A Climate Change Vulnerability Assessment Report for the National Renewable Energy Laboratory

May 23, 2014—June 5, 2015

J. Vogel, M. O'Grady, and S. Renfrow
Abt Environmental Research
Boulder, Colorado

NREL Technical Monitor: Lissa Myers

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Subcontract Report
NREL/SR-3500-64174
September 2015

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NATIONAL RENEWABLE ENERGY LABORATORY

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List of Acronyms

BAE	building area engineer
CCRP	Climate Change Resiliency and Preparedness
DOE	U.S. Department of Energy
ESIF	Energy Systems Integration Facility
GCM	general circulation model
GHG	greenhouse gas
HVAC	heating, ventilating, and air conditioning
IT	information technology
NREL	National Renewable Energy Laboratory
NWTC	National Wind Technology Center
PEMP	Performance Evaluation and Measurement Plan
PV	photovoltaic
RCP	Representative Concentration Pathway
RSF	Research Support Facility
SITE Ops	Sustainability, Infrastructure Transformation, and Engineering Operations
STM	South Table Mountain campus

Executive Summary

Introduction

Observations and projections indicate that the Front Range of Colorado, including the cities of Golden and Louisville, are experiencing a change in climate. In winter 2014, the National Renewable Energy Laboratory (NREL), which has one site in Golden and one near Louisville, worked with Abt Environmental Research[1] to develop a vulnerability assessment and a resiliency action plan. These efforts, which were part of NREL's Climate Change Resiliency and Preparedness project, were funded by the U.S. Department of Energy's Sustainability Performance Office; lessons learned from this pilot project may inform resiliency planning at other U.S. Department of Energy sites.

This Executive Summary presents a combined overview of the two stages of the project, which culminated in this report and *A Resiliency Action Plan for the National Renewable Energy Laboratory* (Vogel et al. 2015). This report covers the vulnerability assessment, but this Executive Summary covers both the vulnerability assessment and the resiliency action plan. The subsequent resiliency action plan report takes the results of this vulnerability assessment and develops and evaluates actions for NREL to consider for reducing those vulnerabilities.

NREL's Vulnerabilities

To begin identifying vulnerabilities that are specific to NREL, the project team first developed a framework to explore NREL's unique circumstances. This framework combines three key organizational objectives, based on NREL's *2014 Annual Plan and Performance Evaluation and Measurement Plan* (NREL 2014) goals and six key resources that are deemed essential to the continued operation of NREL's facilities and research (Table ES-1).

Table ES-1. Impacts Framework

Key Objectives	Key Resources[2]					
	Water	Energy	Physical Space	Site Access	Workforce	Research and Mission
1. Execute research, analysis, and deployment						
2. Deliver facility stewardship						
3. Sustain laboratory operations						

The framework was used to conduct five in-person work group interviews with small groups of NREL staff members to brainstorm a comprehensive list of NREL's vulnerabilities from climate change. The U.S. Environmental Protection Agency's Climate Ready Estuaries Program (EPA 2013) method was used as a guide to perform a risk analysis to discern NREL's highest risk climate change vulnerabilities.

[1]NREL originally contracted with Stratus Consulting Inc., which later became part of Abt Environmental Research, a wholly owned subsidiary of Abt Associates.
[2]For the Impacts Framework NREL defined key resource as a system, program, material, component, or other resource needed to achieve the key objectives.

The risk analysis considered the magnitude of the consequences of vulnerabilities on NREL's key resources, should the potential vulnerability occur. Climate change experts assessed and scored the likelihood that climate variables associated with each vulnerability will change. The magnitude of consequence score was then combined with the likelihood score to determine an overall risk score for the vulnerability; this score was used to determine which vulnerabilities the resiliency action plan would address.

Table ES-2 presents an example of how the consequence and likelihood scores were combined to determine an overall risk score. Red indicates high risk and dark orange indicates medium-to-high risk.

Table ES-2. Example Vulnerability to Workforce and Its Scoring

Vulnerability	Consequence	Climate Variable	Likelihood	Risk Score	Overall Risk Score
Staff may not be able to conduct outdoor research and other outdoor activities	Medium	Increased lightning patterns and longer lightning season	Medium-to-high	Medium-to-high	Medium-to-high
		Increased extreme heat events	High	Medium-to-high	

Only the vulnerabilities with high and medium-to-high overall risk scores were selected for inclusion in the resiliency action plan (see Vogel et al. 2015). Table ES-3 lists the vulnerabilities that received the highest overall risk scores.

Table ES-3. Vulnerabilities with High and Medium-to-High Overall Risk Score

Key Resource	Vulnerability	Associated Climate Variables Likely To Change	Overall Risk Score*
Water	Each campus has only one water supplier and no backup options	Stream flows, precipitation, drought, evapotranspiration	High
	NREL may not be able to continue to rely on evaporative cooling and chillers	Temperature	Medium-to-high
Energy	NREL has only one electricity supplier and depends on electricity to support mission-critical activities, including information technology connectivity	Temperature, precipitation, lightning, fire	High
Physical space	Landslides may occur because the South Table Mountain campus buildings are close to the mesa slope	Precipitation and fire	High
	Site flooding may occur because the South Table Mountain campus has poor drainage	Precipitation	Medium-to-high
	Damage to climate-sensitive equipment may disrupt research	Temperature, precipitation, lightning, fire	Medium-to-high
Site access	Key staff may not be able to access NREL's sites to respond to emergencies and to conduct research; some situations may require staff redundancy	Temperature, precipitation, fire, lightning	Medium-to-high

Key Resource	Vulnerability	Associated Climate Variables Likely To Change	Overall Risk Score*
Workforce	Staff may not be able to conduct outdoor research and other outdoor activities	Temperature and lightning	Medium-to-high
Research/ mission	NREL's reputation as a sustainable campus may be damaged if it moves to traditional air conditioners for space cooling	Temperature	Medium-to-high

* Red indicates high risk and dark orange indicates medium-to-high risk.

Resiliency Actions

During the resiliency action plan stage of the project, the team categorized each high-risk and medium-to-high-risk vulnerability as one to be mitigated, transferred, accepted, or avoided.[3] Eight of the nine vulnerabilities fell in the category of mitigate; only one, "NREL's reputation as a sustainable campus may be damaged," fell in the accept category with no action needed.

Six in-person[4] work group interviews were conducted with small groups of NREL staff members to identify a comprehensive list of potential resiliency actions that could address each of the eight vulnerabilities identified for mitigation (see Table ES-3). Each resiliency action was scored based on three evaluation criteria: effectiveness, feasibility, and cost. These score assignments were based on the preliminary discussions of the work groups and on the team members' professional judgment; work group participants then refined and validated these preliminary scores. One of three recommended approaches was assigned to each action:

- *Do now* (green) was reserved for resiliency actions that were no- or low-regrets actions that NREL should reasonably pursue, even if climate change is not considered.
- *Continue evaluating* (orange) was reserved for resiliency actions that needed further exploration before they could be either endorsed as *do now* actions or completely set aside.
- *Remove from consideration* (red) was reserved for resiliency actions that were untenable for one or more reasons and that should be set aside (see Vogel et al. 2015).

Summary of Findings

Table ES-4 summarizes the resiliency actions, categorized by key resource and vulnerability, which NREL may wish to pursue in the next stage of the project. The table also includes the overall risk score and the project team's recommended approach. These recommendations are preliminary; additional analysis may be necessary to ensure that any selected actions best reflect NREL's capabilities and priorities. For a full discussion of next steps, including best practices in the field of resiliency planning based on the experiences of other organizations, refer to Vogel et al. (2015) Section 4.

[3]Categories were based on those in Climate Ready Estuaries (EPA 2013).
[4]One telephone interview was conducted because of logistical constraints.

Table ES-4. Vulnerabilities, Resiliency Actions, and High-Level Scores[a]

Key Resource	Vulnerability	Overall Risk Score	Resiliency Actions	Recommended Approach
Multiple	Cross-cutting solutions identified to mitigate across multiple vulnerabilities[b]	Not applicable	Integrate climate considerations into existing operations and practices	Do now
			Create and implement a climate monitoring and communication system	Do now
Water	Each campus has only one water supplier and no backup options	High	Develop a water-shortage contingency plan	Do now
			Connect the National Wind Technology Center to a public water system	Continue evaluating
	NREL may not be able to continue to rely on evaporative cooling and chiller	Medium-to-high	Create and implement a climate monitoring and communication system	Do now
			Add conventional backup air conditioning	Continue evaluating
Energy	NREL has only one electricity supplier and depends on electricity to support mission-critical activities, including information technology connectivity	High	Improve demand management	Do now
			Install a battery supply	Do now
			Establish a microgrid	Continue evaluating
Physical space	Site flooding and landslides may occur at the South Table Mountain campus[c]	High/medium-to-high[c]	Evaluate and redesign the site to improve drainage and slope stability	Do now
	Damage to climate-sensitive equipment may disrupt research	Medium-to-high	Integrate climate considerations into existing operations and practices	Do now
			Retrofit climate-sensitive equipment	Continue evaluating

Key Resource	Vulnerability	Overall Risk Score	Resiliency Actions	Recommended Approach
Site access	Key staff may not be able to access NREL's sites to respond to emergencies and to conduct research; some situations may require staff redundancy[d]	Medium-to-high	No resiliency action proposed because NREL is already addressing this issue[d]	No recommended approach beyond current NREL efforts[d]
Workforce	Staff may not be able to conduct outdoor research and other outdoor activities	Medium-to-high	Integrate climate considerations into existing operations and practices	Do now
			Create and implement a climate monitoring and communication system	Do now
			Install outdoor structures for protection from hazardous weather events	Continue evaluating

[a] Table ES-4 presents only the vulnerabilities that received a medium-to-high or high overall risk score, fell in the mitigate category and received a do now or continue evaluating recommendation (see Executive Summary Section NREL's Vulnerabilities).
[b] During the resiliency action plan work group discussions, various cross-cutting resiliency actions came to light; these actions apply to several vulnerabilities.
[c] In the vulnerability assessment stage of the project, landslides and flooding were separate vulnerabilities; their resiliency actions would be similar so they were later combined.
[d] A resiliency action plan work group was not convened to discuss the inability of key staff to access NREL's sites because NREL is already addressing this vulnerability—which is a concern even without considering climate change—through its Continuity of Operations Plan.

