau and 43 miles per hour at Pajarito Peak (Dewart et al. 2017). More recently, high-wind events over the past few years have been severe and damaging. For example, the March 2019 and December 2021 events contained gusts up to 70 miles per hour. Figure 4-12 shows the annual average wind speed at 12 meters above the ground at TA-06 from 1994 to 2019.

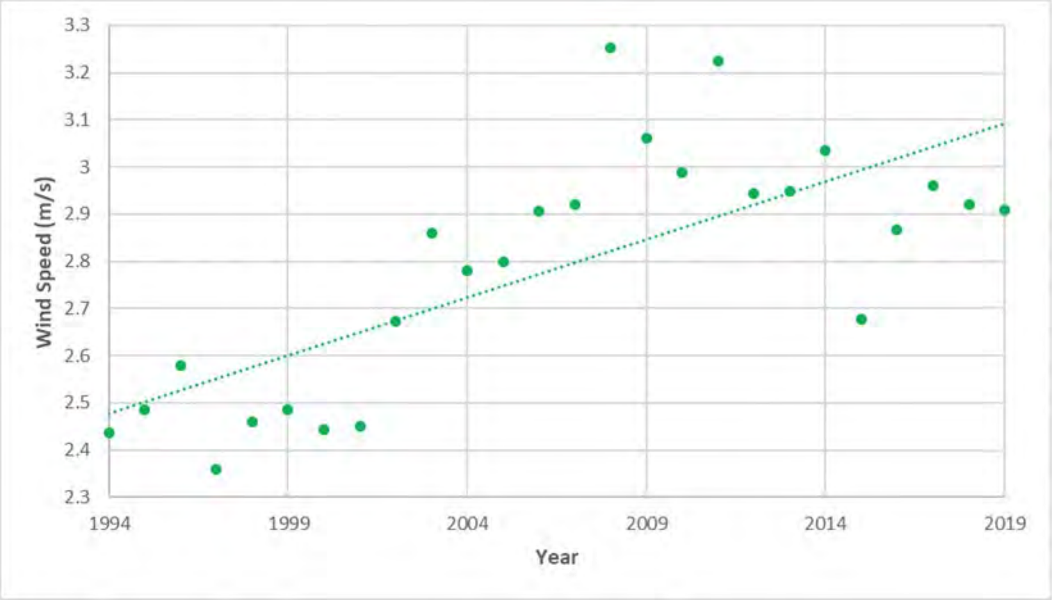

Figure 4-12. Technical Area 06 annual average wind speed at 12 meters above the ground. The dashed line represents the trend line for wind speed, which shows that the annual average wind speed has been increasing since 1994 (Hansen et al. 2020)

Projections

The frequency of wet and windy events is projected to increase in the Southwestern United States (Ridder et al. 2022).

4.11 Secondary Impacts and Site Implications

Many of the climate change hazards discussed in this report interact with one another, leading to secondary impacts, which in turn, have implications for site resources and facilities. For example, increasing temperatures and changes to precipitation could impact wildfire frequencies and vegetation shifts, which in turn, can impact flooding and erosion. Similarly, the shift from snowfall-dominant to rainfall-dominant regimes has implications for infiltration versus runoff and, therefore, long-term water availability and flood events. Secondary impacts could result from one or several climate change hazards and can affect a few or multiple assets.

5 Characterizing Current and Future Impacts of Climate Change

The Risk Assessment Tool was used to characterize current and projected impacts of climate change on the Laboratory's critical assets for the VARP. LANL's facility operations directors[2] (FODs), who are responsible for facility management, provided the following assessments for the assets within their facility operations directorate (FOD), all within their respective domains:

- Descriptions of each hazard's potential direct impacts on critical assets
- Descriptions of any implemented adaptive measures that protect critical assets from hazards
- Assignment of vulnerability
- Assignment of impact

5.1 Hazards with High Impact

The Risk Assessment Tool projected the impact of each hazard type on individual critical assets. Table 5-1 describes more specifically how impacts on individual critical assets were scored.

Table 5-1. Hazard Impact Scoring for Individual Facilities

Impact Scoring		
High Impact	Asset or infrastructure is fully disabled for a long duration (e.g., weeks or more).	100
Medium Impact	Asset or infrastructure is fully disabled for a moderate duration (e.g., days or less), or partially disabled for a long duration.	10
Low Impact	Asset or infrastructure is partially disabled for at most a moderate duration (e.g., days or less).	1
No Impact	There is no impact to the asset or infrastructure due to the hazard.	0

High Impact Hazards are those hazards projected to have high impacts across multiple (two or more) critical assets, as determined in the Risk Assessment Tool. High Impact Hazards for LANL are as follows:

- Wildfire – Increased wildfire frequency
- Precipitation – Increased frequency, intensity, and duration of extreme precipitation events
- Heat Wave – Increased frequency and intensity of extreme heat events
- Flooding – Increased flooding and erosion events
- Thunderstorms – Combined precipitation, wind, and lightning

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[2] The FOD Model at LANL: All site structures are assigned to a responsible associate director (RAD). The FOD is the RAD's principal agent for operations and is responsible for executing non-programmatic work in the RAD's facilities. A FOD's area may include facilities assigned to more than one RAD. LANL comprises six FODs. The FODs collaborate with the RADs to tailor facility/area-specific implementation of requirements based on need, but all will meet requirements and will comply with LANL standardized processes, such as Formality of Operations. Each FOD has a Maintenance Management group assigned to them from MSS Division, charged with facility maintenance for that FOD only.

See Appendix C for a discussion of impacts associated with non-real property critical assets.

Information about the potential impacts of each hazard on each critical asset, as well as adaptive measures currently in place to protect assets against each hazard, is captured in the Risk Assessment Tool. For hazards with high impacts on multiple asset types, a summary is included in the following paragraphs.

Wildfire – Increased Wildfire Frequency

Wildfire has the potential for high impact across multiple asset types, including the site's buildings, onsite waste processes, energy generation and distribution systems, specialized or mission-critical equipment, IT and telecommunication systems, and water and wastewater systems. The Laboratory has implemented multiple mitigation measures against the possibility of wildfire. Adaptive measures in place to defend the site against wildfire include defensible space around the perimeter of the Laboratory, targeted tree and vegetation thinning around firing sites, fire breaks, and more; however, no amount of mitigation can ensure 100-percent effectiveness. (b) (7)(E), (b) (7)(F) (b) (7)(E), (b) (7)(F). Climate change is likely to make wildfires more frequent and more severe (North Carolina Institute for Climate Studies State Summary). The incidence of very large forest fires is projected to increase by mid-century under both RCP 4.5 and RCP 8.5 (CSSR_ch8). Risk of wildfire increases with increasing drought, deteriorating vegetation health and mortality, thunderstorm events, severe wind events, increased annual average temperature, extreme heat wave frequency and intensity, and changes to precipitation patterns.

Precipitation – Increased Frequency, Intensity, and Duration of Extreme Precipitation Events

This hazard is likely to have high impact across multiple assets and infrastructure types, including the site's buildings, onsite waste processing, energy generation and distribution systems, specialized or mission-critical equipment, and water and wastewater systems. Extreme precipitation events could lead to roof failure or flooding—damaging infrastructure and/or equipment that would need repairs—and could (b) (7)(E), (b) (7)(F). Climate change is likely to increase the frequency, intensity, and duration of extreme precipitation events across the United States (CSSR_ch7). The Southwest is projected (2061–2100) to have up to a 15-percent increase in rainfall events above the 95th percentile of 1975–2014 levels. Heavy precipitation days (>10mm) are projected to increase approximately 10 percent (Akinsanola et al. 2020). Increased extreme precipitation events are more likely to damage site assets. Compounding effects could also be anticipated. For example, the impact of extreme precipitation events creates an increased chance for flooding and erosion events, especially in burn scars from wildfires or other places where changes to vegetation and soil increase vulnerability to runoff.

Heat Wave – Increased Frequency and Intensity of Extreme Heat Events

Heat waves are likely to have high impact across multiple assets and infrastructure types, including specialized or mission-critical equipment, onsite waste processing, and energy generation and distribution systems. During an extreme heat event, assets could experience reduced electrical reliability due to increased strain on outdated electrical systems, which could cause the assets to be disabled until electrical failures are repaired. Extreme heat events are anticipated to increase with climate change (Bennett et al. 2021, Field et al 2012, Garfin et al. 2016). Extreme temperatures are projected to increase even more than average temperatures (CSSR_ch6). With increased frequency and intensity of extreme heat events, site assets are more likely to experience reduced electrical reliability in outdated electrical systems.

