A Resiliency Action Plan for the National Renewable Energy Laboratory

May 23, 2014—June 5, 2015

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Abt Environmental Research
Boulder, Colorado

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September 2015

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NATIONAL RENEWABLE ENERGY LABORATORY

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List of Acronyms

CCRP	Climate Change Resiliency and Preparedness
HVAC	heating, ventilating, and air conditioning
IT	information technology
NREL	National Renewable Energy Laboratory
NWTC	National Wind Technology Center
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 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 *Climate Change Vulnerability Assessment Report for the National Renewable Energy Laboratory* (Vogel et al. 2015). This report covers the resiliency action plan, but this Executive Summary covers both the vulnerability assessment and the resiliency action plan. The vulnerability assessment set the stage for the resiliency action plan by identifying NREL's highest-risk 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, which 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 Scores

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 current 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 current 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 current 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 through existing lab-wide initiatives—which is a concern even without considering climate change—through its Continuity of Operations Plan.

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1 Introduction

The second stage in a two-stage project called the National Renewable Energy Laboratory (NREL) Climate Change Resiliency and Preparedness (CCRP) project is summarized in this resiliency action plan. This CCRP pilot project was funded by the U.S. Department of Energy's Sustainability Performance Office and launched in winter 2014. The resiliency action plan begins where the previous stage of the project—the vulnerability assessment—ended.

This report discusses resiliency options to reduce the risk of the highest risk vulnerabilities that were identified in the NREL vulnerability assessment. Section 2 discusses how the project team categorized the highest risk vulnerabilities, Section 3 reviews potential resiliency actions identified by NREL staff to mitigate the highest risk vulnerabilities, and Section 4 concludes with potential next steps for NREL to take to reduce climate-related vulnerabilities.

2 Categorizing the Vulnerabilities

The report, *A Climate Change Vulnerability Assessment Report for the National Renewable Energy Laboratory* (Vogel et al. 2015), concluded the first stage of the CCRP project. That report identified and scored nine high-risk vulnerabilities that are specific to NREL's resources and operations (Table 1). The project team carried these vulnerabilities into this next stage of the project. See the full report for a full description of NREL's vulnerabilities as assessed through the vulnerability assessment process.

Table 1. Vulnerabilities with the Highest Overall Risk Scores

Key Resource	Vulnerability	Overall Risk Score
Water	Each campus has only one water supplier 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 to 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/ mission	NREL's reputation as a sustainable campus may be damaged	Medium-to-high

IT: information technology.
STM: South Table Mountain campus.

The first step in the resiliency action plan process entailed organizing these high-risk vulnerabilities into categories based on the best path forward for each. The U.S. Environmental Protection Agency's Climate-Ready Estuaries Program (EPA 2013) method was adapted to conduct this part of the process. One of the following four path categories was assigned to each vulnerability: *transfer* the risk to another party, *avoid* the risk by removing the root cause of the vulnerability, *accept* the risk associated with the vulnerability and purposefully choose to do nothing, or *mitigate* the risk by taking steps to reduce the consequence of the vulnerability.

Table 2 categorizes each vulnerability that progressed from the vulnerability assessment stage of the project. Each vulnerability falls into the *mitigate* category, with one exception: "NREL's reputation as a sustainable campus may be damaged" fell into the *accept* category, with no action needed. Some resiliency actions that are typically considered less sustainable, such as "Use traditional air conditioners" (Section 3.3.1), could be unavoidable and the associated damage to NREL's reputation slight.