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1 Introduction

The U.S. Department of Energy's (DOE's) National Renewable Energy Laboratory (NREL), in Golden, Colorado, focuses on renewable energy and energy efficiency research. Its portfolio includes advancing renewable energy technologies that can help meet the nation's energy and environmental goals. NREL seeks to better understand the potential effects of climate change on the laboratory—and therefore on its mission—to ensure its ongoing success. Planning today for a changing climate can reduce NREL's risks and improve its resiliency to climate-related vulnerabilities.

This report presents a vulnerability assessment for NREL. The assessment was conducted in fall 2014 to identify NREL's climate change vulnerabilities and the aspects of NREL's mission or operations that may be affected by a changing climate.

The report begins with a background on the impetus for the assessment, continues with the assessment, and concludes with information about the next steps in the adaptation process. Appendices A, B, and C include an overview of the region's latest climate science and recent extreme events, and Appendix D is a document that the project team created to support the vulnerability assessment process.

NREL selected a risk management method established by the U.S. Environmental Protection Agency's Climate Ready Estuaries Program (EPA 2013) as a guide for the analysis. The risk management process presents a systematic way to look at potential climate-related risks and the potential impact of those risks if they were to happen on achieving organizational goals.

The vulnerability assessment is the first part of a two phase project collectively called NREL's Climate Change Resiliency and Preparedness Project (CCRP). NREL hired adaptation experts from Stratus Consulting Inc. (now known as Abt Environmental Research (Abt)), an environmental consulting firm with demonstrated local adaptation planning experience and established relationships with climate science experts from Western Water Assessment (WWA) to lead the project. WWA a consortium of climate scientists from the University of Colorado at Boulder and the National Atmospheric and Oceanic Administration Regional Integrated Sciences and Assessments program and other regional partners provided specific climate science analysis that supported the project. Abt and WWA in partnership with a core group of NREL project staff (together referred to as "the project team") executed the CCRP project.

1.1 Climate Change along Colorado's Front Range

The major motivation for NREL's vulnerability assessment was climate change. Climate science indicates that climate is already changing and will continue to change (Stocker et al. 2013). The Front Range of Colorado, including NREL's sites in Golden and near Louisville, is likely to experience rising temperatures, changes in precipitation, and increasingly severe weather events. Section 1.1.1 through Section 1.1.4 summarize the current state of knowledge about the observed and projected effects of climate change on Colorado.[5] For more details, see Appendix A.

[5]This summary and Appendices A, B, and C were developed based on the expertise of climate experts at the Western Water Assessment, a National Oceanic and Atmospheric Administration Regional Integrated Sciences and Assessments program associated with the University of Colorado.

1.1.1 Observations

Ongoing climate observations show some changes in Colorado and along the Front Range and indicate:

- A warming trend, particularly since the mid-1990s
- No long-term discernable trend in annual precipitation amounts, April 1 snowpack, heavy precipitation, or flooding events
- A 1- to 4-week shift earlier in the timing of snowmelt and peak spring runoff that is likely due to a combination of higher spring temperatures and enhanced solar radiation absorption from deposits of dust on snow (Lukas et al. 2014)
- An increase in drought conditions in the last 30 years that reflects the combined effects of below-average precipitation and higher temperatures since 2000.

1.1.2 Climate Projections

Projections of climate in Colorado and along the Front Range rely on climate models.[6] These projections vary in severity depending on the atmospheric greenhouse gas (GHG) concentration trajectory and emissions scenarios used. In summary, projections show:

- Increases in statewide temperatures by 2050 of +2.5°F to +5°F, relative to the 1971–2000 period under a moderate-emissions scenario (RCP 4.5[7]); and of +3.5°F to +6.5°F under a high-emissions scenario (RCP 8.5) (Lukas et al. 2014)
- Disagreement about average annual precipitation changes, with a –5% to +6% change by 2050 under a moderate-emissions scenario (RCP 4.5); and a –3% to +8% change under a high-emissions scenario (RCP 8.5)
- Increases in winter precipitation
- An even chance of increases or decreases in annual stream flow along the Front Range
- A 1- to 3-week shift earlier in the timing of spring runoff by 2050 that will cause late summer and early autumn runoff to decrease (Lukas et al. 2014)
- Decreases in relative humidity along the Front Range, with the greatest decreases in spring and summer (Wright et al. 2010; Pierce et al. 2013).[8]

1.1.3 Extreme Event Projections

Extreme events (heat waves, severe drought, heavy precipitation, and winter storms) generally have a much greater effect on socioeconomic and ecosystem structures and functionality than do changes in climate averages. Their sudden or single-event nature makes extreme events harder to

---

[6] Climate models, or general circulation models (GCMs), are numerical models that simulate the physical processes in the atmosphere, ocean, cryosphere, and land surface. They are the most sophisticated tools available for simulating the response of the global climate system to increasing GHG concentrations. (See Appendix A.)

[7] The Representative Concentration Pathways (RCPs) provide various projections of GHG concentrations to be used in climate change analysis and predictions. The four pathways: RCP8.5, RCP6, RCP4.5, and RCP2.6 come from the Intergovernmental Panel on Climate Change Fifth Assessment Report.

[8] This climate variable features no vulnerabilities, because only an increase in relative humidity would pose a problem for NREL.

prepare for and adjust to than incremental changes over longer periods. In summary, the model projections of extremes in Colorado and along the Front Range show, with varying levels of confidence:

- Increases in the frequency of intense heat waves (Lukas et al. 2014).
- A sharp increase in the ratio of new record-high temperatures to record-low temperatures during the 21st century (Meehl et al. 2009). Observations already indicate that the frequency of new record-high temperatures has doubled in relation to new record-low temperatures in the United States; in the absence of climate change, the ratio should be one-to-one.
- A greater proportion of precipitation will be received from the heaviest precipitation events because of climate change (Wuebbles et al. 2014); this is partly related to the increases in moisture and energy that are associated with individual storm systems. The available observations in Colorado do not yet provide discernable evidence of this trend; however, other parts of the United States and the world have experienced increases in the frequency of heavy precipitation events (Melillo et al. 2014).
- Transition from hail to rain along the Front Range as temperatures warm; this results in higher flash-flood risks (Garfin et al. 2013).
- Intensified drought caused by future warming and its influence on the hydrologic cycle—earlier snowmelt, increased evapotranspiration, and drier soils (Garfin et al. 2013).
- Intensified heat waves, droughts, and wildfires by 2050 caused by climate change (Lukas et al. 2014).

1.1.4 A Note about Climate Variability

Natural climate variability strongly influences climate and weather extremes. Even under a severe climate change scenario, climate variability will continue to influence interannual to interdecadal changes in climate, weather, and associated climate extremes.

In the Intermountain West, natural climate variability is modulated primarily by processes that are related to the ocean circulation on interannual, interdecadal, and multidecadal timescales and accompanying atmospheric teleconnections. These include the following phenomena:

- **The El Niño Southern Oscillation.** This large-scale ocean-atmosphere climate interaction is linked to a periodic warming in sea surface temperatures across the central and east-central equatorial Pacific.
- **The La Niña Southern Oscillation.** This represents periods of below-average sea surface temperatures across the east-central equatorial Pacific.
- **The Pacific Decadal Oscillation.** This robust, recurring pattern of ocean-atmosphere climate variability is centered over the midlatitude Pacific basin.
- **The Atlantic Multidecadal Oscillation.** This ocean current with different modes on multidecadal time scales affects the North Atlantic Ocean, especially sea surface temperatures.

Colorado tends to be drier in years that combine a La Niña, a negative Pacific Decadal Oscillation, and a positive Atlantic Multidecadal Oscillation.

Scientists currently cannot accurately predict these phenomena at yearly to decadal timescales or understand how they are affected by climate change. For example, scientists do not yet know whether Colorado will experience more frequent or intense El Niño or La Niña events because of climate change. Therefore, interannual and interdecadal climate changes are uncertain.

1.2 NREL's Climate Change Resiliency and Preparedness Project

DOE has been formally planning for climate change at a national level since 2011. Its efforts include adding climate change as an integral part of its 2014–2018 Strategic Plan (DOE 2014b), creating a Climate Change Adaptation Planning Work Group, and producing an agency-wide Climate Adaptation Plan (DOE 2014a).

DOE is also working to better understand how its sites can become more resilient to changes in climate. As part of the Fiscal Year 2015 Site Sustainability Plan that each DOE site must submit, DOE has requested that each site complete the DOE Climate Change Adaptation Screening Assessment to assess historical climate impacts and any adaptation strategies that have been implemented. DOE's Sustainability Performance Office has supported pilot projects at four of DOE's sites—NREL, Idaho National Laboratory, Pacific Northwest National Laboratory, and the Thomas Jefferson National Accelerator Facility—for climate change adaptation site planning. The Sustainability Performance Office will use the lessons learned from these pilot projects to provide adaptation planning guidance for other DOE sites.

NREL launched its CCRP project in summer 2014. The project has two stages: (1) a vulnerability assessment to identify how climate change could affect NREL's ability to meet its mission, and (2) a resiliency action plan to explore adaptation options to enhance NREL's resiliency to climate change. The remainder of this report discusses the vulnerability assessment.

2 Vulnerability Assessment

The ultimate goal of the vulnerability assessment was to identify NREL's highest risk vulnerabilities to climate change so that the project team could evaluate relevant resiliency options. To accomplish this, the project team worked sequentially to:

- Create an impacts framework to help identify potential vulnerabilities.
- Develop risk-based scores for NREL's potential vulnerabilities.
- Identify NREL's highest risk vulnerabilities.

An important aspect of the work on the vulnerability assessment was periodic input and guidance from the NREL CCRP steering committee. The committee, which first met before NREL hired Abt Environmental Research, consists of representatives from across the laboratory.

2.1 Creating an Impacts Framework

The climate change impacts framework, which was developed as the first step in identifying NREL's potential climate change vulnerabilities, consisted of three key objectives and six key resources that were used to identify NREL-specific climate change vulnerabilities. This approach was selected based on feedback and input from the steering committee.

The impacts framework and the guiding questions it generated helped the project team to conduct a comprehensive review of NREL's potential climate change vulnerabilities through interviews with staff work groups, or focus groups, which are described in the following sections.