Flooding – Increased Flooding and Erosion Events

Increased flooding and erosion are likely to impact multiple assets and infrastructure types, including specialized or mission-critical equipment, site buildings, energy generation and distribution systems, and onsite waste processing. Flooding and erosion can impact assets by flooding ground floors, flooding high-voltage equipment, and causing erosion of earthen shielding. (b) (7)(E), (b) (7)(F) (b) (7)(E), (b) (7)(F). Climate change is likely to cause increased flooding and erosion because of the likelihood of more frequent and intense rain events (Davenport et al. 2020). Increasing mid-winter precipitation events, combined with warmer winters, are also likely to increase the likelihood of flooding (Garfin et al., 2016, Bennett et al., 2021). Along with increased wildfire, sediment flows after fires are predicted to double for one-third of watersheds in the southwest under a higher emissions scenario (Garfin et al). Site assets are more likely to experience damage and closures with increased flooding and erosion events.

Thunderstorms – Combined Precipitation, Wind, and Lightning

This hazard has the potential for high impact across multiple asset types, including the site's buildings, onsite waste processing, energy generation and distribution systems, specialized or mission-critical equipment, and water and wastewater systems. Thunderstorms could lead to roof failure, flooding, or damage from wind or lightning, (b) (7)(E), (b) (7)(F). Climate change is likely to increase the frequency and severity of thunderstorms. Thunderstorms could increase as much as 100 percent in parts of the continental U.S. by 2099, with the number of severe storm weather days in the southwest specifically predicted to increase (Trapp et al., 2007). Increased thunderstorm activity is more likely to damage site assets. Thunderstorms are of particular concern because they combine multiple secondary impacts such as high-wind events, lightning-caused wildfires, and flooding due to heavy rains.

5.2 Vulnerability/Site Adaptive Capacity

The Risk Assessment Tool was also used to identify highly vulnerable critical assets. High vulnerability is ascribed to a critical asset that lacks existing adaptive measures or whose existing adaptive measures are likely to fail in the event of a hazard.

Highly vulnerable critical assets identified in the Risk Assessment Tool are those that are assigned a Vulnerability of either "Likely to Fail" or "Almost Certain to Fail" when facing a climate change hazard. Table 5-2 describes how vulnerability is scored.

Table 5-2. Vulnerability Scoring

Vulnerability Scoring		
Almost certain to fail	No adaptive measures in place or such measures are almost certain to fail when facing this hazard (>95% failure rate).	100
Likely to fail	It is likely that the adaptive measures will fail when facing this hazard (50–95% failure rate).	70
Unlikely to fail	It is unlikely that the adaptive measures will fail when facing this hazard (5–50% failure rate).	30
Very unlikely to fail	It is very unlikely that the adaptive measures will fail when facing this hazard (<5% failure rate).	1

Energy Generation and Distribution Systems

A few critical assets in this category could be vulnerable to flooding in those locations where existing stormwater management infrastructure is not designed to withstand flooding. Updated stormwater management infrastructure could mitigate this vulnerability.

Onsite Waste Processing

Some critical assets are vulnerable to increased frequency and intensity of extreme heat events where few or no adaptive measures are in place. Extreme heat events cause increased strain on electrical systems. Several critical assets in this category could also be vulnerable to flooding, where existing stormwater management infrastructure is not designed to withstand flood events. Updated stormwater management infrastructure could mitigate this vulnerability. A small number of critical assets are vulnerable to increased frequency, intensity, and duration of extreme precipitation events, and one critical asset is vulnerable to thunderstorms, citing current infrastructure such as older roofs as "Likely to Fail."

Site Buildings

Some critical assets are vulnerable to increased frequency and intensity of extreme heat events where few or no adaptive measures are in place. Extreme heat events and higher community consumption limit power availability. A few critical assets are vulnerable to increased frequency, intensity, and duration of extreme precipitation events where few to no adaptive measures exist to prevent roof failure or flooding of equipment. A small number of critical assets could be vulnerable to increased severe windstorm events where no adaptive measures are in place to protect electrical power supply from damage by high winds. Only one critical asset is vulnerable to flooding, with existing stormwater management infrastructure in place but not designed to withstand flooding. One critical asset's adaptive measures are likely to fail against thunderstorms, citing outdated stormwater management infrastructure.

Specialized or Mission-Critical Equipment

Some critical assets are vulnerable to increased frequency and intensity of extreme heat events where few or no adaptive measures are in place should these heat events cause limitations on power availability associated with higher community consumption. Some critical assets are vulnerable to thunderstorms, flooding, and increased frequency, intensity, and duration of extreme precipitation events where few to no adaptive measures are in place that can prevent critical assets from experiencing roof failure or flooding of equipment. Adaptive measures that are likely to fail against these hazards are cited as outdated, with a greater than 50-percent likelihood of failure. A small number of critical assets could be vulnerable to increased severe windstorm events where no adaptive measures are in place to protect electrical power supply from damage caused by high winds.

Water and Wastewater Systems

A small number of critical assets could be vulnerable to increased frequency and intensity of extreme heat events. There are no adaptive measures in place should heat events cause limitations to cooling tower capacity due to higher ambient temperatures. Some critical assets are vulnerable to thunderstorms, flooding, and/or increased frequency, intensity, and duration of extreme precipitation events where few to no adaptive measures are in place to prevent roof failure or flooding of equipment. Adaptive measures that are likely to fail against these hazards are cited as outdated, with a greater than 50-percent likelihood of failure. A few critical assets could be vulnerable to increased severe windstorm events where no adaptive measures are in place to protect electrical power supply from damage caused by high winds.

Additional Observations

All critical assets have few or no adaptive measures in place to protect them from drought; however, drought is not anticipated to impact any critical assets at the LANL site. LANL and Los Alamos County rely on deep groundwater aquifers for their water supply. The Laboratory does not rely on surface water. The aquifers are not considered at risk due to climate change impacts (Bennett and Vesselinov, 2017).

The next section of this report presents the Risk Matrix, which applies the criticality, hazard likelihood, impact, and vulnerability scores to each of the Laboratory's 141 real property, MDI-rated critical assets to calculate their VARP Risk Scores. Further discussion of VARP Risk Scores is included in Section 6.

6 Characterize Vulnerabilities with a Risk Matrix

Using DOE's Risk Assessment Tool, LANL created a risk matrix to help visualize the vulnerabilities of critical assets against climate change hazards. The VARP Risk Matrix was created by entering the results of the previous steps, as described in this report, into the Risk Assessment Tool, discussed in this section.

The Risk Matrix helps to visualize the total risk that critical assets have against climate change hazards. The full Risk Matrix calculates VARP Risk Scores for each of the MDI-rated critical assets against each of the climate change hazards. Using the 141 critical assets and 10 climate change hazards, the Risk Assessment Tool produced 1,410 individual VARP Risk Scores for LANL. See Appendix E for the complete LANL Risk Matrix showing individual VARP Risk Scores for each critical asset against each climate change hazard.

How VARP Risk Scores Are Calculated

VARP Risk Scores consider the Criticality Score of each critical asset (VARP Step 2), the projected likelihood of climate change hazards (VARP Step 4), the Impact Score for each climate change hazard on each critical asset (VARP Step 5), and the Vulnerability Score of each critical asset to each climate change hazard (VARP Step 5). Equations 6-1 and 6-2 show the calculations used in the Risk Assessment Tool.

$$\text{Risk} = \text{Criticality} \times \text{Hazard Likelihood} \times \text{Impact} \times \text{Vulnerability} \qquad \text{(Eq. 6-1)}$$

$$\text{VARP Risk Score} = \text{Log}_{10}(\text{Risk}) + 3.5 \qquad \text{(Eq. 6-2)}$$

VARP Risk Score and Color Key	
High	>7
Medium	3.5–7
Low	<3.5
No	Zero Calculated Risk

LANL generated an additional Risk Matrix using an average of the risk scores for each critical asset in an asset type category. Average VARP Risk Scores by asset type are shown numerically in Table 6-1 and were calculated using the average of the calculated Risk from VARP Step 5. Equation 6-3 shows this calculation.

$$\text{Average VARP Risk Score by Asset Type} = \text{Log}_{10}\,(\text{Average Risk}) + 3.5 \qquad \text{(Eq. 6-3)}$$

A combination of factors, including geographic location in the high desert, wide variations in topography, and historic precedent, resulted in identification of 10 hazards that are increasingly likely to impact the LANL site because of climate change. All 10 hazards received a Hazard Likelihood rating of either "Likely" or "Almost Certain," the two highest possible ratings in the Risk Assessment Tool. Because of this in-built rating algorithm, none of LANL's critical assets received a VARP Risk Score of "Low" against any climate change hazards.