Table 2. Risk Categorization for Vulnerabilities with the Highest Overall Risk Scores

Vulnerability	Overall Risk Score	Risk Categorization
Each campus has only one water supplier and no backup options	High	Mitigate[a]
NREL may not be able to continue to rely on evaporative cooling and chillers	Medium-to-high	Mitigate[a]
NREL has only one electricity supplier and depends on electricity to support mission-critical activities, including IT connectivity	High	Mitigate[a]
Landslides may occur because the STM buildings are close to the mesa slope	High	Mitigate
Site flooding may occur because the STM has poor drainage	Medium-to-high	Mitigate
Damage to climate-sensitive equipment may disrupt research	Medium-to-high	Mitigate
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	Medium-to-high	Mitigate[b]
Staff may not be able to conduct outdoor research and other outdoor activities	Medium-to-high	Mitigate
NREL's reputation as a sustainable campus may be damaged	Medium-to-high	Accept

[a] According to the definition of *transfer* used in this project, an organization cannot turn a risk over to another party unless that party agrees to assume it. The single-source providers did not agree to take on NREL's risk through the process of this project, so these risks are categorized as *mitigate*. NREL may decide to work with service providers to recategorize them as *transfer*.
[b] Although this risk was categorized as *mitigate*, NREL is already addressing this through its Office of Emergency Preparedness' Continuity of Operations Plans that are specific to each NREL organization.

3 Developing and Assessing Potential Resiliency Actions by Vulnerability

The next step in the resiliency action plan process was to identify actions NREL could take to reduce the magnitude of consequences of the eight vulnerabilities selected for mitigation. Six in-person[5] interviews were conducted with small groups of NREL staff to identify a wide-ranging list of potential resiliency actions. The work groups discussed each potential action through the lens of three evaluation criteria: effectiveness, feasibility, and cost (see Box 1).

Box 1. Evaluation Criteria and Their Scoring

The work groups discussed each resiliency action in light of three evaluation criteria: effectiveness, feasibility, and cost.

- *Effectiveness* is the resiliency action's capacity to reduce the vulnerability's overall risk. (*Risk*, as defined in the vulnerability assessment, was the combined magnitude of consequence and likelihood that a vulnerability will affect NREL's mission.)
- *Feasibility* is a measure of whether the action could be implemented, both technically and organizationally.
- *Cost* is the monetary outlay that a particular action would require, as described in more detail in Table 3.

Based on these discussions, one of three scores—*good*, *fair*, or *poor*—was assigned to each evaluation criterion for the resiliency action under discussion. The score assignments were based on the preliminary discussions of the work groups and professional judgment. The work group participants were then engaged in an iterative process for refining and validating these preliminary scores. These judgments and recommendations must be confirmed before significant investments are made based on these scores. Additional research and independent fact-checking may be required to substantiate these preliminary understandings. Table 3 provides details about the three scores.

The resiliency actions were processed and organized iteratively for presentation in this final plan. The final step was to assign each action one of three recommended approaches—*do now*, *continue evaluating*, or *remove from consideration* (see Box 2).

The remainder of Section 3 provides information about the resiliency actions that were identified for each of the highest risk vulnerabilities. Each section includes a table that details potential actions, their scores against the three evaluation criteria, and the recommended approach. For each action that scored as *do now* and *continue evaluating*, a detailed discussion is presented. For each action that was recommended as *remove from consideration*, a justification is provided in the introduction of each section; however, no subsection for that resiliency action is included. NREL staff identified a few additional resiliency actions that pertain to water and energy supply during review but after the original in-person interviews. Section 3.2 and Section 3.3 include brief comments about these additional actions but no detailed evaluation, because these actions were not subject to the same level of collective discussion as those that were generated by the work groups. NREL should nonetheless consider these newly identified actions and explore others as they arise during subsequent rounds of resiliency planning. Resiliency plans are

[5] One phone interview was conducted because of logistical constraints.

dynamic works in progress and require regular evaluation and modification as priorities shift, new information emerges, funding priorities change, and projects are completed.