2.1.1 Identify Key Resources and Objectives

To develop the impacts framework, the project team first identified NREL's key resources and organizational objectives. The key resources were selected during extensive discussions about the operations, practices, and procedures that NREL commonly employs to conduct its work. These resources are essential to the continued operation of NREL's facilities and research areas. The project team also identified NREL's key objectives—the laboratory's mission-critical areas of work—based on NREL's *2014 Annual Plan and Performance Evaluation and Measurement Plan* (PEMP) goals (NREL 2014). The PEMP is a resource for identifying key organizational objectives because it is a guiding document for meeting annual DOE goals.

The following three key objectives were identified, with associated Fiscal Year 2014 PEMP goals listed as subbullets:

1. Execute research, analysis, and deployment
    - PEMP Goal 1.0—Advancing Science and Technology
    - PEMP Goal 4.0—Credible and Objective Analysis and Decision Support
    - PEMP Goal 5.0—Accelerating Commercialization and Increasing Deployment
2. Deliver facility stewardship
    - PEMP Goal 2.0—Stewarding Major Research Facilities

3. Sustain laboratory operations
    - PEMP Goal 6.0—Environment, Safety, and Health Management
    - PEMP Goal 7.0—Business Operations
    - PEMP Goal 8.0—Infrastructure Development and Site Operations
    - PEMP Goal 9.0—Security and Emergency Management.

Table 1 shows the final list of key resources and objectives that informed the vulnerability assessment effort.[9]

Table 1. Impacts Framework

Key Objectives	Key Resources					
	Water	Energy	Physical Space	Site Access	Workforce	Research and Mission
1. Execute research, analysis, and deployment						
2. Deliver facility stewardship						
3. Sustain laboratory operations						

2.1.2 Develop Questions To Uncover Potential Vulnerabilities

The matrix format of Table 1 provided a structure for developing 38 questions that guided interviews with NREL staff work groups. These questions aimed to explore the role that climate factors played in meeting the three key objectives across each of the six key resources. (See Appendix E for the complete list of questions.)

2.2 Identifying NREL's Potential Vulnerabilities

Five in-person work group interviews with small groups of NREL staff were conducted to identify a comprehensive list of NREL's potential vulnerabilities associated with climate change. The participants were selected and grouped based on their depth of expert knowledge about NREL systems: their diverse perspectives, expertise, interests, and backgrounds. The work group discussions involved a brief project overview, a review of projected climate changes for the Colorado Front Range (Appendix B), and the aforementioned list of guiding questions, which flowed from the impacts framework. The work group discussions focused on identifying and ranking potential climate-related vulnerabilities in specific areas at NREL:

[9] For clarity and ease moving forward into the resiliency action plan stage of the CCRP effort, some categories of potential vulnerability that were initially approached as belonging to separate key resources were combined. For example, water and heating, ventilating, and air conditioning (HVAC) now appear together as Section 2.2.1 and concerns about workforce redundancy during emergencies were incorporated into Section 2.2.3. Similarly, participants discussed at length an additional key resource that was loosely translated as NREL's research and mission. Given the strong focus of the discussions, this additional key resource has been included to ensure its consideration as an area of potential vulnerability; see Section 2.2.6.

- Building operations
- Facilities/building area engineers (BAEs)
- Laboratory operations
- National Wind Technology Center (NWTC) operations
- Researchers and analysts
- South Table Mountain (STM) site operations.

The staff work group discussions were used as the basis for identifying NREL's potential climate-related vulnerabilities by key resource. A method established by the U.S. Environmental Protection Agency's Climate Ready Estuaries Program (EPA 2013) was used to conduct a risk analysis to discern NREL's highest risk vulnerabilities to climate change.

The risk analysis considered the magnitude of the consequences of potential vulnerabilities for NREL's key resources, should the potential vulnerability occur (see Box 1) and the likelihood that climate variables associated with the potential vulnerability will change (see Box 2). The risk analysis culminated by combining the magnitude of consequence score with the likelihood score to determine a risk score for each climate variable and, finally, an overall risk score for each vulnerability (see Box 3).

Sections 2.2.1 through 2.2.6 present highlights from the risk analysis for the vulnerabilities identified, together with a detailed table. The narrative focuses only on the consequence and likelihood scores that ultimately led to an overall risk score of medium-to-high or high (**bolded**). The tables in each section provide details about the consequences, likelihoods, risks, and overall risk scores.

Box 1. Scoring Potential Vulnerabilities by Their Magnitude of Consequence

A consequence score was determined for each potential vulnerability; *consequence* was defined as its impact on the key resource, should the potential vulnerability occur, as measured against the three key objectives described in Section 2.1.

The team considered the following five categories of consequence:

- The effect on internal operations, including the scope and duration of service interruptions, reputational risk, and the potential to encounter regulatory problems
- The effect on capital and operating costs, including all capital and operating costs and revenue implications caused by the climate change impact
- The number of NREL staff affected
- The health effects on NREL staff, including worker safety
- The environmental effects, including the release of toxic materials, effects on biodiversity, changes to the area's ecosystem, and impacts on historic sites.

The categories considered when assigning a high, medium, or low consequence score were:

- **Low magnitude of consequence.** The three key objectives would either experience no major effect, or an in-place backup system could cover the failure.
- **Medium magnitude of consequence.** The three key objectives would be somewhat affected.
- **High magnitude of consequence.** The three key objectives would be significantly affected. For example, NREL depends on water across the organization, but each site relies on a single water provider. Service interruptions would hinder almost every staff member's work and have serious implications for NREL's ability to achieve Key Objectives 1 and 3.

Box 2. Scoring Climate Variables by the Likelihood of Change

Climate experts from the Western Water Assessment assigned a score for the likelihood that specific climate variables will change based on current projected climate changes for the Front Range (Table 2). A variable was assigned a higher likelihood of occurrence if the climate models demonstrated strong agreement about its direction and degree of change. A variable was assigned a lower likelihood of occurrence if the models showed less agreement. In addition to the typical scores of low, medium, and high, the climate experts on the project team included low-to-medium and medium-to-high.

Table 2. Climate Variables of Concern and Associated Likelihood of Changing

Colors indicate the likelihood of change, from red (high likelihood) through yellow (low likelihood)

Climate Variable	Likelihood
Increased annual average temperatures Increased extreme heat events Earlier peak stream flows Increased likelihood of fire and longer fire season Increased minimum nighttime temperatures	High
Increased intensity of summer rainfall Increased intensity of winter storms Increased drought intensity Increased evapotranspiration Changes in lightning patterns and longer lightning seasons Reduction in late summer stream flow Reduction in raw water quality Higher particulate loading Increased intensity of storm events	Medium-to-high
Increased pollen count Landslides	Medium
Increased likelihood of ice storms	Low-to-medium
Shifts in annual and seasonal precipitation amounts Changes in total annual stream flows Changes in wind patterns	Low

Box 3. Scoring Each Potential Vulnerability for Risk and Overall Risk

The final step in scoring each potential vulnerability was to assess it for risk; the risk score was a combination of the consequence score (Box 1) and the climate variable likelihood score (Box 2). At this point the vulnerability is no longer referred to as “potential” because the risk score or overall risk score can be used to categorize vulnerabilities into highest risk vulnerabilities and lower tier vulnerabilities. Some low-risk vulnerabilities may not be worthy of further consideration. Most potential vulnerabilities were associated with more than one climate variable. Thus, a risk score was assigned to each vulnerability/climate variable combination; those risk scores were then used to determine an overall risk score for each vulnerability, irrespective of the specific climate variable.

A risk score matrix was used to develop a risk score for each potential vulnerability/climate variable combination to define a risk score of low, low-to-medium, medium, medium-to-high, or high (Figure 1). The consequence and likelihood scores were then averaged to establish a risk score for each vulnerability/climate variable combination. When a score fell between two possible rankings, the higher of the two scores was used to determine a risk score. For example, a potential vulnerability that received a high consequence and a low-to-medium likelihood score received a medium-to-high risk score.

The risk scores associated with each vulnerability/climate variable combination were compared to determine an overall risk score for each vulnerability; the highest risk score for that vulnerability was selected. Climate variables were not prioritized. For example, if a vulnerability was associated with three climate variables, and the risk score associated with two ranked as a low-to-medium risk and one as a medium-to-high risk, the overall risk was ranked medium-to-high.

Vulnerabilities that received a medium-to-high or high overall risk score are considered further in the resiliency action plan. Vulnerabilities that received a medium overall risk score would be good candidates to consider in a subsequent round of the resiliency action plan. Vulnerabilities that received a low or low-to-medium overall risk score should be monitored over time but do not require immediate action.

Figure 1. Risk score matrix

Consequence \ Likelihood	Low	Low-to-medium	Medium	Medium-to-high	High
High	Medium	Medium-to-high	Medium-to-high	High	High
Medium	Low-to-medium	Medium	Medium	Medium-to-high	Medium-to-high
Low	Low	Low-to-medium	Low-to-medium	Medium	Medium

2.2.1 Water

Water is an essential resource for the STM and NWTC sites. The STM site consumes approximately 20 million gallons of water annually. The end uses of water are broken down as follows: domestic (35%), cooling systems (30%), evaporative cooling (15%), irrigation (10%), research (5%), and leakage (5%). The two most significant water-related vulnerabilities identified were NREL’s reliance on a **single water supplier** for each campus and its use of **evaporative cooling and chillers**. The Consolidated Mutual Water Company provides water to the STM through a piping system. One independent supplier delivers water to the NWTC by truck. The water is stored onsite in short-term storage tanks. NREL does not have the capacity for significant backup supply at either site and Colorado water law prohibits the retention of rainfall and reuse of water resources. Water supply ranked as a high-consequence vulnerability, and evaporative cooling and chillers ranked as a medium-consequence vulnerability because of their importance to Key Objectives 1 and 3, laboratory research and operations.