6 Characterize Vulnerabilities with a Risk Matrix

The following Risk Matrix summarizes Risks by asset type. To fit the table into the report format, not all climate change hazards that were assessed are included in this table. "Increased annual average temperature," "Changes to average and total annual precipitation," "Increased frequency, intensity, and duration of extreme drought events," and "Decreased water availability" are omitted from Table 6-1 because the calculated VARP Risk Score for those four hazards is "None" for all critical assets.

Table 6-1. LANL VARP Risk Matrix Summary Showing LANL's Average VARP Risk Scores* across Asset Types and Climate Change Hazards

		Hazards					
Asset Type	Count	Increased Heat Wave Events	Increased Precipitation Events	Increased Thunder-storms	Increased Flooding Events	Increased Wildfire Frequency	Increased Severe Wind Events
Specialized or mission-critical equipment	48	8.5	8.8	8.4	7.7	8.4	7.8
Energy Generation and Distribution Systems	30	7.5	7.5	7.5	7.5	7.8	5.7
Onsite Waste Processing	18	8.6	8.0	7.8	7.6	8.1	6.9
Site Buildings	25	7.2	8.2	7.8	7.4	7.7	7.2
Water and Wastewater Systems	18	6.4	7.9	7.9	6.8	7.6	6.8
IT and Telecommunication Systems	2	7.2	7.2	4.7	6.7	7.7	4.7

*Average VARP Risk Scores = Log_{10} (Average Risk) + 3.5. Zero Calculated Risk is not shown.

6.1 Hazards with Zero Calculated Risk

(b) (7)(E), (b) (7)(F)

- (b) (7)(E), (b) (7)(F)
-
-
-

(b) (7)(E), (b) (7)(F)

6.2 Hazards with Calculated Risk

One hazard, wildfire – increased wildfire frequency, received the same Impact Score and Vulnerability Score for every critical asset. The difference in VARP Risk Scores, which range from Medium to High, is caused by the differing Criticality Scores assigned in VARP Step 2. All critical assets that received a Criticality Score of Moderate or High (MDI score of 80–100) received a VARP Risk Score in the High Risk range; all critical assets that received a Criticality Score of Low (MDI score of 70–79) received a VARP Risk Score in the Medium Risk range.

- (b) (7)(E), (b) (7)(F) (b) (7)(E), (b) (7)(F) LANL is protected from wildfire by defensible space around the perimeter, tree and vegetation thinning around targeted areas on the campus (e.g., firing sites), fire breaks, and several other in-place adaptive measures. Collectively, (b) (7)(E), (b) (7)(F)

The remaining five climate hazards had greater variation in VARP Risk Scores depending on Asset-specific vulnerabilities and impacts.

- (b) (7)(E), (b) (7)(F)
-
-

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(b) (7)(E), (b) (7)(F)

[redacted]

6.3 Additional Observations

In several cases, even critical assets that were assigned Low Impact with adaptive measures that are Unlikely to Fail sometimes received a VARP Risk Score in the High Risk range. This result can occur when High Criticality assets are faced with climate change hazards with a likelihood projection of Almost Certain. In this scenario, critical assets had to be assigned a Low Impact with adaptive measures that are Very Unlikely to Fail to receive a VARP Risk Score of Medium Risk instead of High Risk.

Out of 1,410 individual VARP Risk Scores calculated for each critical asset against each climate change hazard, zero fell into the Low Risk Range. This outcome resulted because all 10 of the climate change hazards had a projected likelihood of either Likely or Almost Certain, the two highest rankings in the Risk Assessment Tool.

7 Identify and Assess Resilience Solutions

The VARP Planning Team along with SMEs from around the site were asked to identify and assess resilience solutions that can help to mitigate the vulnerabilities identified in the VARP Risk Matrix created in Step 6. These individuals represented groups from each ALD. The VARP received proposed resilience solutions from divisions across the site, including the Emergency Management Division Office, EPC-DO, Utilities and Institutional Facilities, High Performance Computing, Earth and Environmental Sciences, and Infrastructure Programs Office. Additionally, the recommendations listed for the identified Non-MDI critical assets in Appendix C were considered for resilience solutions. All solutions were identified as potential solutions for vulnerable critical asset and hazard pairings.

7.1 Focus Areas for Resilience Solutions

In developing resilience solutions, the VARP Planning Team focused primarily on the critical assets that were shown to be potentially vulnerable to climate change hazards, receiving a VARP Risk Score in the High Risk range. The Team focused on identifying resilience solutions that can protect site critical assets from increased wildfire frequency, increased precipitation events, increased heat wave events, and increased thunderstorms because these hazards pose the highest overall risk to the Laboratory.

In parallel with the VARP efforts, LANL's Sustainability Program has partnered with an outside engineering firm, JGMS/AECOM, to develop a campus-wide *Net-Zero Emissions Plan* (Net-Zero Plan). Although still in progress, the Net-Zero Plan will provide LANL with tangible solutions and projects to reach various emission reduction and net-zero goals as outlined in Executive Order 14057, *Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability*. As such, when identifying potential resilience solutions for the VARP, SMEs were asked to include resilience solutions that also support the net-zero planning efforts. Examples include the onsite solar PV (photovoltaic) array, the battery storage system, and the heat recovery steam generator, among others. Resilience solutions chosen to proceed to Step 8 that also support net-zero planning efforts will be tracked in the DOE Sustainability Dashboard, allowing LANL to also track net-zero efforts and help meet net-zero goals. It is recommended that net-zero solutions continue to be included in subsequent VARP efforts.

7.2 Analysis of Potential Resilience Solutions

The analysis assessed the effectiveness and feasibility of the solution, identified the critical asset(s) the solution could make more resilient, the potential hazard(s) addressed, the cost, and the potential community and environmental impacts (both positive and negative). The following categories were identified for each proposed solution:

- *Solution*: Identify the solution being considered
- *Brief Description*: Provide an overview of the solution and why it is needed
- *Critical Asset(s)*: Identify the assets/infrastructure identified in Step 2 that will be made more resilient by the solution
- *Hazards*: Identify the anticipated climate-related impact(s) being addressed by the solution

- *Expected Effectiveness*: Identify the resilience solution's capacity to reduce the overall risk; risk is defined as the combined magnitude of consequences and likelihood that a vulnerability will affect the site
- *Feasibility*: Provide an assessment of whether the solution can be implemented financially, legally, technically, and organizationally
- *Cost and Funding Type*: Estimate the expected monetary cost and likely funding sources, e.g., appropriated funds, performance contract
- *Site Benefit*: Provide the benefits that the DOE site will receive from the resilience solution
- *Community Impact*: Provide the impacts (positive or negative) that the surrounding community will receive from the resilience solution; specify if the impacts will affect an energy or environmental justice community
- *Environmental Impact*: List benefit or detriment to the site ecology and greenhouse gas (GHG) emissions, if any
- *Recommended Approach*: Provide the site's recommended path forward

In determining the recommended approach for each proposed resilience solution, the VARP Planning Team considered all listed categories. Hazards addressed, expected effectiveness, feasibility, cost and funding type, and timeline were given extra weight in the Team's consideration.

For proposed resilience solutions that are not recommended to proceed to Step 8, the VARP Planning Team recommends reconsideration of all during the next VARP process. With more information and time, many proposed resilience solutions not recommended to proceed to Step 8 could be feasible for the Laboratory.

7.3 Summary of Identified Resilience Solutions

A condensed analysis for all proposed resilience solutions is shown in Table 7-1, with further analysis that shows additional metrics included in Appendix F.