Table 3. Evaluation Criteria Scoring for Resiliency Actions*

Evaluation Criterion	Score: Description		
	Good	Fair	Poor
Effectiveness	Would completely or nearly eliminate the vulnerability's risk	Would significantly reduce part or all of the vulnerability's risk	Would not significantly reduce the vulnerability's risk
Feasibility	Could be implemented technically and organizationally	Could be implemented technically and organizationally, with some reservations, or only a part of the action could be implemented	Could not be implemented technically or organizationally
Cost	Would have low monetary costs relative to other types of projects evaluated. This score was primarily applied to desk-style projects, often with no or few infrastructure components.	Would have moderate monetary costs relative to other types of projects evaluated; actions that were assigned this score often included a modest infrastructure component	Would have high monetary costs relative to other types of projects evaluated; actions that were assigned this score often included significant infrastructure components

*In Table 4 through Table 10, *good* scores appear in dark blue, *fair* scores appear in medium blue, and *poor* scores appear in light blue.

Box 2. Recommended Approaches and Their Scoring

The evaluation criteria scores (see Box 1) were used to make one of three recommendations for each resiliency action:

- *Do now* (green) was reserved for no- or low-regrets* actions that NREL should reasonably pursue, whether or not it considers climate change.
- *Continue evaluating* (orange) was reserved for resiliency actions that need more information before they could be either endorsed as *do now* actions or removed from consideration.
- *Remove from consideration* (red) was reserved for actions that were untenable for one or more reasons.

In exploring the recommended approaches, readers should note the following:

- The recommended approach for each resiliency action did not represent an "average" of the three evaluation criteria scores but was based on expert judgment.
- The judgments were based on the information that emerged during the work group discussions. In many cases, when the available information was uncertain or could significantly alter the viability of an action, that action was placed in the *continue evaluating* category.
- The project team attempted to score each resiliency action consistently across vulnerabilities, not just within a vulnerability. For example, if an action was assigned a *do now* score, that score will stand when viewed against actions for other vulnerabilities, not just when viewed against other actions within that same vulnerability.
- The criteria were not prioritized and were weighted more or less equally. Depending on an individual's prioritization of the three evaluation criteria, he or she could assign each resiliency action a different recommended approach than the project team did. For example, an individual with a resource-constrained perspective might emphasize cost; an individual with a technical perspective might instead prioritize feasibility or effectiveness.

In summary, the scores provide a way to present a possible prioritization of resiliency actions and to model the kind of process and approach that NREL may wish to take as it begins to research, select, and implement resiliency actions after the resiliency action plan is complete.

* No-regrets strategies provide benefits under current and projected climate conditions. When NREL spends money on a no-regrets strategy, it will reduce facility risk to current climate stressors, make the laboratory more resilient to future climate change, and ensure the investment is worthwhile regardless of the climate future. A low-regrets strategy may involve some cost that is not fully justified under current climate conditions.

3.1 Cross-Cutting Solutions

Several cross-cutting resiliency actions emerged during the work group discussions that could mitigate multiple vulnerabilities or that could serve as overarching mechanisms to address climate change. These actions were particularly evident across the vulnerabilities that have natural overlap, such as "Damage to climate-sensitive equipment may disrupt research" and "Staff may not be able to conduct outdoor research and other outdoor activities."

In this section, these cross-cutting resiliency actions are introduced first; additional information about these actions also appears in the applicable vulnerability-specific sections.

Two cross-cutting actions were assigned to the *do now* category: **Integrate climate considerations into current operations and practices** and **Create and implement a climate monitoring and communication system.** NREL also considered an alternative that would require a fixed part of the facilities improvement budget to be allocated to projects that address climate change. The project team recommended that this action be removed from further consideration because projects that prioritize climate change add constraints to the budget allocation process. Instead, climate change considerations should be globally incorporated into budget allocation strategies. Table 4 summarizes these actions.