Climate experts scored seven climate variables that can affect water supply with a medium-to-high or high likelihood:

- Earlier peak stream flows, which could mean less water is available in late spring and summer
- Reduced late summer stream flows, which could also lead to water shortages in late summer and fall
- An increase in the intensity of summer rainfall, which could lead to flooding events that impair water quality or damage the water supply infrastructure
- An increase in the intensity of winter storms, which could lead to water supply infrastructure failure
- An increase in drought intensity, which could increase water demand and put pressure on NREL's single water suppliers for each campus
- An increase in evapotranspiration, which could lead to greater passive loss of water supplies and consequent water shortages
- An increase in fires and fire season length, which could lead to water supply disruption because of reservoir sedimentation and water quality impairment.

Climate experts scored one climate variable that can affect evaporative cooling and chillers with a high likelihood: an increase in average annual temperature, which could reduce the efficiency and effectiveness of evaporative cooling and chillers.

Because of their risk scores, water supply has an overall risk score of high and the reliance on evaporative cooling and chillers has an overall risk score of medium-to-high. Table 3 provides full details about the consequence, likelihood, risk, and overall risk scores for water.

Table 3. Water: Consequence, Likelihood, Risk, and Overall Risk Scores*

Vulnerability	Consequence	Climate Variable	Likelihood	Risk Score	Overall Risk Score
Each campus has only one water supplier and no backup options	High	Earlier peak stream flows	High	High	High
		Changes in total annual stream flows	Low	Medium	
		Reduced late summer stream flows	Medium-to-high	High	
		Increased intensity of summer rainfall	Medium-to-high	High	
		Increased intensity of winter storms	Medium-to-high	High	
		Shift in annual and seasonal precipitation amounts	Low	Medium	
		Increased drought intensity	Medium-to-high	High	
		Increased evapotranspiration	Medium-to-high	High	
		Increased likelihood of fire and longer fire season	High	High	
NREL may not be able to continue to rely on evaporative cooling and chillers	Medium	Increased annual average temperatures	High	Medium-to-high	Medium-to-high
The need for high-quality water for certain research areas may not be met	Low	Reduced raw water quality	Medium-to-high	Medium	Medium
		Reduced late summer stream flows	Medium-to-high	Medium	
		Increased likelihood of fire and longer fire season	High	Medium	
		Increased intensity of summer rainfall	Medium-to-high	Medium	
		Higher particulate (sediment) loading	Medium-to-high	Medium	

*See Box 1, Box 2, and Box 3 for details about scoring methodology.

2.2.2 Energy

NREL needs a consistent and reliable energy supply. Although thermal energy is used for heating, it is not a substantial risk because NREL has on-site renewable resources and additional capabilities to source natural gas. However, all of NREL's information technology (IT) infrastructure, its buildings, and its research areas depend on a reliable source of electricity. From renewable energy technologies such as photovoltaic (PV) cells and wind turbines, NREL produces the equivalent of approximately 20% of the electricity that it uses. However, NREL receives the majority of its electricity from the Xcel Energy electricity grid and does not currently have the capacity to use on-site renewable power in the event of a grid power outage. NREL relies on the grid to distribute and provide the base load of campus power.

NREL depends on a **single electricity supplier** for its electricity. It has only enough diesel generator backup capacity to maintain emergency operations and shut down processes. If NREL's electricity supply were compromised, it could face serious consequences to its research and compromise worker safety. All of NREL's IT infrastructure would also be compromised, so staff would not be able to access NREL's networks remotely. Because a stable electricity supply is critical to NREL's research and operations (Key Objectives 1 and 3), a single electricity supplier ranked as a high-consequence vulnerability.

Climate experts scored six climate variables that can affect NREL's energy supply with a low-to-medium,[10] medium-to-high, or high likelihood:

- An increase in average annual temperatures, which could reduce the efficiency of electricity transmission and increase electricity demand
- An increase in the intensity of summer rainfall, which could lead to flooding events that could damage the energy supply or transmission infrastructure
- An increase in the likelihood of ice storms, which could damage the energy supply or transmission infrastructure
- An increase in the intensity of winter storms, which could damage the energy supply or transmission infrastructure
- An increase in lightning patterns and a longer lightning season, which could damage the energy supply or transmission infrastructure
- An increase in fires and fire season length, which could damage the energy supply or transmission infrastructure.

Because of its risk scores, having a single electricity supplier has an overall risk score of high. Table 4 provides full details about the consequence, likelihood, risk, and overall risk scores for energy.

[10]For this vulnerability, a low-to-medium likelihood climate variable was included because, associated with the high-consequence score, it leads to a medium-to-high risk score.

Table 4. Energy: Consequence, Likelihood, Risk, and Overall Risk Scores*

Vulnerability	Consequence	Climate Variable	Likelihood	Risk Score	Overall Risk Score
NREL has only one electricity supplier and depends on energy to support mission-critical activities, including IT connectivity	High	Increased annual average temperatures	High	High	High
		Increased intensity of summer rainfall	Medium-to-high	High	
		Increased likelihood of ice storms	Low-to-medium	Medium-to-high	
		Increased intensity of winter storms	Medium-to-high	High	
		Changes in lightning patterns and longer lightning seasons	Medium-to-high	High	
		Increased likelihood of fire and longer fire season	High	High	
		Changes in wind patterns	Low	Medium	

* See Box 1, Box 2, and Box 3 for details about scoring methodology

2.2.3 Physical Space

NREL relies on physical space[11] to achieve Key Objectives 1, 2, and 3. Office space, research laboratories, and research equipment, including chemicals and other materials stored outdoors, are critical to NREL's operations. NREL's physical space is constantly exposed to climate and is inherently affected by climate changes. Thus, consequence scores were assigned to known concerns that already affect NREL's physical space: **landslides may occur because the STM buildings are close to the mesa slope**, which scored high consequence for potential landslides; the potential for site flooding, which scored medium consequence, given that **site flooding may occur because of poor drainage**; and because **damage to climate-sensitive equipment may disrupt research**,[12] which scored medium consequence.

Climate experts scored two climate variables that could affect the STM buildings, given their proximity to the mesa slope and the possibility of landslides, with a medium or medium-to-high likelihood:

- An increase in the intensity of summer rainfall, which could saturate soils and increase the chance of a landslide
- An increase in fires and fire season length, which could denude the mesa slope of vegetation and increase the chance of landslides.

Climate experts scored two climate variables that can affect the STM, given poor drainage, with a medium-to-high likelihood:

- An increase in the intensity of summer rainfall, which could overwhelm the designed drainage capacity at both campuses
- An increase in the intensity of winter storms, which could overwhelm the designed drainage capacity at both campuses, especially in the case of fast snowmelt.

Climate experts scored seven climate variables that can affect research equipment, given its sensitivity to climate, with a medium-to-high or high likelihood:

- An increase in average annual temperatures, which could reduce the effectiveness of some outdoor equipment or render it inoperable
- An increase in extreme heat events, which could reduce the effectiveness of some outdoor equipment or render it inoperable
- An increase in the intensity of summer rainfall, which could lead to flooding that would damage outdoor equipment or render it temporarily inoperable
- An increase in the intensity of winter storms, which could damage some outdoor equipment or render it temporarily inoperable

[11]Physical space is defined as NREL's land, campus buildings, materials and equipment, facilities, and site infrastructure.

[12]Although DOE regularly assesses the condition of NREL's equipment, which is documented in the Condition Assessment Information System, climate-related concerns are currently not considered in the Condition Assessment Information System process.

- An increase in lightning patterns and a longer lightning season, which could damage some outdoor equipment or render it temporarily inoperable, particularly at the NWTC
- An increase in fires and fire season length, which could disrupt research and damage outdoor equipment
- An increase in minimum nighttime temperatures, which could disrupt research and affect outdoor equipment.

Because of its risk scores, the following overall risk scores were assigned for physical space: the potential for landslides because the STM buildings are close to the mesa slope (high); the potential for site flooding because of poor drainage (medium-to-high); and potential disruptions to research because of equipment sensitivity to climate (medium-to-high). Table 5 provides full details about the consequence, likelihood, risk, and overall risk scores for physical space.

Table 5. Physical Space: Consequence, Likelihood, Risk, and Overall Risk Scores*

Vulnerability	Consequence	Climate Variable	Likelihood	Risk Score	Overall Risk Score
Landslides may occur because the STM buildings are close to the mesa slope	High	Increased intensity of summer rainfall	Medium-to-high	High	High
		Increased likelihood of fire and longer fire season	High	High	
Site flooding may occur because the STM has poor drainage	Medium	Increased intensity of summer rainfall	Medium-to-high	Medium-to-high	Medium-to-high
		Increased intensity of winter storms	Medium-to-high	Medium-to-high	
Damage to climate-sensitive equipment may disrupt research	Medium	Increased annual average temperatures	High	Medium-to-high	Medium-to-high
		Increased extreme heat events	High	Medium-to-high	
		Increased intensity of summer rainfall	Medium-to-high	Medium-to-high	
		Increased intensity of winter storms	Medium-to-high	Medium-to-high	
		Changes in lightning patterns and longer lightning seasons	Medium-to-high	Medium-to-high	
		Increased likelihood of fire and longer fire season	High	Medium-to-high	
		Changes in wind patterns	Low	Low-to-medium	
		Increases to minimum nighttime temperatures	High	Medium-to-high	
NREL may not be able to continue to use ambient air for temperature control in many facilities (RSF, ESIF, laboratory stations and high-bay laboratories at the NWTC)	Low	Increased annual average temperatures	High	Medium	Medium
		Increase in extreme heat events	High	Medium	
		Changes in relative humidity	Medium-to-high	Medium	
		Increased intensity of winter storms	Medium-to-high	Medium	
		Increased likelihood of fire and longer fire season	High	Medium	
		Changes in wind patterns	Low	Low	
		Increased pollen count	Medium	Low-to-medium	

* See Box 1, Box 2, and Box 3 for details about scoring methodology.
ESIF: Energy Systems Integration Facility
RSF: Research Support Facility

2.2.4 Site Access

Site access to the STM and NWTC campuses—both physical access to and within NREL sites via roadways, and remote access via IT connectivity—is critical for meeting all three of NREL's key objectives. This key resource is distinct from physical space.

Physical site access. Staff and delivery personnel access the NREL campuses via three entrances at the STM and one entrance at the NWTC. Some NREL staff members need to be onsite either all or part of the time to conduct their work. Depending on the job function, analysts must be onsite at least 5% of the time and research-intensive staff must be onsite at least 50% of the time. Site operations staff need to be onsite a greater percentage of the time; as many as 40% of site operations staff need to be onsite at all times. However, site operations staff represent only 4% of the total NREL population.