Table 7-1. Potential Resilience Solutions Identified by the LANL VARP Planning Team

(b) (5), (b) (7)(E), (b) (7)(F)

[redacted]

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(b) (5), (b) (7)(E), (b) (7)(F)

(b) (5), (b) (7)(E), (b) (7)(F)

[redacted]

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(b) (5), (b) (7)(E), (b) (7)(F)

[redacted]

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(b) (5), (b) (7)(E), (b) (7)(F)

[redacted]

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(b) (5), (b) (7)(E), (b) (7)(F)

[redacted]

(b) (5), (b) (7)(E), (b) (7)(F)

[redacted]

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(b) (5), (b) (7)(E), (b) (7)(F)

[redacted]

8 Develop and Implement a Portfolio of Resilience Solutions

All potential resilience solutions identified in Step 7 were evaluated to determine the final Portfolio of Resilience Solutions to be tracked in the DOE Sustainability Dashboard. Projects were eliminated from this list if

- work was not scheduled to begin in the next 4 years before the next VARP;
- significant information for the project was unidentified; and/or
- the projects were determined to be unfeasible for the Laboratory at this time due to maintenance, funding, or other obstacles.

Additionally, proposed resilience solutions identified for Energy Generation and Distribution Systems critical assets that are not included in the 2022 Integrated Resource Plan (IRP) were not included in the final Portfolio due to scope limitations. The 2022 IRP addresses Los Alamos Power Pool planning strategies for rate stability, resiliency and reliability, mitigating risks due to market volatility, decarbonization goals, and clean energy standards for 2022–2041.

Once the resilience solutions for the final Portfolio were identified, their priority rank was determined. Each resilience solution in the Portfolio was ranked Low, Medium, or High. These rankings were assigned based on several factors, including the number and magnitude of key vulnerabilities mitigated, costs and benefits of resilience investments, and mission and operational impacts avoided or mitigated.

The final Portfolio of Resilience Solutions includes 19 projects or activities that mitigate vulnerabilities for all asset types and climate change hazards identified with a VARP Risk Score of Medium or High in the VARP Risk Matrix. Additionally, the final Portfolio of Resilience Solutions addressed vulnerabilities of critical assets identified by the Non-MDI Subgroup, including Ecosystem Services and Site Stewardship, Community Relations and Dependencies, and Workforce.

The final Portfolio of Resilience Solutions is included in Table 8-1 with the following categories:

- Solution: Identify the solution being considered
- Priority rank: Ranking of importance of project to mitigating vulnerabilities at the Laboratory (High, Medium, or Low)
- Timing: Planned start and end dates
- Funding Mechanism: Estimate the expected monetary cost and likely funding source(s) (Indirect/Direct, Performance Contracts, or Hybrid/Other)
- Implementation Status: Current stage of project
    - Identified: needs reliable estimates
    - Confirmed: estimates are reliable
    - Planned: cost effective & will fund
    - Funded: funds authorized
    - Awarded: funds awarded & work begun
    - Operational: in place & fully functional
    - Cancelled: no intention to fund

Table 8-1. LANL Portfolio of Resilience Solutions

(b) (5), (b) (7)(E), (b) (7)(F)

[redacted]	Implementation Status
[redacted]	Confirmed
[redacted]	Identified
[redacted]	Identified
[redacted]	Confirmed
[redacted]	Funded
[redacted]	Funded
[redacted]	Funded
[redacted]	Identified
[redacted]	Funded
[redacted]	Operational
[redacted]	Identified
[redacted]	Identified
[redacted]	Identified
[redacted]	Identified
[redacted]	Confirmed
[redacted]	Identified
[redacted]	Identified
[redacted]	Identified

(b) (5), (b) (7)(E), (b) (7)(F)	Implementation Status
	Identified

The estimated cost for all resilience solutions included in the final Portfolio totals approximately $87 million. Several of these projects have already begun work and/or have confirmed funding, totaling $41.7 million worth of project costs with an identified funding path. The remaining approximately $45.5 million in project costs do not yet have confirmed funding and will require the identification of a funding source to meet the resiliency goals for LANL outlined in this VARP.

Projects included in this Portfolio of Resilience Solutions will be tracked annually in the Sustainability Dashboard to monitor their progress.

9 Resilience Planning

Planning for climate change includes uncertainty—not only about how the climate will differ in the future but also how technologies and climate policies may change in parallel. A robust plan should be adaptable to changing expectations and evidence as well as facilitate monitoring of progress and evaluation of implemented solutions. Table 9-1 includes a summary of LANL's plan to monitor, evaluate, and reassess.

9.1 Monitoring, Evaluation, and Reassessment

Table 9-1. Monitoring, Evaluation, and Reassessment Plan Summary

(b) (5), (b) (7)(E), (b) (7)(F)

[redacted]

9.2 Collaboration with Other Initiatives

LANL is at the forefront of climate change and resilience research and development. Researchers will continue to work on innovative resilience solutions to combat climate change impacts locally, nationally, and globally. This research and development will be applied to the vulnerabilities identified in the VARP for LANL and identify other solutions to these complex challenges. The VARP highlights vulnerabilities associated with climate change hazards to critical assets at the site and recommends resilience solutions to mitigate those vulnerabilities, but this initiative is not unilateral. Just as the VARP built on other existing initiatives and processes, it will also inform and collaborate with concurrent and future initiatives. Because the VARP data and process will be revisited every 4 years, the following initiatives will also inform future VARPs. NA-LA and Triad consistently address risks, vulnerabilities, and challenges posed by global climate change and work to address those issues. Pollution prevention, source reduction, and sustainability goals continue to be implemented through existing programs and as part of our Environmental Management System.

9.2.1 Long-Term Strategy

The Laboratory's Environmental Protection and Compliance Division is in the process of re-evaluating and refining the current institutional strategy for long-term environmental stewardship and sustainability.

The strategy reflects an ongoing and comprehensive system of environmental protection, compliance, resource management, monitoring, analysis, and stakeholder communications capabilities that collectively provide the environmental stewardship and sustainability framework and process for the Laboratory. It is based on a 2013 *Long-Term Strategy for Environmental Stewardship & Sustainability Compendium* that

- clearly defines Laboratory environmental stewardship and sustainability policy and strategy;
- sets the vision, goals, and objectives for environmental stewardship and establishes metrics for accurately monitoring and measuring environmental protection and performance;
- provides an approach to integrating stewardship efforts across the Laboratory's organizations and programs designed to ensure that the entire life cycle of work at the Laboratory is designed and executed in a manner that is protective of human health and the environment; and
- establishes a framework for providing relevant, relatable, and transparent communication about the Laboratory's environmental stewardship performance to internal and external stakeholders.

The revision initiative uses the Compendium as a foundation. It focuses on ensuring that known and anticipated changes in institutional mission drivers and scope execution, operational and regulatory requirements, institutional policy, and land use planning/execution are appropriately incorporated into the revised strategy. It also considers actual or anticipated changes in environmental conditions and risks/hazards, such as climate change, that could drive modifications in the strategy scope and execution.

In the near term, the strategy revision is focused on establishing an official inventory of environmental protection controls in place across the Laboratory, identifying opportunities for more effective communication, more effective integration with management processes/plans/assessments, and identification of environmental initiatives and projects ready for investment.

Revising and refining the strategy provides an opportunity to evaluate the implications of climate change for planning and executing future long-term environmental stewardship and sustainability. The analysis provided in this VARP will be used to inform the long-term strategy revision process to ensure that the revised Laboratory's policies, systems, and stewardship and sustainability initiatives are responsive to shifts in the environmental conditions and risks/hazards associated with climate change.

Likewise, an effectively revised long-term strategy can be used to reinforce and enable execution of VARP resilience solutions and other initiatives/projects, including

- increasing employee awareness of climate change impacts;
- increasing long-term analytical capacity to evaluate/respond to climate change;
- improving forest health and wildland fire management capabilities;
- improving storm water and erosion control infrastructure;
- creating more resilient and protective watersheds; and
- improving communications, relationships, and trust with regional land managers and other stakeholders to enable more effective/comprehensive response to climate change.