Table 4. Cross-Cutting Solutions Identified to Mitigate across Multiple Vulnerabilities*

Action	Description	Evaluation Criteria and Score			Recommended Approach
		Effectiveness	Feasibility	Cost	
Integrate climate considerations into current operations and practices	Provide a framework to integrate climate considerations into current operations and practices, including facility management plans, laboratory operating procedures, and equipment purchases	Good	Good	Fair	Do now
Create and implement a climate monitoring and communication system	Create and implement a system to monitor and communicate indoor and outdoor climate variables, including building temperatures, so staff can dress accordingly; provide lightning and outdoor temperature predictions for outdoor safety	Fair	Fair	Fair	Do now
Allocate a set part of facilities funding toward issues that address climate change	Require a set part of facility funding to be allocated toward issues that address climate change to provide an ongoing funding stream to incorporate climate considerations into NREL's facility management	Fair	Poor	Fair	Remove from consideration

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

3.1.1 Integrate Climate Considerations into Current Operations and Practices

The action of integrating climate considerations into current operations and practices emerged as a theme in many of the resiliency action work groups. Independent research showed that other federal agencies have also evaluated and recommended integrating climate considerations into current practices. As the U.S. Department of Defense notes in its *2014 Climate Change Adaptation Roadmap*, "Adaptation to climate change cannot be a separate decision-making process, but rather integrated into the Department's existing management processes. Therefore, the Department will review and, as needed, make changes to existing plans, policies, programs, and operations to incorporate climate change considerations" (DOD 2014, p. 9). NREL should implement a similar strategy for incorporating climate considerations at NREL facilities.

Although this action was identified as a cross-cutting solution that NREL can integrate into current policies and practices, two specific vulnerabilities should be mitigated: "Damage to climate-sensitive equipment may disrupt research" and "Staff may not be able to conduct outdoor research and other outdoor activities." The specific suggestions were to:

- Continue to update safety plans.
- Update laboratory-level procedure templates to ensure managers are incorporating climate considerations into their procedures.
- Incorporate climate change projections into the process for purchasing and upgrading outdoor and climate-sensitive equipment (e.g., add climate-related questions to infrastructure checklists, install backup or supplementary equipment).
- Add climate-related questions to operations and research project plans.
- Create a monitoring system for extreme events to help staff plan appropriately for conditions at the worksite.
- Include climate considerations in facility design and planning.

Effectiveness. The overall effectiveness of integrating climate consideration into current operations and practices was scored as *good*, based on work group discussions and on the recommendations from the U.S. Department of Defense's independent evaluation of a similar action. The resiliency actions that could result from such a policy are expected to be effective. As climate and climate change projections continue to evolve, this action will provide identified catalysts and targeted mechanisms through which NREL can integrate climate considerations into its operations and practices without developing a separate decision-making process.

Feasibility. This action's feasibility was scored as *good*, both technically and organizationally. Logistically, this action is quite feasible; NREL already reviews and updates its operating procedures and health and safety plans at regular intervals; adding regular consideration of climate change should be straightforward. However, one potential barrier to this action is that current climate change projections must be incorporated and assessed. NREL does not currently have this capability in-house. Given that current mechanisms might be used to contract with external experts, this potential barrier is not strong enough to decrease the feasibility score for this action.

Cost. Despite the potential need to contract with outside climate experts to update and assess climate risks, the direct cost of integrating climate considerations into current policies and procedures is good. However, addressing the findings from such a review may incur additional financial costs. For example, reviews of climate-sensitive equipment may result in changes to testing and maintenance schedules or to new equipment purchases. However, taking a proactive approach to incorporating climate change into equipment purchases can lead to long-term cost savings because NREL may purchase more effective and longer lasting equipment, which would lower maintenance and replacement costs. Based on these potentially conflicting cost considerations, the action integrate climate consideration into current programs and practices was scored as *fair*.

Recommended approach. Integrate climate change considerations into current operations and practices is a no- or low-regrets action: the framework is already available, and this action strongly aligns with NREL's mission as a leader in sustainability. This action has strong potential to consistently mitigate climate change risks and will provide NREL the flexibility to deal with changing climate concerns. NREL should thus approach this as a *do now* action.