Although most of NREL's staff can work remotely, especially for short periods, **key staff must have access to NREL's sites to respond to emergencies and conduct research**. This is particularly important because the lack of staff redundancy is an issue at NREL. Given the importance of physical access to NREL's research and operations (Key Objectives 1 and 3), this vulnerability scored as a medium-to-high consequence.

IT connectivity. Remote connection to NREL is also essential, both onsite and to enable NREL staff to work remotely. NREL's data center is not cloud-based; a power outage would prevent staff from accessing data and connecting with one another (Section 2.2).

Climate experts scored five climate variables that can affect key staff access to NREL's sites with a medium-to-high or high likelihood:

- An increase in heat events, which could render working both indoors and outdoors untenable
- An increase in the intensity of summer rainfall, which could lead to more frequent and severe flooding and make travel to and around NREL difficult
- An increase in fires and fire season length, which could make travel to and around NREL difficult if roads are closed
- An increase in lightning patterns and a longer lightning season, which could affect NREL access, particularly at the NWTC
- An increase in the intensity of winter storms, which could make travel to and around NREL difficult.

Because of its risk scores, the inability of key staff to access NREL's sites was assigned an overall risk score of medium-to-high. Table 6 provides full details about the consequence, likelihood, risk, and overall risk scores for site access.

Table 6. Site Access: Consequence, Likelihood, Risk, and Overall Risk Scores*

Vulnerability	Consequence	Climate Variable	Likelihood	Risk Score	Overall Risk Score
Key staff may not be able to access NREL sites to respond to emergencies and to conduct research; some situations may require staff redundancy	Medium	Increased extreme heat events	High	Medium-to-high	Medium-to-high
		Increased intensity of summer rainfall	Medium-to-high	Medium-to-high	
		Increased likelihood of fire and longer fire season	High	Medium-to-high	
		Increased lightning patterns and longer lightning season	Medium-to-high	Medium-to-high	
		Increased intensity of winter storms	Medium-to-high	Medium-to-high	
Only one access point is available for supply delivery in many buildings	Low	Increased intensity of summer rainfall	Medium-to-high	Medium	Medium
		Increased intensity of storm events	Medium-to-high	Medium	
		Landslides	Medium	Low-to-medium	
		Increased likelihood of fire and longer fire season	High	Medium	
		Increased likelihood of ice storms	Low-to-medium	Low-to-medium	

* See Box 1, Box 2, and Box 3 for details about scoring methodology.

2.2.5 Workforce

Even without considering climate change, climate inherently affects NREL's staff: some need to **conduct outdoor research and other outdoor activities**, such as maintenance of outdoor equipment, which may be sensitive to climate. This section focuses exclusively on staff's ability to conduct outdoor research. (See Section 2.2.3 for more information about equipment sensitivity to climate.) Because this vulnerability may affect all three key objectives if staff cannot conduct outdoor research on its campuses, it was assigned a medium consequence score.

Climate experts scored two climate variables that can affect staff's ability to conduct outdoor research and other outdoor activities with a medium-to-high or high likelihood:

- An increase in lightning patterns, which could prevent staff from working outdoors for periods of time or affect working hours, especially at the NWTC site
- An increase in extreme heat events, which could prevent staff from working outdoors or affect working hours.

Because of its risk scores, the need to conduct outdoor research and other outdoor activities was assigned an overall risk score of medium-to-high (Table 7).

Table 7. Workforce: Consequence, Likelihood, Risk, and Overall Risk Scores*

Vulnerability	Consequence	Climate Variable	Likelihood	Risk Score	Overall Risk Score
Staff may not be able to conduct outdoor research and other outdoor activities	Medium	Increased lightning patterns and longer lightning season	Medium-to-high	Medium-to-high	Medium-to-high
		Increased extreme heat events	High	Medium-to-high	

* See Box 1, Box 2, and Box 3 for details about scoring methodology.

2.2.6 Research and Mission

Several cross-cutting aspects of NREL's operations, including NREL's reputation as a leader in sustainability and its position in the local community; its various outdoor research areas that are exposed to climate, the interconnected nature of NREL's work and off-campus dependencies, and other broad-scale aspects of NREL are vulnerable to the effects of climate change.

The need for minimum nightly temperatures for certain research areas and sustainable operations is NREL's most significant research- and mission-related vulnerability. It influences NREL's reputation for having a sustainable campus and impacts climate-sensitive equipment (Section 2.2.3). **NREL's reputation as a sustainable campus** was assigned a medium consequence because of its importance to fulfilling Key Objectives 2 and 3.

Climate experts scored one climate variable that can damage NREL's reputation as a sustainable campus with a high likelihood: An increase in heat events, which could reduce the reliability of evaporative cooling and affect passive cooling. This may require more energy-intensive forms of cooling to maintain a suitable working environment in NREL buildings. Because of its risk scores, NREL's reputation as a sustainable campus was assigned an overall risk score of high.

Table 8 provides full details about the consequence, likelihood, risk, and overall risk scores for research and mission.

Table 8. Research and Mission: Consequence, Likelihood, Risk, and Overall Risk Scores[a]

Vulnerability	Consequence	Climate Variable	Likelihood	Risk Score	Overall Risk Score
NREL's reputation as a sustainable campus could be damaged	Medium	Increased extreme heat events	High	Medium-to-high	Medium-to-high
The NWTC's research agenda could be disrupted[b]	Low	Changes in wind patterns	Low	Low	Low

[a] See Box 1, Box 2, and Box 3 for details about scoring methodology.
[b] Research at the NWTC would likely be more positively than negatively affected by changes to wind patterns, so this vulnerability received a low consequence score.

2.3 Identifying NREL's Highest Risk Vulnerabilities

After NREL's vulnerabilities were identified and scored, they were reordered according to the associated key resources or climate variables in question (Section 2.2.1 through Section 2.2.6), and according to their rank, from high to low. Table 9 summarizes the high-risk and medium-to-high-risk vulnerabilities, which are addressed by Vogel et al. (2015).

Table 9. Vulnerabilities with the Highest Overall Risk Score*

Key Resource	Vulnerability	Overall Risk Score
Water	NREL has only one water supplier for each campus and no backup options	High
	NREL may not be able to continue to rely on evaporative cooling and chillers	Medium-to-high
Energy	NREL has only one electricity supplier and depends on electricity to support mission-critical activities, including IT connectivity	High
Physical space	Landslides may occur because the STM buildings are close to the mesa slope	High
	Site flooding may occur because the STM has poor drainage	Medium-to-high
	Damage to climate-sensitive equipment may disrupt research	Medium-to-high
Site access	Key staff may not be able to access NREL's sites to respond to emergencies and conduct research; some situations may require staff redundancy	Medium-to-high
Workforce	Staff may not be able to conduct outdoor research and other outdoor activities	Medium-to-high
Research and mission	NREL's reputation as a sustainable campus may be damaged	Medium-to-high

* See Table 3 through Table 8 and Box 3 to understand the reasons these vulnerabilities were assigned an overall risk score of medium-to-high or high.

3 Next Stage: The Resiliency Action Plan

Increasing resiliency requires that the vulnerability of NREL's key resources to climate change be reduced. The risk scores for identified vulnerabilities can be lowered by reducing their consequences. This is the focus of the resiliency action plan.

To help NREL become more resilient, potential actions will be identified to reduce the consequence score for each medium-to-high or high-risk vulnerability. This process will take place during the final stage of NREL's CCRP project, through a series of steps:

1. **Categorize the vulnerabilities.** Categorize each key vulnerability into one of four categories for action:
   - Mitigate risks—take steps to reduce the consequence of the vulnerability.
   - Transfer risks—share the vulnerability with another party or insure against it.
   - Accept risks—retain the vulnerability and choose to do nothing.
   - Avoid risks—eliminate the vulnerability by removing the root cause or changing organizational goals.
2. **Identify resiliency options.** For vulnerabilities that are classified under the "mitigate" category, work with key NREL staff to develop a list of resiliency options, including those that involve changes to NREL management, operational practices, or infrastructure.

3. **Prioritize the resiliency options.** Evaluate the resiliency options according to a set of criteria, including effectiveness, feasibility, and cost.
4. **Develop the resiliency action plan.** Synthesize the findings from the process and offer actionable resiliency options for NREL as it moves forward with its CCRP project.

Glossary

Adaptation	Adjustment in natural or human systems to a new or changing environment that exploits beneficial opportunities or moderates negative effects (U.S. Global Climate Change Research Program (2015).
Climate	The average of weather over some period of time (which can be hundreds to thousands of years). The World Meteorological Organization standard uses 30 years of weather observations to measure climate. A climate can be thought of as the mean and variance of weather over 30 years (WMO 2015).
Climate change	Typically denotes a significant change in average conditions but can also be the result of a change in variance of weather or in extreme weather conditions.
Climate change impacts	Negative or positive effects that changes in climate variables may have on human systems. Examples include damage to equipment, changes in maintenance cycles, and increased asthma rates.
Climate preparedness	Efforts to adapt (prepare) for climate-related effects. Also see *adaptation* and *resiliency*.
Climate variables	Measurable aspects of climate. Examples include temperature, precipitation, wind, humidity, extreme events, drought, and flooding.
Consequence	A measure of the impact of a vulnerability on a key resource, as measured against key objectives.
Likelihood	A measure of the possibility that a climate variable will change.
Resiliency	A capability to anticipate, prepare for, respond to, and recover from significant multihazard threats with minimum damage to social well-being, the economy, and the environment (U.S. Global Climate Change Research Program (2015).
Risk	Threats to life, health and safety, the environment, economic well-being, etc. Typically evaluated in terms of how likely an event is (probability) and the damages that would result (consequences) (U.S. Global Climate Change Research Program 2015).

Vulnerability	The degree to which an affected unit (a person, a facility, a community, etc.) faces risk from climate. It considers whether the unit is exposed to a climate driver and the extent to which the driver can affect the unit. A key factor in determining vulnerability is the resiliency of the unit. Greater likelihood and consequence increase vulnerability; greater resiliency decreases vulnerability.
Weather	Typically the climate conditions experienced at a particular point in time. It may be the temperature range over a day or a short period, precipitation, wind, etc. Thirty years of weather is used to statistically define climate.