9.2.2 Campus Master Planning

LANL's 2021 CMP was the Laboratory's first comprehensive site plan in more than 20 years. The CMP established a long-term, mission-driven vision for the Laboratory based on principles of sustainability, resilience, environmental stewardship, and preservation of cultural and historical resources. The plan will be updated yearly to reflect changes to mission, incorporate technological advances, and respond to environmental concerns, including climate change. The CMP is developed in parallel with other LANL plans, projects, and initiatives, including the VARP. Several of the resilience solutions recommended in the VARP are fully integrated with the CMP, including siting of the onsite solar PV array, incorporation of stormwater infrastructure, providing shade structures on new buildings, and promoting resilient landscape practices and materials.

9.2.3 Natural Phenomena Hazard Mitigation

DOE O 420.1C, *Facility Safety*, establishes facility and programmatic safety requirements for DOE, including the mitigation of natural phenomena hazards (NPHs). Chapter IV, Natural Phenomena Hazards Mitigation, requires LANL to perform a 10-year NPH assessment. This assessment will ensure that LANL safety class and safety-significant structures, systems, and components will perform assigned safety functions during and after design-basis NPH events. The NPH events include earthquakes, volcanic eruptions, extreme winds, precipitation, floods, and lightning, as well as secondary phenomena (if necessary) such as drought, fog, frost, extreme temperatures, landslides, subsidence, surface collapse, uplift, and waterspouts. The next NPH Assessment deliverable is due in 2024. LANL SMEs are collecting and evaluating data to model various flood levels in watersheds within the LANL boundary, as well as estimating extreme wind gusts.

The NPH Assessment provides information for both climate change hazards and critical assets. The NPH Assessment evaluates the ability of structures, systems, and components to perform safety functions during and after a hazard which correlates to the impact of hazards on critical assets and implemented adaptive measures in the VARP. Hazards evaluated in the NPH Assessment that overlap with hazards addressed by this VARP include strong winds, precipitation, floods, drought, and extreme temperatures.

9.2.4 Enduring Mission Waste Management Plan

The Enduring Mission Waste Management Plan (EMWMP) for LANL was initiated in 2016 to define key strategies to manage the wide range of wastes produced in the execution of Laboratory missions. In 2020, the EMWMP established goals for the implementation of the Office of Enterprise Stewardship (NA-53), *Radioactive Waste Management Program Plan*, and primarily focused on the execution plan for transuranic (TRU) waste during fiscal year 2022. Details of the Laboratory's enduring TRU waste strategy are included in the Integrated Strategy. Many of the strategies described in earlier plans have been successfully implemented. Waste minimization efforts have eliminated many sources of radioactive and hazardous waste. The contractual development of offsite shipping to government and commercial treatment, storage, and disposal facilities has opened the path for eliminating onsite waste disposal. A Transuranic Waste Facility is in operation to allow the storage of TRU waste for offsite shipments. Upgrades to the Radioactive Liquid Waste Treatment Facility were approved, and construction of the Low-Level Liquid Waste Facility is complete. (b) (7)(E), (b) (7)(F) (b) (7)(E), (b)

The primary strategy for the management of waste at LANL is to characterize, package, manage, and ship waste offsite in a safe, compliant, and efficient manner. The VARP works to support the goals of the EMWMP by ensuring that assets and infrastructure necessary to achieve source reduction of waste and support efficient offsite shipment are resilient to the impacts of climate change.

9.2.5 Site Sustainability Plan

The Site Sustainability Plan (SSP) is an annual update that summarizes the work that LANL has completed over the past fiscal year to meet DOE goals such as energy and water usage, waste management, electronics stewardship, and adaptation and resilience. Although the SSP is focused on progress that has taken place, an additional component includes future project plans. LANL intends to incorporate resilience projects from the VARP into the Sustainability Program budget and enter updates into the SSP. Some of the first resilience projects are the Heat Recovery Steam Generator Installation, the onsite solar PV array, and a hydrogen fueling station for buses.

9.2.6 Net-Zero Emissions Planning

As previously discussed in Step 7, future versions of the VARP should continue to include and support net-zero emissions efforts on campus. These efforts include considering net-zero assets in the critical asset list (for example, the 10 MWh PV array) and continuing to identify solutions that parallel the campus-wide Net-Zero Plan. Ensuring that the VARP continues to support net-zero efforts (and vice versa) will help LANL reach its sustainability and climate resiliency goals.

10 Acronyms and Abbreviations

Acronym	Definition
ALD	Associate Laboratory Directorate
ASER	Annual Site Environmental Report
CARP	Climate Adaptation and Resilience Plan
CMP	Campus Master Plan
CMR	Chemistry and Metallurgical Research
CSSR	Climate Science Special Report
DARHT	Dual-Axis Radiographic Hydrodynamic Test Facility
DOE	U.S. Department of Energy
EMWMP	Enduring Mission Waste Management Plan
EO	Executive Order
EPC-DO	Environmental Protection and Compliance Division
ERICA	Energy Resilient Infrastructure and Climate Adaptation (initiative)
FOD	facility operations director/directorate
FSI	Future Supercomputer Infrastructure
GHG	greenhouse gas
GI/LID	Green Infrastructure/Low Impact Development
GIS	geographic information system
GPP	general plant project
HPC	high-performance computing
IRP	Integrated Resource Plan
IT	Information Technology
LAICS	Los Alamos Integrated Communication System
LANL	Los Alamos National Laboratory
MDI	Mission Dependency Index
MW	megawatt
NA	not applicable
NA-LA	NNSA Los Alamos Field Office
NASA	National Aeronautics and Space Administration
NCA4	National Climate Assessment
NISC	Nonproliferation International Security Center
NNSA	National Nuclear Security Administration
NOAA	National Oceanographic and Atmospheric Administration
NPH	natural phenomena hazards
NSSB	National Security Sciences Building

Acronym	Definition
PV	photovoltaic
RAD	responsible associate director
RCP	Representative Concentration Pathway
RLW	radioactive liquid waste
RLWTF	Radioactive Liquid Waste Treatment Facility
SCC	Strategic Computing Complex
SERF	Sanitary Effluent Reclamation Facility
SME	subject matter experts
SSP	Site Sustainability Plan
SWEIS	Site-Wide Environmental Impact Statement
TA	Technical Area
TRU	transuranic (waste)
VARP	Vulnerability Assessment and Resilience Plan
VPN	virtual private network

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Appendix A Real-Property Critical Assets

Table A-1. Real-Property Critical Assets with Property ID, MDI Scores, and Criticality Scores

(b) (7)(E), (b) (7)(F)

[redacted]

Appendix A Real-Property Critical Assets

(b) (7)(E), (b) (7)(F)

[redacted]

(b) (7)(E), (b) (7)(F)

[redacted]

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(b) (7)(E), (b) (7)(F)

[redacted]

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(b) (7)(E), (b) (7)(F)

[redacted]

(b) (7)(E), (b) (7)(F)

[redacted]

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Appendix B Additional Assets Recommended by Stakeholders

Table B-1. List of Assets Recommended as Mission Critical by Stakeholders that Either Are Not on MDI or Do Not Score >70

(b) (7)(E), (b) (7)(F)

[redacted]

Appendix C Non-MDI Critical Asset Evaluation

In addition to DOE guidance for the VARP, LANL considered other site assets that were not included in the MDI but are important components of LANL's mission. The purpose of this non-MDI critical assets section is to provide a brief description of critical non-MDI assets at LANL and what is known about the impact of these climate change hazards on each asset. This section includes recommendations from the subject matter experts about mitigating or further investigating climate change impacts that were considered when developing the portfolio of resilience solutions in Steps 7 and 8 of the VARP. The following key indicates colors used in the impact assessment of critical assets.

Impact of Climate Change Hazard	Associated Color
Negative Impact	🟧
More Information Needed to Assess Impact	🟦
No Negative Impact Expected	⬜

Ecosystem Services and Site Stewardship

LANL has a biologically diverse landscape with a long history of occupancy by tribal communities. Four critical assets have been identified at LANL in the category of Ecosystem Services and Site Stewardship:

- Protected and Sensitive Wildlife and Plant Species,
- Forests and Other Ecosystems,
- Regional Aquifer, and
- Cultural Resources.

Protected and Sensitive Wildlife and Plant Species

The Laboratory has a wide diversity of habitats, resident federally listed threatened and endangered species, and a range of other protected and sensitive species. Inclusion of these habitats and species as critical assets addresses LANL's compliance requirements, stewardship responsibilities, tribal and other local community concerns, and institutional reputation.