3.1.2 Create and Implement a Climate Monitoring and Communication System

Several work groups discussed how to create and implement a climate monitoring and communication system, which would provide staff with information about daily indoor office temperatures, current weather, and forecasts before the next workday. System components might include:

- Proactive information sharing, which would provide a way to lower the risk of NREL's reliance on evaporative cooling and chillers if temperature increases, water shortages, or increased humidity levels reduce heating, ventilating, and air conditioning (HVAC) equipment efficiency or effectiveness. If staff knew in advance that indoor air temperatures or humidity levels would be higher than normal, they could dress more appropriately or, if possible, choose to work remotely.
- A climate monitoring and communication system, which could reduce disruptions to research that relies on climate-sensitive equipment. A tailored suite of climate information could help laboratory managers make informed decisions about their research operations.
- An alert system, which would communicate potentially hazardous weather, such as lightning storms or extreme heat. This could help NREL reduce the risks associated with conducting outdoor research. NREL currently uses limited information to evaluate wind speed and lightning potential to evaluate when work should be suspended for safety reasons. Enhancing this type of monitoring and notification system and extending it to NREL's subcontractors would significantly enhance safety for outdoor construction activities. Providing staff with customized weather alerts to communicate local hazardous conditions would reduce the exposure of staff members who work outdoors and would enable them to adjust their research and operation schedules to accommodate such hazards.
- As a cobenefit, advance knowledge of outdoor climate variables such as wind speed and solar radiance, which could improve NREL's weather-dependent research.
- A mobile phone application, which enables staff members to remotely access information that is specific to their needs. NREL could use a phased approach based on technical feasibility and cost to implement this system. That is, the simplest and least-expensive information could be included in the first phase; complex and expensive information could be rolled out in later phases. NREL already uses live graphical displays of weather dashboards that communicate current weather conditions at the mesa top and at the National Wind Technology Center (NWTC). Weather data will also be integrated into the Energy Intelligent Campus system for the STM. Expanded information could include

forecasts of indoor climate conditions and customized details to inform outdoor researchers and operations staff about current or forecasted hazardous conditions.

Effectiveness. Based on this assessment, the effectiveness of this action was scored as *fair*. A climate monitoring and communication system will reduce—but not eliminate—vulnerabilities to NREL's HVAC systems and improve researchers' ability to safely and effectively conduct outdoor research.

Feasibility. The feasibility of this action varies across the suggested indoor and outdoor applications. Creating a way to monitor and communicate indoor conditions every day is technically feasible. Because of its strong nexus with NREL's mission as a sustainable campus, and because it could build on the weather dashboard system, it may also be organizationally feasible.

The technical feasibility of monitoring and forecasting customized outdoor climate conditions is variable and uncertain. The National Weather Service already forecasts climate variables that are less localized and that would be feasible in a communication system. However, localized weather events such as lightning storms and scattered showers are more difficult to forecast at a useful scale.

Because the feasibility across components varies, this action was scored as *fair*. However, if NREL were to implement a phased approach, some individual phases could be scored higher.

Cost. The cost of this action would also vary across the indoor and outdoor components. A customizable system to communicate the climate conditions of workspaces to the appropriate staff so each person has enough time to incorporate the information into his or her morning routines and daily planning would be the highest cost component. NREL has monitoring software, but some might need to be replaced. A software program to communicate this information would be relatively expensive.

The marginal costs for adding outdoor variables to this system would likely depend on the information and on how localized that information needs to be. Because the NWTC currently has a lightning alert system that identifies energy levels and disturbances within certain distances from the site, expanding that technology to the STM may be relatively inexpensive. NREL would need to conduct more research to obtain a cost estimate. Because the main system is expected to be of medium cost, and because the cost estimates for the various subcomponents are uncertain, this action was scored as *fair,* with the caveat that actual cost estimates cannot be made until program requirements are defined.

Recommended approach. Although the individual evaluation scores are lower than other *do now* projects, this action was assigned to the *do now* category because it aligns so well with several of NREL's goals, including NREL's mission to maintain a sustainable campus and its focus on maintaining that sustainability despite changing climate conditions. This action would also mitigate multiple vulnerabilities and provide research cobenefits.