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Appendix A. Climate Change along the Front Range

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A.1 Global Climate Change

The global climate system is sensitive to concentrations of long-lived atmospheric GHGs, of which the most important is carbon dioxide. The concentration of carbon dioxide, as well as several other potent GHGs such as methane and nitrous oxide, has been steadily rising since the beginning of the industrial period, but most rapidly since the 1900s. The preindustrial concentration of carbon dioxide has been close to 290 ppm, and by 2013 its atmospheric concentration reached 400 ppm—a value the Earth's climate system has certainly not seen in the last 800,000 years (based on the longest ice-core record; Lüthi et al. 2008). Based on other proxy records, there has not been such a high value in the last five million years (Seki et al. 2010).

Increases in these GHGs is thought to be the primary factor in causing the recently observed radiative imbalance, or additional heat retained in our climate system because of increases in the trapping of outgoing infrared emissions from the Earth's surface by added GHGs of 1 W/m^2 at the top of atmosphere (Hansen et al. 2005). Most of the additional heat (>90%) retained in our climate system is absorbed by oceans, and the rest by the land surface and the atmosphere (IPCC 2013). This increase in the thermal potential of our climate system is the phenomenon of "global warming" (see Figure A-1 for trends in the upper ocean heat content).

We expect this process to occur based on physical principles, and this understanding has been repeatedly confirmed by over 40 years of climate modeling effort, which has become increasingly sophisticated during that period. Our climate models predict that the warming of our climate system will continue to increase during the 21st century with further increases in atmospheric GHG concentrations, and that this warming response primarily depends on the future trajectory of anthropogenic, or man-made, GHG emissions. Furthermore, because of the long atmospheric lifetimes of gases such as carbon dioxide, it is the total net emission, and not the trends in emissions, that will commit us to a particular climate future the next hundreds to thousands of years (Solomon et al. 2009).

A.2 General Circulation Models

GCMs are mathematical representations of the Earth's climate system (e.g., atmosphere, ocean, land surface including vegetation) and processes within it (e.g., atmosphere and ocean circulation, precipitation, wind, land surface processes including evapotranspiration). GCMs are our primary tools to assess climate response to future changes in the external drivers of our climate system, in particular, changes in atmospheric concentrations of GHGs. GCMs have improved tremendously in last few decades, and have also become increasingly complex and computationally intensive over that time period (see Chapter 3 in Lukas et al. 2014 for more detail on GCMs).

We have greater confidence in GCMs for representing large-scale (on the order of 1,000 km) systems and processes than we do for them representing smaller spatial scales. This is in part because GCMs are currently limited by computational requirements to operate at spatial scales smaller than 100 km, thereby inadequately representing finer-scale systems and processes.

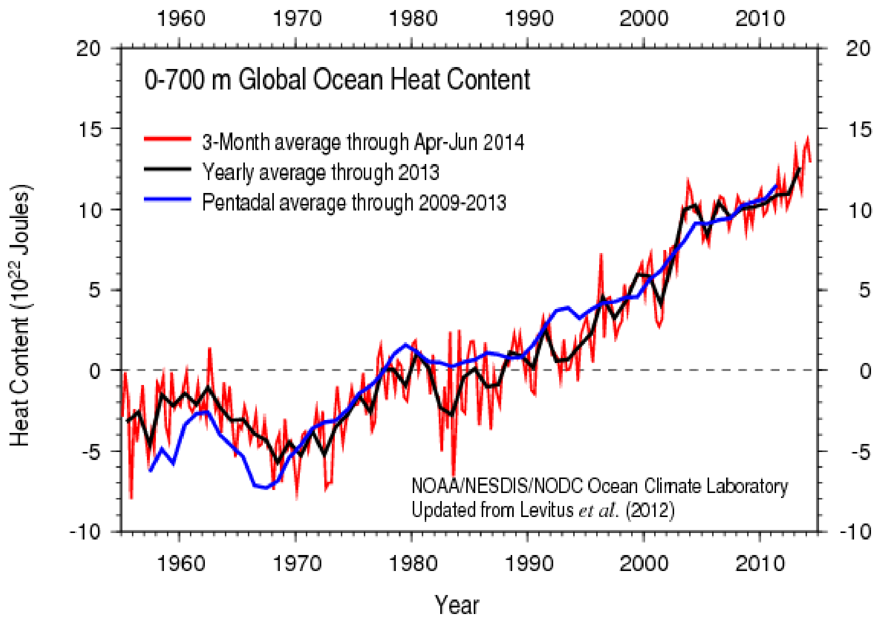


Image source: NOAA (2013)

Figure A-1. Trends in the upper ocean heat content

This is presumably a much better measure of global warming, or additional heat retained in the Earth's climate system, because of increases in anthropogenic GHGs.

For example, for the western United States, these models do not facilitate the actual elevation range of the mountain systems or their complex topographical influence on regional and basin-scale atmospheric circulation. Because of the coarse resolution at which these models operate, mountain systems become smooth and high flat places in these models. For example, in the models, the highest elevation in the Colorado Rockies does not reach above 8,000 ft (2,400 m), whereas, in reality, the highest point in Colorado is 14,440 ft (4,401 m).

Furthermore, in part because of the lower elevations of mountain ranges along the West Coast, the interior western United States has a strong wet bias—it receives higher modeled precipitation than is actually observed. Such a wet bias on a regional scale would influence land surface processes, including the nature of temperature response with climate change. Lower-elevation gradients in the models also affect important seasonal aspects of the hydrologic cycle in the Colorado Rockies. One important example of this is the earlier melting of snowpack because in these models snowpack is at a much lower elevation than in actuality.

Another source of uncertainty for the southwestern United States comes from the inadequate representation of the North American monsoon system. Therefore, we have lower confidence in future projections for monsoonal-generated precipitation. Furthermore, the warm season convective rainfall occurs at sub-grid scales, or spatial scales smaller than the size of a GCM grid box, and therefore, it is not physically simulated but rather represented (through a process known as parameterization) based on the understanding of certain observed relationships between variables such as humidity and air temperature. The choice of methods used for parameterization varies among GCMs. These methodological choices and inconsistencies further suppress our confidence in future projections related to warm season precipitation as opposed to cold season precipitation, where our understanding of causes is much more traceable and physically consistent.

Furthermore, at regional scales, the inter-GCM projections of future climate have a large range in the magnitude of change. For example, they project anywhere from +2.5°F to +5°F increases in temperature for Colorado by 2050 for a moderate GHG emissions scenario. For some climate variables, such as precipitation, there is also an additional discrepancy associated with the direction of change (e.g., models project anywhere from a –5% to a +6% change in annual precipitation for Colorado for a moderate GHG emissions scenario).

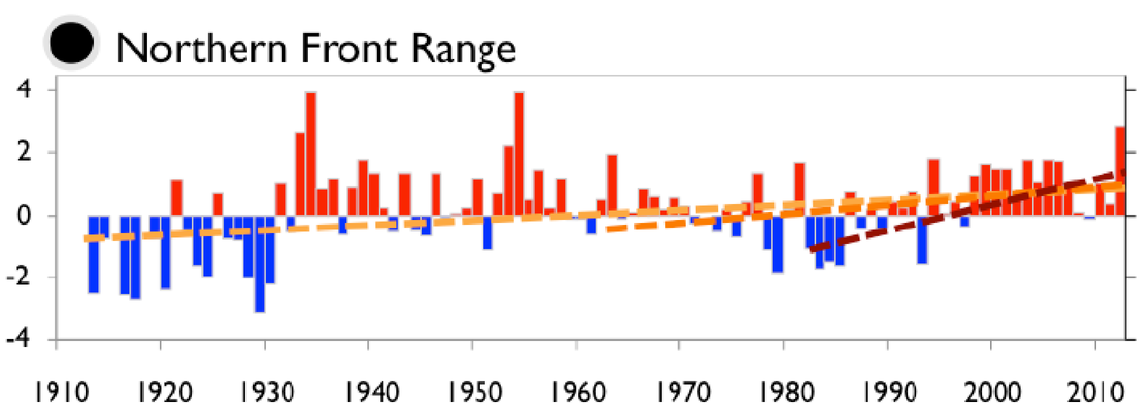
A.3 Downscaling

To address biases in the GCMs at regional scales and, in certain cases, to improve the simulation of regional scale systems and processes within a climate modeling framework, downscaling of GCM-derived outputs is performed. Additionally, downscaled data are, in many instances, a prerequisite to running the impacts models (e.g., ecosystem response models, hydrologic models). Downscaling certainly reduces the GCM biases and better represents the climate of a particular region, but it does not reduce the inherent "uncertainties" of GCM projections. In fact, the downscaling process can introduce additional errors to the GCM future climate projections. More information on downscaling and its relevance to our region can be found in Daniels *et al.* (2012) and Lukas *et al.* (2014, Chapter 3).

A.4 Regional Climate Change: Colorado's Northern Front Range

A.4.1 Observations

The Front Range's regional climate shows a warming trend in the instrumental record. However, most of the warming (>2°F) has occurred in the last few decades, particularly since the mid-1990s (Figure A-2). The temperature trend is the same for all of Colorado. This warming is plausibly connected to the anthropogenic climate change but it is difficult to make definitive attribution at this spatial scale (Lukas *et al.* 2014).



Source: Reproduced from Lukas et al. 2014

Figure A-2. Annual temperature departures for the 1913–2012 time period relative to 1971–2000 average in Colorado's northern Front Range

Linear trends through 2012 shown by yellow (100-year), orange (50-year), and dark red (30-year) lines are statistically significant (>97.5%).

For annual precipitation amounts, there is no long-term discernable trend either statewide or along the Front Range. Similarly, there is no long-term trend in the April 1 snowpack (April 1 snow water equivalent) in the region although it has been mostly below average since 2000 across much of the state. Statewide, there are also no shifting trends in heavy precipitation and flooding events. There is, however, some evidence that the timing of peak snowmelt and associated runoff has shifted earlier by 1 to 4 weeks. This is most likely related to both higher spring temperatures and enhanced solar radiation absorption from the dust-on-snow phenomenon (Lukas et al. 2014).