The following documents identify these species and LANL's current management practices and recommendations:

- *Threatened and Endangered Species Habitat Management Plan for LANL*
- *Migratory Bird Best Management Practices Source Document for LANL*
- *Sensitive Species Best Management Practices Source Document for LANL*
- *Pollinator Plan for LANL*

Summary of Hazard Evaluation

Due to the expansive drought that is occurring in the southwestern United States, wildlife and plant species at the Laboratory face substantial challenges in the coming years. Rising temperatures, drought events, increased frequency of wildfire, and decreased water availability are identified as the most prevalent climate hazards for this asset class.

Table C-1. Assessment of the Impact of Identified Climate Change Hazards for LANL on the Protected and Sensitive Wildlife Species Sub-Tier Critical Asset Categories

Protected and Sensitive Wildlife Species										
Sub-Tier Critical Assets	Hazards									
	Annual Temperature Increase	Increased Heat Wave Events	Annual Precipitation Changes	Increased Precipitation Events	Annual Water Decrease	Extreme Drought Events	Increased Thunder-storms	Increased Flooding Events	Increased Wildfire Frequency	Increased Severe Wind Events
Federally listed species	🟧	🟧	🟧	⬜	🟧	🟧	⬜	⬜	🟧	⬜
Migratory birds	🟧	🟧	🟧	⬜	🟧	🟧	⬜	⬜	🟧	⬜
State listed species	🟧	🟧	🟧	🟧	🟧	🟧	⬜	🟧	🟧	🟧
Sensitive species	🟧	🟧	🟧	🟧	🟧	🟧	⬜	🟧	🟧	🟧
Pollinators	🟧	🟦	⬜	🟧	🟧	🟧	⬜	🟧	🟧	⬜

Recommendations

(b) (5)

- [redacted]

Forested and Other Ecosystems

Forest and woodland ecosystems, wetlands, and healthy soils at LANL provide services on which the Laboratory relies for maintaining facilities and infrastructure, planning operations, and controlling movement of contaminants off LANL property. Examples of these services include flood protection, protection of soil and sediment from erosion, and mitigation of wind events. As the vegetative communities in these ecosystems are damaged or changed, the Laboratory has experienced increased flooding, damage to roads and infrastructure, power outages, changes in operational conditions and planning requirements, and diversion of resources to engineered solutions to mitigate the loss of natural services. Including these ecosystems as critical assets addresses protection of MDI critical assets, stewardship responsibilities, some compliance requirements, institutional reputation, and tribal and other local communities' concerns—especially regarding offsite transport of contaminants. Drought, wildfire, decreased water availability, and flooding are identified as the most prevalent climate hazards for this asset class.

The following documents identify LANL's current management practices and recommendations:

- *LANL All-Hazards Emergency Management Plan* (EMD-PLAN-100)

- *Los Alamos National Laboratory Wildland Fire and Forest Health Annual Operating Plan for Fiscal Year 2022* (EMD-PLAN-201, R2; LA-CP-22-20056)
- *Threatened and Endangered Species Habitat Management Plan for LANL* (LA-UR-22-20556)

Summary of Hazard Evaluation

Tree mortality is increasing with higher temperatures and drought. Direct tree mortality occurs with windstorm events. Widespread loss of trees and other vegetation adversely affects soil health and alters how the ecosystem functions and the services it provides.

Table C-2. Assessment of the Impact of Identified Climate Change Hazards for LANL on the Forested and Other Ecosystems Sub-Tier Critical Asset Categories

Forested and Other Ecosystems										
Sub-Tier Critical Assets	Hazards									
	Annual Temperature Increase	Increased Heat Wave Events	Annual Precipitation Changes	Increased Precipitation Events	Annual Water Decrease	Extreme Drought Events	Increased Thunder-storms	Increased Flooding Events	Increased Wildfire Frequency	Increased Severe Wind Events
Forest and Woodland Ecosystems	🟧	🟧	🟧	⬜	🟧	🟧	⬜	🟧	🟧	🟧
Soil Health	⬜	⬜	⬜	🟧	🟧	🟧	⬜	🟧	🟧	🟧
Wetlands	🟦	🟧	🟧	🟧	🟧	🟧	⬜	🟧	🟧	⬜
Flood Plains	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	⬜

Recommendations

(b) (5)

[redacted]

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Regional Aquifer

Groundwater from the regional aquifer is the source of water for drinking and industrial uses at the Laboratory and for drinking and commercial uses in Los Alamos County. The water supply and distribution system for both the Laboratory and Los Alamos County is operated and maintained by Los Alamos County. Including the water quantity and quality in the regional aquifer as critical assets addresses the Laboratory's operational need for water, stewardship responsibilities, some compliance requirements, institutional reputation, and tribal and other local communities' concerns. Drought, extreme heat events, and changes in annual precipitation are identified as the most prevalent climate hazards for the aquifer level due to possible impacts on water demand and aquifer recharge. The subject matter experts did not anticipate any negative impacts of climate change on groundwater quality based on current information.

Summary of Hazard Evaluation

Table C-3. Assessment of the Impact of Identified Climate Change Hazards for LANL on the Regional Aquifer Sub-Tier Critical Asset Categories

Regional Aquifer										
Sub-Tier Critical Assets	Hazards									
	Annual Temperature Increase	Increased Heat Wave Events	Annual Precipitation Changes	Increased Precipitation Events	Annual Water Decrease	Extreme Drought Events	Increased Thunder-storms	Increased Flooding Events	Increased Wildfire Frequency	Increased Severe Wind Events
Aquifer Level	🟦	🟧	🟧	🟦	⬜	🟧	⬜	⬜	⬜	⬜
Groundwater Quality	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜

Recommendations

(b) (5)

[redacted]

Cultural Resources

Cultural resources include archaeological sites such as Archaic lithic scatters, Ancestral Puebloan room blocks, and Homestead cabins; and historic facilities such as bunkers used during the Manhattan Project and buildings used for significant research during the Cold War. The Laboratory has substantial compliance requirements and stewardship responsibilities related to cultural resources. The status of these resources are subjects of intense interest to tribal and other local communities. The following documents identify LANL's current management practices and recommendations:

- *A Plan for the Management of the Cultural Heritage at Los Alamos National Laboratory, New Mexico* (Cultural Resources Management Plan; LA-UR-19-21590)
- *Programmatic Agreement among the U.S. Department of Energy, National Nuclear Security Administration, Los Alamos Field Office, the New Mexico State Historic Preservation Office and*

the Advisory Council on Historic Preservation Concerning Management of the Historic Properties of Los Alamos National Laboratory, Los Alamos, New Mexico (Programmatic Agreement; LA-UR-17-22581)

Summary of Hazard Evaluation

Impacts from climate change can disturb, damage, and destroy archaeological sites, traditional cultural properties, cultural landscapes, and built-environment resources. Severe windstorms, flooding and erosion events, and wildfire are identified as the most prevalent climate hazards for cultural resources on Laboratory property. LANL does not currently have a systematic way to address these impacts to cultural resources.

Table C-4. Assessment of the Impact of Identified Climate Change Hazards for LANL on the Cultural Resources Sub-Tier Critical Asset Categories

Cultural Resources										
Sub-Tier Critical Assets	Hazards									
	Annual Temperature Increase	Increased Heat Wave Events	Annual Precipitation Changes	Increased Precipitation Events	Annual Water Decrease	Extreme Drought Events	Increased Thunder-storms	Increased Flooding Events	Increased Wildfire Frequency	Increased Severe Wind Events
Archaeological Sites	🟧	⬜	⬜	⬜	⬜	⬜	⬜	🟧	🟧	🟧
Traditional Cultural Properties	🟧	⬜	⬜	⬜	⬜	⬜	⬜	🟧	🟧	🟧
Cultural Landscapes	🟧	🟧	⬜	⬜	🟧	🟧	⬜	🟧	🟧	🟧
Built Environment Resources	🟧	⬜	⬜	⬜	⬜	⬜	⬜	🟧	🟧	🟧

Recommendations

(b) (5)

[redacted]

Community Relations and Dependencies

LANL resides in a landscape occupied by indigenous peoples and was later also settled by European immigrants and their descendants. Multiple communities and tribal properties are potentially impacted by Laboratory operations. Laboratory employees live in these communities.