3.2 Each Campus Has Only One Water Supplier and No Backup Options

NREL's reliance on one water supplier for the STM and one for the NWTC scored as a high-risk vulnerability. The work group discussed two types of actions for addressing this risk: (1) actions for securing additional or backup supply, and (2) actions for developing strategies to operate with less water, should the suppliers reduce their supplies (see Table 5).

Table 5. Each Campus Has Only One Water Supplier and No Backup Options*

Action	Description	Evaluation Criteria and Score			Recommended Approach
		Effectiveness	Feasibility	Cost	
Develop a water-shortage contingency plan	Provide a framework for reducing demand and prioritizing limited supply during water shortages	Good	Good	Good	Do now
Connect the NWTC to a public water system	Connect the NWTC to and purchase water from the City of Arvada's water supply distribution system	Fair	Good	Poor	Continue evaluating
Purchase water rights	Purchase water rights with enough seniority to ensure necessary supply during water shortages; a distribution and treatment system must be built	Good	Poor	Poor	Remove from consideration
Drill a well	Drill a well onsite or on adjacent property; water rights must be purchased and a distribution and treatment system built	Fair	Poor	Poor	Remove from consideration
Create on-site water storage	Build a 1-million-gallon tank on the mesa top to provide a temporary supply during an emergency for the STM; the single source would still supply the tank	Poor	Poor	Poor	Remove from consideration

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

Ultimately, **Develop a water-shortage contingency plan** was scored as *do now*. **Connect the NWTC to a public water system** was scored as *continue evaluating*. A summary of the evaluation of these alternatives follows.

As Table 5 shows, three actions should be removed from consideration: **Purchase water rights, Drill a well onsite** or on an adjacent property, and **Create on-site water storage**. Purchase water rights was removed because of the poor technical feasibility and high costs associated with building a distribution and treatment system. Drill a well was removed because of high costs and the poor feasibility that stems from complexities associated with obtaining a permit from the state. Preliminary conversations with a State of Colorado engineer revealed that because NREL is located on the edge of a basin, a permit would likely not be issued. Drilling a well onsite and finding a location to drill offsite would be technically infeasible because a distribution and treatment system would have to be built. Create on-site storage was removed because it would not reduce the vulnerability associated with having a single supplier. Its feasibility is also poor because NREL does not own a storage or distribution system and on-site storage requires treatment; per Colorado drinking water regulations, this action would require this new infrastructure.

During the iterative process of developing and evaluating the resiliency actions and this plan, several additional actions were identified that merit further consideration:

- Detect and fix water leaks in NREL's infrastructure.
- Develop a treatment facility to allow water reuse.
- Purchase a nonpotable water supply and build an on-site storage facility to offset landscaping and research water use (as opposed to drinking water use).

These late-breaking additional actions are not included in the analysis, but NREL should explore them as opportunities allow.

3.2.1 Develop a Water-Shortage Contingency Plan

Colorado and other similarly arid and semiarid regions are experiencing increased intensity and frequency of droughts; thus, water-shortage contingency plans are becoming common for organizations and businesses in these areas. Further, Executive Order 13693 mandates that federal facilities that are larger than 5,000 gross square feet move toward net-zero water use by 2025. Water-shortage contingency plans provide a framework to systematically reduce demand if a water supply is disrupted or a shortage occurs for some other reason. Plans also include a demand-management strategy to identify and prioritize water uses that are most needed and to minimize adverse effects on operations, workers' health, and safety under various scenarios of curtailment. Some plans include a schedule-based approach to emergency shortages with certain buildings operating on designated days.

Effectiveness. The overall effectiveness of a water-shortage contingency plan depends on several factors. NREL's ability to further reduce its demand may be difficult given its conservation efforts to reduce water use. Organizational adoption and commitment to fund and implement strategies will also influence effectiveness. Strategies that address operational, user, and research needs may conflict with each other if they are not developed in a prioritized and tactical manner. Finally, NREL will need to ensure that the strategies it pursues are achievable and legal, given current public- and private-water infrastructure and laws; the public water purveyor, Consolidated Mutual, will need to be included in these strategies.