The statewide trend in the Palmer Severity Drought Index depicts increases in soil moisture drought conditions in last 30 years, reflecting combined effects of below-average precipitation since 2000 and increases in temperature. The anthropogenic climate change may have increased the severity of the recent drought events. Nonetheless, tree-ring records going back 1,000 years or more show multiple droughts before 1900 that were more severe and sustained for a longer duration (Lukas et al. 2014).

A.5 Projections

Projections of future climate responses are dependent on the atmospheric GHG concentration trajectory.[13] By 2050, statewide temperatures are projected to increase by +2.5°F to +5°F relative to the 1971–2000 period under a moderate emissions scenario (RCP 4.5), and by +3.5°F to +6.5°F under a high emissions scenario (RCP 8.5) (Lukas et al. 2014).

For annual precipitation, the models do not agree on the sign of change, and project a –5% to +6% change by 2050 under a moderate emissions scenario (RCP 4.5), and –3% to +8% under a high emissions scenario (RCP 8.5). However, nearly all projections indicate increases in winter precipitation. Responding to projections in precipitation and temperature, April 1 snow water equivalent in the Front Range is projected to change between –20% and +10%.

For stream flow projections in the Front Range, there is an even chance of increases and decreases in annual natural stream flow. However, there is a greater agreement among models that peak spring runoff will shift early by 1 to 3 weeks by 2050. This also causes late summer and early autumn runoff to decrease (Lukas et al. 2014). Another process that affects this peak runoff is dust-on-snow, which, in extreme dust years such as 2009 and 2013, could have shifted peak spring runoff 6 weeks earlier (Deems *et al.* 2013). The combination of increased temperature and dust-on-snow could further augment the impact on runoff.

A.6 Extremes

Extreme events, such as heat waves, severe drought, heavy precipitation, and winter storms, and associated consequences generally have a much greater impact on socioeconomic and ecosystem structures and functionality. Our understanding of how many of these climate extremes will change is still somewhat limited (see Figure A-3) because of the underlying complexity associated with the interplay of processes and conditions that drive these extremes.

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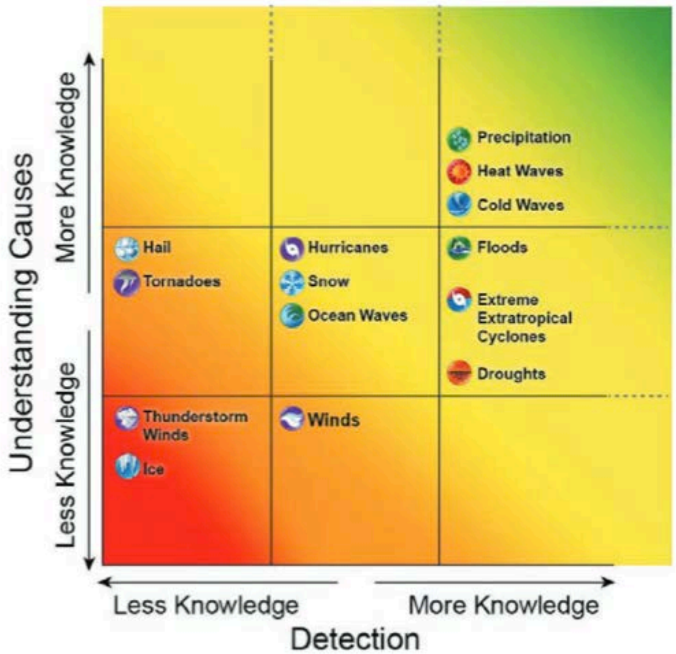
[13]However, by the mid-21st century the influence of choosing a particular emissions pathway is smaller than the inter-GCM range on a specific climate projection.



Source: Reproduced from Wuebbles et al. (2014)

Figure A-3. One rendition of our current understanding and detection of changes in different climate and weather extremes because of climate change

We have a greater confidence in projections of extremes that are more strongly influenced by temperature such as heat waves. We expect increases in the frequency of more intense heat waves in the future (Lukas et al. 2014). We are already finding that the frequency of new record-high temperatures have doubled in relation to new record-low temperatures for the United States as a whole, whereas in the absence of climate change, the ratio should be one-to-one. Climate models predict that the ratio of new record-high temperatures to record-low temperatures will continue to increase sharply during the 21st century (Meehl *et al.* 2009).

Models also project that a greater proportion of future precipitation will be received from the heaviest precipitation events because of climate change (Wuebbles *et al.* 2014). This is in part related to increases in moisture and energy associated with individual storm systems. Although based on observations in Colorado there is no discernable evidence of this trend; other parts of the United States and world show increases in the frequency of very heavy precipitation events (Melillo *et al.* 2014). There is also a medium-low confidence that transition from hail to rain in the Front Range will result in higher flash flood risk (Garfin *et al.* 2013).

Drought is generally expected to intensify because of future warming and its influence on the hydrologic cycle (i.e., earlier snowmelt, increased evapotranspiration and drier soils) (Garfin *et al.* 2013). Most climate models project that heat waves, droughts, and wildfires will intensify by 2050 in Colorado because of climate change (Lukas *et al.* 2014).

A.7 Climate Variability

One factor that strongly influences climate and weather extremes is the natural climate variability in our climate system which, For the Intermountain West, natural climate variability is modulated primarily by processes related to the ocean circulation on inter-annual, inter-decadal, and multidecadal timescales and accompanying atmospheric teleconnections. These include the phenomena identified as the El Niño Southern Oscillation, the La Niña Southern Oscillation, the Pacific Decadal Oscillation, and the Atlantic Multidecadal Oscillation. In general, Colorado tends to be drier in years that combine a La Niña, a negative Pacific Decadal Oscillation, and a positive Atlantic Multidecadal Oscillation.

We also have limited understanding of how these phenomena will be affected by climate change (i.e., Will there be more frequent or intense El Niño or La Niña events because of climate change?). Nonetheless, even under a severe climate change scenario, climate variability will continue to influence inter-annual to inter-decadal changes in our climate and weather, as well as associated climate extremes.

Appendix B. High-Level Overview of Projected Climate Changes for the Front Range[14]

B.1 Temperature

- Increase in average temperatures (including nighttime lows)
- Increase in the magnitude and frequency of extreme hot temperatures (i.e., heat waves)
- Increase in winter minimum temperatures.

B.2 Precipitation

- More precipitation to occur in higher-intensity events (e.g., increased intensity and frequency of flooding)
- More precipitation to fall as rain than snow
- Increase in stream temperatures (from both higher air temperatures and post-snowmelt low flows)
- Earlier snowmelt and peak runoff events; longer duration of low-flow periods.

B.3 Other

- Increase in the intensity and frequency of droughts from higher temperatures
- Increase in the intensity of storm events
- Decrease in water quality (because of more extreme precipitation events, fires, tree mortality, and higher duration of low flows)
- Changes in lightning patterns (we expect increases in lightning activity and a longer lightning season)
- Increase in fire risk and a longer fire season
- Changes in wind patterns (although this is as uncertain as the future sign of precipitation, in part due to the same cause: changes in large-scale circulation)
- Changes in vector-borne diseases (e.g., West Nile virus)
- Increases in pollen count and other allergens (e.g., dust)
- Changes in growing seasons (based on temperatures above freezing, but the effective growing season is also affected by water stress and heat waves, among other factors).

[14] Appendix B was developed based on the expertise of climate experts at the Western Water Assessment, a National Atmospheric and Oceanic Administration Regional Integrated Sciences and Assessments program associated with the University of Colorado.

Appendix C. Notable Destructive Weather Events Since 1985[15]

Table A-1. Destructive Weather Events in Colorado Since 1985

Date	Event Type	Location	Deaths	Damage in 2013 Dollars (Millions)	Description
January 1987	Wind storm	Boulder, Lakewood, Golden	0	$11.5	Widespread residential and infrastructure damage from gusts of 60–100 miles per hour.
July 1990	Hailstorm	Denver metropolitan area, Colorado Springs	0	$1,070	Supercell thunderstorm traveled from Estes Park to Colorado Springs, passing directly over Denver with large hail. Thousands of roofs and cars damaged. Costliest hailstorm in U.S. history.
July 1997	Flood	Fort Collins, Sterling	5	$290	Two consecutive days of heavy convective precipitation in and near Fort Collins; on July 28 more than 10 inches fell in 6 hours in the Spring Creek watershed on the west side of Fort Collins. Resulting flash flood on Spring Creek heavily damaged Colorado State University and residential areas, and caused 5 fatalities. The following day, 13 inches fell on Pawnee Creek near Sterling, causing damaging flash flooding there.
October 1997	Snowstorm	Multiple counties along Front Range, and in Eastern Plains	9	No data available	Unavailable
April–May 1999	Flood	Colorado Springs, Manitou Springs, Pueblo, La Junta	0	$85	Multiday rain event caused severe flooding on Fountain Creek, Monument Creek, and the Arkansas River.
October 2001–September 2002	Drought	Statewide	No data available	$1,600	One of the driest water years on record in all parts of the state, with low peak snowpack, extremely low runoff, multiple large wildfires, and severe agricultural impacts.

[15] Appendix C was developed based on the expertise of climate experts at the Western Water Assessment, a National Atmospheric and Oceanic Administration Regional Integrated Sciences and Assessments program associated with the University of Colorado.