The County of Los Alamos provides services to the Laboratory that are critical to conducting operations. These services include the provisioning and distribution of water, fire protection, combined purchases of electricity, solid waste disposal, and maintenance and clearing of local roads.

Effects of climate change on local communities and elements of their infrastructure—and on the services that the County of Los Alamos provides to LANL—could be a vulnerability for critical operations on LANL property.

Los Alamos County

Los Alamos County staff provided the following evaluation of the potential impacts of climate change hazards on county departments that provide services used by LANL. Extreme heat and precipitation events, thunderstorms, flooding and erosion, and increased average annual temperatures were identified as the most prevalent climate hazards for the organizations that provide the services of water and electricity, fire response, road construction and maintenance, solid waste disposal, and public transportation.

Summary of Hazard Evaluation

Table C-5. Assessment of the Impact of Identified Climate Change Hazards for LANL on the Los Alamos County Sub-Tier Critical Asset Categories

Los Alamos County										
Sub-Tier Critical Assets	Hazards									
	Annual Temperature Increase	Increased Heat Wave Events	Annual Precipitation Changes	Increased Precipitation Events	Annual Water Decrease	Extreme Drought Events	Increased Thunder-storms	Increased Flooding Events	Increased Wildfire Frequency	Increased Severe Wind Events
Department of Public Utilities	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
Los Alamos Fire Department	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
Traffic and Street Support	🟧	🟧	🟧	🟧	🟧	🟦	🟧	🟧	🟦	🟧
Environmental Services Division	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧

Los Alamos County										
Sub-Tier Critical Assets	Hazards									
	Annual Temperature Increase	Increased Heat Wave Events	Annual Precipitation Changes	Increased Precipitation Events	Annual Water Decrease	Extreme Drought Events	Increased Thunder-storms	Increased Flooding Events	Increased Wildfire Frequency	Increased Severe Wind Events
Atomic City Transit Division	🟧	🟧	⬜	🟧	⬜	⬜	🟧	🟧	🟦	🟦

Recommendations

- (b) (5)

Tribal Communities and Other Surrounding Communities

As part of the VARP process, tribal and surrounding community engagement has been identified as a critical asset. LANL will provide technical assistance to DOE in engagements with the Tribes and other surrounding communities going forward to

- ensure that existing resiliency measures do not result in disproportionately adverse impacts and ideally benefit surrounding Tribes and communities,
- identify how LANL can provide technical assistance regarding climate change resilience for these communities,
- identify how these communities can be involved in the next VARP effort starting in 2025–2026, and
- identify what LANL can learn from the feedback provided by the traditional legacies of these communities.

DOE will first initiate engagement with individual neighboring Tribes to provide an overview of the DOE VARP effort and then open conversation with the respective Tribe on their feedback regarding engagement going forward. If the Tribal communities show interest, LANL would provide technical assistance, as requested through DOE, with climate change science for the region and more details on how to complete a VARP. LANL will adjust its technical assistance based on the feedback from DOE and these communities.

Recommendations

- (b) (5)

Workforce

LANL's workforce is an ultimate critical asset in accomplishing its mission, and LANL prioritizes the safety and health of its workforce. This section examines potential climate change hazards that affect LANL's workers. Including LANL workers as critical assets addresses protection of worker health and safety, some compliance requirements, and institutional reputation. Wildfire, increased extreme heat events, higher average annual temperatures, and storm events are identified as the most prevalent climate hazards for this asset class.

Summary of Hazard Evaluation

Table C-6. Assessment of the Impact of Identified Climate Change Hazards for LANL on the Laboratory Employees and Subcontractors Sub-Tier Critical Asset Categories

Laboratory Employees and Subcontractors										
Sub-Tier Critical Assets	Hazards									
	Annual Temperature Increase	Increased Heat Wave Events	Annual Precipitation Changes	Increased Precipitation Events	Annual Water Decrease	Extreme Drought Events	Increased Thunder-storms	Increased Flooding Events	Increased Wildfire Frequency	Increased Severe Wind Events
Indoor On Site	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟧	⬜
Mixed Indoor/ Outdoor On Site	🟧	🟧	⬜	🟧	⬜	⬜	🟧	⬜	🟧	🟧
Outdoor On Site	🟧	🟧	⬜	🟧	⬜	⬜	🟧	⬜	🟧	🟧
Indoor Hybrid	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟧	⬜
Indoor Telework	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟧	⬜
Indoor Remote	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜

Recommendations

- (b) (5) [redacted]
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Appendix D Climate Hazard Likelihood

Table D-1. Climate Hazard Likelihood Table from the DOE Risk Assessment Tool

Hazard #	Regional Hazards Impacting DOE Site	Hazard Description	Secondary Impacts	Site Resource Implications	Compounding Hazards	Current Annual Frequency at the Site	Current Hazard Likelihood	Projected Effect of Climate Change	Confidence in Projection	Sources of Information	Projections from NOAA Climate Resilience Toolkit	Projected Annual Frequency at the Site with Climate Change	Projected Hazard Likelihood with Climate Change
1	Heat Wave	Increased average annual temperature	Water availability and groundwater recharge from warmer winters and lower winter snowpack, faster snow melt, changing growing seasons, ecology/biology, disease outbreaks (pests, viruses)	Utilities, water, energy, facilities, workforce, site ecology	Increased heat waves, drought, vegetation change, precipitation pattern shifts	3	Almost Certain	Increase	Very High Confidence	USEPA (2022), Vose et al. (2017)	Climate Explorer - graphs: average daily maximum temperature and number of days over 100°F are increasing under both scenarios; ncics.org - NM state summary predicts increased average temperature	3	Almost Certain
2	Heat Wave	Increased frequency and intensity of extreme heat events	Wildfire likelihood, local ecology mortality, labor capacity, increased energy requirements for cooling, air quality	Water, energy, workforce, site ecology	Increased average temperature, drought, precipitation pattern shifts, vegetation change (land cover shifts leading to greater warming), decreased water availability	2	Almost Certain	Increase	Very High Confidence	Guirguis et al. (2018), Perkins-Kirkpatrick and Lewis (2020), Oleson et al. (2015), Vogel et al. (2019), Vose et al. (2017), Peterson et al. (2013), Bennett et al (2021), Field et al. (2012), Garfin et al. (2016)	Climate Explorer - increase in number of days with maximum temperature over 95/100/105°F under both scenarios. Greater number of days with minimum temperature over 80°F, and fewer (down to 0) days with maximum temperature below 32°F.	3	Almost Certain
3	Precipitation	Changes to average and total annual precipitation	Water availability, shifts to local ecology, groundwater recharge	Water, financial resources, site ecology, cultural resources	Increased drought and flooding events, changes to landscape structure	1	Likely	No Change	Medium Confidence	Easterling et al. (2017), Pascale et al. (2017), Cook and Seager (2013), Hansen et al. (2020)	Climate Explorer - RCP4.5: little change in total precipitation; RCP8.5 slight decrease	1	Likely
4	Precipitation	Increased frequency, intensity, and duration of extreme precipitation events	Water availability, local ecology mortality, flooding and erosion, water quality	Utilities, water, energy, facilities, workforce safety, emergency response, financial resources, site ecology, cultural resources	Increased chance for flooding and erosion events, especially in burn scars or other places where vegetation changes make landscape more vulnerable to runoff	2	Almost Certain	Increase	High Confidence	Stephens (2018), Luong et al. (2017), Meyer and Jin (2017), Pasquale et al. (2017) Cook and Seager (2013), Min et al. (2011), Ossandón et al. (2021), Bartels et al. (2020), Easterling et al. (2017), Akinsanola et al. (2020), Milly (2002)	Crt-climate-explorer.nemac.org - increase in number of days with >2" and >3" of precipitation; also increase in number of dry days	3	Almost Certain
5	Drought	Decreased water availability	Water availability, snowpack, groundwater recharge, increased wildfire likelihood, local ecology mortality	Utilities, water, site ecology	Increased drought, extreme temperature, and average temperature	3	Almost Certain	Increase	High Confidence	Stephens (2018), Houston et al. (2021), Solander et al. (2017), Sandoval-Solis et al. (2013), Sheng (2013, Li et al. (2021), Bennett et al. (2020), Elias et al. (2015), Bennett et al. (2022), Williams et al. (2022), Easterling et al. (2017), Bennett and Vesselinov (2017)	ncics.org - NM state summary: drought intensity predicted to increase; snowpack accumulation predicted to decrease	3	Almost Certain
6	Drought	Increased frequency, intensity, and duration of extreme drought events	Wildfire likelihood, water availability, precipitation pattern change	Water, energy, workforce, site ecology	Increased average temperature, extreme heat wave events frequency and intensity, changes to precipitation patterns even if total precipitation remains constant	1	Likely	Increase	High Confidence, Very High Confidence	Climate Impact Lab, Bennett et al. (2020), Bennett et al. (2021), Ault et al. (2016), Cook et al. (2015), Williams et al. (2022), Wehner et al. (2017), Easterling et al. (2017)	Drought.gov - continuous drought conditions will persist; Climate Explorer - increase in number of dry days	3	Almost Certain