Date	Event Type	Location	Deaths	Damage in 2013 Dollars (Millions)	Description
June–July 2002	Wildfire	Teller and Jefferson Counties	1	$50	The Hayman Fire burned 138,000 acres and more than 200 residences, making it the largest wildfire in Colorado history; later wildfires have since surpassed it as the most destructive. It ignited and spread during severe drought conditions, abetted by several periods of high winds.
March 2003	Snowstorm	Fort Collins, Boulder, Denver metropolitan area	No data available	$118	A very strong 3-day upslope snowstorm brought huge amounts of snow and blizzard conditions to most of the Front Range and the adjacent plains. Storm totals included 32 inches in Denver and 87 inches in Rollinsville.
December 2006	Snowstorm	Multiple counties	No data available	No data available	An upslope snowstorm first dropped more than 20 inches on the Denver metropolitan area, then shifted east and south, with totals of 12 to 36 inches in southeastern Colorado and 30 to 48 inches in the foothills and mountains of southern Colorado. Strong winds created drifts and led to enormous loss of livestock.
May 2008	Tornado, hailstorm	Windsor	1	$210	An EF3 tornado destroyed 80 homes and damaged 770 others in and around Windsor during a damaging hailstorm.
July 2009	Hailstorm, strong winds	Englewood, Arvada, Wheat Ridge, Lakewood, Brighton	No data available	$840	A line of severe thunderstorms with damaging winds dropped large hail over a swath of the Denver metro area and spawned two weak tornadoes.
September 2010	Wildfire	Boulder County	0	$229	The Fourmile Canyon Fire started after a month of extremely dry conditions, on a day with unusually strong winds for early September. Most of the 169 homes destroyed were burned on the first day of spread. Approximately 6,500 acres were burned, and the city of Boulder itself was at risk on September 10.
June 2012	Wildfire	Larimer County	1	$114	The High Park fire was ignited by lightning after a very dry winter and spring and burned more than 87,000 acres and at least 259 homes.
June–July 2012	Wildfire	Woodland Park, Manitou Springs, Colorado Springs	2	$453	The Waldo Canyon Fire burned during severe to extreme drought conditions; strong outflow winds from a thunderstorm on June 26 pushed the fire into the western portion of Colorado Springs, where most of the 346 homes destroyed in the fire were lost. More than 18,000 acres burned. The Waldo Canyon Fire was the most costly wildfire in Colorado history.

Date	Event Type	Location	Deaths	Damage in 2013 Dollars (Millions)	Description
June 2013	Wildfire	Black Forest, Colorado Springs	2	$293	The Black Forest Fire ignited during moderate drought conditions on a red-flag-warning day; temperatures were in the 90s and relative humidity was below 10%. The fire rapidly spread through forested suburban neighborhoods, destroying 511 homes in all, and burning more than 14,000 acres. The Black Forest Fires was the most destructive wildfire, in terms of homes lost, in Colorado history.
September 2013	Flood	Loveland, Lyons, Longmont, Jamestown, Boulder, Morrison, Evans, Colorado Springs	10	$2,000	A near-stationary weather system funneled copious subtropical moisture against the Front Range, leading to 1-week rainfall totals of 10 to 18 inches over a large area. Creeks and rivers from the Wyoming border to Colorado Springs flooded, with the worst flooding on the Big Thompson River, St. Vrain Creek, Left Hand Creek, and Coal Creek. More than 20,000 homes were damaged or destroyed. The Front range suffered incredible and widespread damage to civil infrastructure—roads, bridges, water conveyance, and water treatment.

Appendix D. Vulnerability Work Group Guiding Questions

In preparation for the workgroup, we developed the following questions to help you understand what type of information we will be soliciting from the discussion. We are not asking you to answer these questions in detail prior to the workgroup. However, we ask that you review the questions, identify any knowledge gaps, and, if necessary, seek the appropriate information from your colleagues prior to the workgroup so that we may maximize our time together.

In general, this workgroup interview will help us understand:

- The vulnerabilities of NREL systems to changes in climate
- The needs and thresholds for your systems, operations, or areas (hereafter referred to as "system" or "systems"), above or below which they would face extreme strain (in the case of a one-time occurrence) or you would have to rethink the way you do business (in the case of a long-term change in trend)
- How your systems currently interact with weather or natural resources and if that is likely to change in the future
- If there are potential changes to climate that might impact your systems in the future that are not currently being considered
- If you already had to adapt to changes in climate, or if you have already considered potential changes to your systems.

E.1 Issues and Concerns

1. The following have been identified as some of NREL's key resources (think of a resource as an input you need for your systems). Which of these do your systems rely on? For the key resources of relevance to your systems, please consider the specific resource questions listed below for that resource.
    a. Water
    b. Energy utilities
    c. HVAC
    d. Physical space (e.g., land, buildings, storage, facilities, site infrastructure)
    e. Site access (e.g., internet connectivity, external roadways)
    f. Workforce.
2. Are there other key resources we are missing?

E.2 General Questions to Consider

These are questions to consider as you think about the more specific resource questions below.

1. Overall:
    a. Are the systems in good condition? What are the expected lifetimes of the systems? Do the conditions of the systems make it more or less likely to handle an extreme event? Would upgrading the systems make them more or less likely to handle an extreme event?
    b. If the systems failed, would there be safety issues? Impacts to mission fulfillment? Regulatory impacts? Operating and maintenance impacts?
2. Are there data gaps and further research needed pertaining to maintaining your systems or understanding the risks to your systems?
3. Are there existing resiliency efforts at NREL other than business continuity planning, emergency preparedness planning, and/or sustainable design guidelines that already address these issues? In your opinion, how can climate best be integrated into existing systems?
4. Are you aware of tools or technologies currently available to address climate change and resiliency at NREL, or locally/regionally/nationally?
5. The next phase of our work will be focused on identifying resiliency measures or adaptations, but it is still helpful to think of them at this stage. In particular, in the event of the resource being compromised, is there an alternate resource or material that would provide the functionality for your research? Or, are there other resiliency measures you could turn to?

E.3 Key Resources

E.3.1 Water

Are there components of your systems that depend on water for buildings or equipment operations, or for conducting research, etc.? Although there is much uncertainty about how precipitation patterns might change in the future, they are likely to change. To fully assess possible vulnerabilities, consider what would happen to your systems if there was:

- Too much water?
- Too little water?
- Poor water quality?
- A variable water supply?

1. What are the water supply thresholds of your system, for example:
    a. How many weeks/months/years of severe drought could your systems withstand before you would have to enact an emergency procedure or change operations?
    b. What levels of contamination are worrisome in your water supply?
2. Are there implications to your systems if there are large annual or seasonal variations in water supply?
3. Is water storage available to ensure that adequate supply is available?

4. Are there areas of research that depend on water that meet specific quality parameters (such as deionized water)?
5. Are there future research areas or planned capital projects that will change water needs (such as increased quantity or changed quality requirements)?
6. Which aspects of NREL operations (i.e., specific buildings or functions) would be most susceptible to changes in water quantity or quality?

E.4 Energy Utilities (electricity, gas, solar, wind, and biomass)

Energy supply might be impacted in the future due to a changing climate. For example, hotter average temperatures would result in increased cooling degree days and might result in more service outages. Hotter average temperatures might also result in a significant increase in utility rates. More frequent extreme events might result in more outages, or less reliable service.

1. What research areas or laboratory operations are most dependent on a consistent supply of utilities?
2. What type of utilities do your systems depend on?
3. Where are they sourced? Do you have multiple suppliers? Are you dependent on external sources of utilities?
4. Is the quality of supply a concern?
5. How long of a utility outage can your systems tolerate?
6. Do you store any of your utility supply onsite? If so, what are the temperature-related storage requirements?
7. What backup systems are in place? If so, how long will those backup supplies last?
8. Are there future research areas or planned capital projects that will change utility needs (e.g., increase quantity or change quality requirements)?

E.5 Heating, Ventilating, and Air Conditioning

A changing climate is very likely to have implications for HVAC systems. For example, both average and extreme temperatures are rising, which may put additional strain on air-conditioning systems, although this also may provide some relief to heating systems in the winter months. Extreme precipitation events may cause leaking in ventilation systems.

1. Which research areas or aspects of laboratory operations depend on consistent temperature, air flow, and air quality? Is there a specific concern?
2. Which aspects of research or operations are most vulnerable to prolonged extreme temperatures (i.e., have the hardest time coping with or recovering from)? What implications are there currently for your HVAC system during periods of extreme heat?
3. In what ways, if any, is your HVAC system unique?
4. Describe the backup systems for your HVAC system.
5. Are there future research areas or planned projects that will change HVAC needs (e.g., increase quantity or change quality requirements)?

E.6 Physical Space (land, buildings, storage)

Climate is an integral part of our physical space. Our land, buildings, and storage are impacted by climate every day. For example, NREL's physical space might be particularly vulnerable to changes in climate if increased temperatures result in increased wear and tear on pavements, which would have implications for maintenance and budget cycles. Increased extreme events can increase the likelihood of damage and changes in precipitation may alter flood patterns and make it difficult to access worksites.

1. What are the space requirements for your area of research or to support your area of laboratory operations, including material storage, office, and laboratories? How much building vs. land area is required?
2. Are there outdoor physical space requirements for your systems (e.g., are components of your systems stored outdoors)? If so, what are the climate thresholds of concern for them (e.g., the amount of moisture that can be tolerated, the amount of heat which would cause concern)?
3. What facilities are most at-risk to flooding? What are the current flood thresholds for your building? What aspects of facilities are just outside the current floodplain? What if a historic major event was predicted to occur twice as often in the future?
4. What facilities are susceptible to changes in temperatures (both changes in extremes as well as extreme fluctuations between extremes), aside from HVAC needs (this could be outdoor research equipment, building material damage, etc.)?
5. What facilities are susceptible to increases in extreme events (lightning, hailstorms, wind, etc.) to your building, research, ability to perform research?
6. Are there future research areas or planned projects that would change site building and land requirements?

E.7 Site Access (including internet connectivity and external roadways)

Will changes in climate affect site access, including IT systems and external roadways? For example, a wild fire could block the main entrance to your facility, or increased temperatures might result in increased strain on your IT systems.

1. What areas of research or operations require onsite staff? How many staff must be onsite?
2. What areas of research could be impacted by disruptions to transportation networks (for materials, services)?
3. What kind of events would make accessing the research site impossible?
4. Are there future research areas or planned projects that will change access requirements?

E.8 Workforce

Changes in climate are likely to have implications to your workforce. For example, increased temperatures can cause heat stress; changes to climate might result in changes to disease vectors, especially those borne by insects; extreme events may make it difficult for your workforce to get to work; or staff health might be compromised due to decreased air quality.

1. How critical is the onsite attendance of your staff to the performance of your work area? How much of the work can be performed remotely if needed?
2. Do you have redundancy in staff critical to performing research or operations?
3. How long can disruptions/lack of staffing be tolerated before research is impacted?
4. What percentage, if any, of your workforce works outside of the facility?
5. What does it take to maintain a productive working temperature in your facilities?
6. Are there planned future research areas or capital projects that will impact staffing?
7. Are there plans in place to address increased disease outbreaks and other health-related concerns at a campus level?