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Hazard #	Regional Hazards Impacting DOE Site	Hazard Description	Secondary Impacts	Site Resource Implications	Compounding Hazards	Current Annual Frequency at the Site	Current Hazard Likelihood	Projected Effect of Climate Change	Confidence in Projection	Sources of Information	Projections from NOAA Climate Resilience Toolkit	Projected Annual Frequency at the Site with Climate Change	Projected Hazard Likelihood with Climate Change
7	Other	Thunderstorm: combined precipitation, wind, and lightning	Hail and heavy winds, wildfire risk due to high winds and lightning strikes, flooding, erosion	Utilities, water, energy, facilities, workforce safety, emergency response, financial resources, site ecology, cultural resources	Wildfire	2	Almost Certain	Increase	Low Confidence in Exact Patterns	Wright (2018), Meyer and Jin (2016), Garfin et al. (2016), Trapp et al. (2007)	Weather.gov - weather.gov/abq/svrwxclimo; average of 26 thunderstorm wind events per year 1979–2009, and average of 70 per year 2009–2019	3	Almost Certain
8	Flooding and Erosion	Increased flooding and erosion events	Water availability, local ecology mortality, water quality, erosion especially relevant in burn scars	Utilities, water, energy, facilities (roads, buildings), workforce, emergency response, financial resources, site ecology, cultural resources	Risk highest in places where vegetation changes due to water availability or where wildfire has increased runoff potential	0.3	Anticipated	Increase	Not mentioned in NCA4	Stephens (2018), Gonzales et al. (2018), Walterscheid et al. (2013), Romero et al. (2018), Easterling et al. (2017), Qiu (2021), Garfin et al. (2016), Pagan (2016), Davenport et al. (2020)	FEMA - NMflood.org; FloodFactor.com Los Alamos flood risk is minor to moderate but increasing	1	Likely
9	Wildfire	Increased wildfire frequency	Tree mortality, erosion, flooding, worker safety, labor capacity, facilities safety, air quality	Utilities, water, energy, facilities, workforce, emergency response, financial resources, site ecology, cultural resources	Drought, vegetation health and mortality, thunderstorm events, wind events, increased average temperature, extreme heat wave frequency and intensity, changes to precipitation patterns	0.2	Anticipated	Increase	High Confidence	SEA (2019), Shurter et al. (2016), Abatzoglou and Williams (2016), Allen et al. (2010), Garfin et al. (2014), Gonzales et al. (2018), Jolly et al. (2015), Keyser et al. (2020), Loehman et al. (2018), Mueller et al. (2020), Wehner et al. (2017)	ncics.org - NM state summary; both frequency and severity of wildfires are projected to increase	1	Likely
10	Strong Wind	Increased severe windstorm events	Tree mortality, worker safety, air quality	Workforce, site access, site ecology, financial resources, facilities, utilities	Thunderstorms, vegetation change (less wind protection)	3	Almost Certain	Increase	Not mentioned in NCA4	March 2019 and Dec. 2021 events, O'Grady et al. (2021), Garfin et al. (2014), Hansen et al. (2020), Dewart et al. (2017), Ridder et al. (2022)	Data drawn from storm events database: ncdc.noaa.gov	3	Almost Certain

Appendix E VARP Risk Matrix

Table E-1. VARP Risk Scores for Specialized or Mission-Critical Equipment

(b) (7)(E), (b) (7)(F)

[redacted]

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(b) (7)(E), (b) (7)(F)

[redacted]

Appendix E VARP Risk Matrix

(b) (7)(E), (b) (7)(F)

[redacted]

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(b) (7)(E), (b) (7)(F)

[redacted]

Table E-2. VARP Risk Scores for Energy Generation and Distribution Systems

(b) (7)(E), (b) (7)(F)

[redacted]

(b) (7)(E), (b) (7)(F)

[redacted]

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(b) (7)(E), (b) (7)(F)

[redacted]

Table E-3. VARP Risk Scores for Onsite Waste Processing

(b) (7)(E), (b) (7)(F)

[redacted]

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(b) (7)(E), (b) (7)(F)

[redacted]

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Table E-4. VARP Risk Scores for Site Buildings

(b) (7)(E), (b) (7)(F)

[redacted]

~~**OFFICIAL USE ONLY**~~

(b) (7)(E), (b) (7)(F)

[redacted]

Table E-5 VARP Risk Scores for Water and Wastewater Systems

(b) (7)(E), (b) (7)(F)

[redacted]

~~OFFICIAL USE ONLY~~

(b) (7)(E), (b) (7)(F)

Table E-6. VARP Risk Scores for IT and Telecommunication Systems

(b) (7)(E), (b) (7)(F)

Appendix F Complete Information from SMEs for Proposed Resilience Solutions

The resilience solutions identified by the VARP Planning Team and SMEs from around the site were selected to mitigate the vulnerabilities identified in the VARP Risk Matrix created in Step 6. All solutions were identified as *potential* solutions for vulnerable critical asset and hazard pairings. The analysis conducted used the following table to determine which resilience solutions would be tracked in the final portfolio on the DOE Sustainability Dashboard using the following criteria:

- *Solution*: Identify the solution being considered
- *Brief Description*: Provide an overview of the solution and why it is needed
- *Critical Asset(s)*: Identify the assets/infrastructure identified in Step 2 that will be made more resilient by the solution
- *Hazards*: Identify the anticipated climate-related impact(s) being addressed by the solution
- *Expected Effectiveness:* Identify the resilience solution's capacity to reduce the overall risk; risk is defined as the combined magnitude of consequences and likelihood that a vulnerability will affect the site
- *Feasibility*: Provide an assessment of whether the solution can be implemented, financially, legally, technically, and organizationally
- *Cost and Funding Type*: Estimate the expected monetary cost and likely funding source(s) (Indirect/Direct, Performance Contracts, or Hybrid/Other)
- *Site Benefit*: Provide the benefits that the DOE site will receive from the resilience solution
- *Community Impact*: Provide the impacts (positive or negative) that the surrounding community will receive from the resilience solution. If the impacts will affect an energy or environmental justice community, please specify.
- *Environmental Impact*: List benefit or detriment to the site ecology and GHG emissions, if any
- *Timing:* Planned start and end dates
- *Implementation Status:* Current stage of project
    - Identified: needs reliable estimates
    - Confirmed: estimates are reliable
    - Planned: cost effective & will fund
    - Funded: funds authorized
    - Awarded: funds awarded & work begun
    - Operational: in place & fully functional
    - Cancelled: no intention to fund
- *Recommended Approach*: Provide the site's recommended path forward
- *Priority Rank:* Ranking of importance of project to mitigating vulnerabilities at the Laboratory (High, Medium, or Low)

Appendix F Complete Information from SMEs for Proposed Resilience Solutions

Table F-1. All Proposed Resilience Solutions (For undefined acronyms, see Acronyms and Abbreviations in Section 10.)

(b) (5), (b) (7)(E), (b) (7)(F)

[redacted]

~~OFFICIAL USE ONLY~~

(b) (5), (b) (7)(E), (b) (7)(F)

[redacted]

~~**OFFICIAL USE ONLY**~~

(b) (5), (b) (7)(E), (b) (7)(F)

[redacted]

(b) (5), (b) (7)(E), (b) (7)(F)

[redacted]

~~OFFICIAL USE ONLY~~

(b) (5), (b) (7)(E), (b) (7)(F)

[redacted]

~~OFFICIAL USE ONLY~~

(b) (5), (b) (7)(E), (b) (7)(F)

[redacted]

~~OFFICIAL USE ONLY~~