Despite the possible challenges of reducing NREL's water use, the effectiveness of developing a water-shortage contingency plan was scored as *good* because it can allow operations to continue, even during drought conditions.

Feasibility. Developing a water-shortage contingency plan would be organizationally and technically feasible. Developing a plan is thus a no- or low-regrets action even without the pressures of climate change; developing a plan was scored as *good* for feasibility.

Cost. The cost of producing a water-shortage contingency plan is low because it does not rely on expensive infrastructure or equipment investments, so the action was scored as *good* for cost.

Recommended approach. Given the scores, Develop a water-shortage contingency plan was recommended as *do now*.

3.2.2 Connect the National Wind Technology Center to a Public Water System

The water supply at the NWTC is especially vulnerable because the water is trucked in from a single-source provider, which makes the site vulnerable to water-supply and site-access issues. The assessment showed that these vulnerabilities are likely to be exacerbated with climate change. NREL has submitted a request to connect the NWTC to a public water system, although the status of that request was unknown at the time this plan was written.

Effectiveness. This action would eliminate the additional vulnerability of requiring consistent access to the NWTC for water deliveries; however, the NWTC would remain reliant on a single-source supplier. For these reasons, Connect NWTC to a public water system was assigned a *fair* score for effectiveness.

Feasibility. NREL has already begun to pursue the feasibility of connecting the NWTC to the City of Arvada public water supply; thus, the action was scored as *good* for feasibility.

Cost. The cost to connect the NWTC to the City of Arvada's water supply is estimated at $2.8 million; this action received a score of *poor* for cost.

Recommended approach. Although NREL is already considering this action, it was recommended as *continue evaluating* because of its poor cost and fair effectiveness.

3.3 NREL May Not Be Able to Continue to Rely on Evaporative Cooling and Chillers

Most of the resiliency options that address NREL's water supply vulnerability also address NREL's reliance on water for use in evaporative cooling and chillers. However, three alternatives were identified that specifically address NREL's reliance on evaporative cooling and chillers (Table 6):

- ***Create and implement a climate monitoring and communication system***. This *do now* option is described as a cross-cutting action in Section 3.1.2.
- ***Add conventional backup air conditioning***. This was recommended as a *continue evaluating* option.
- ***Retrofit the high-performance computer***. NREL should remove this option from consideration because of extremely high costs and low feasibility. The option is technically possible but would require replacing the Energy Systems Integration Facility's cooling towers with dry coolers and increasing cooling fan energy use. Thus, it

would reduce water use but simultaneously require more grid electricity, which would effectively increase NREL's vulnerability of relying on a single electricity supplier (Section 3.4).

Table 6. NREL May Not Be Able to Continue to Rely on Evaporative Cooling and Chillers*

Option	Description	Evaluation Criteria and Score			Recommended Approach
		Effectiveness	Feasibility	Cost	
Create and implement a climate monitoring and communication system	Create and implement a system to monitor and communicate indoor and outdoor climate variables, including building temperatures, so staff can dress accordingly and provide lightning and outdoor temperature predictions for outdoor safety	Fair	Fair	Fair	Do now
Add conventional backup air conditioning	Add conventional coolers and backup air conditioners for use during periods of prolonged or intense humidity or heat	Good	Fair	Fair	Continue evaluating
Retrofit the high-performance computer	Retrofit the high-performance computer so that it is not cooled by chillers that rely on water	Fair	Poor	Poor	Remove from consideration

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

3.3.1 Add Conventional Backup Air Conditioning

NREL should continue to evaluate this action for periods of prolonged or intense humidity or heat. NREL currently uses energy efficient ambient air and evaporative cooling to cool its offices and laboratories because of the arid Colorado climate. Increased extreme temperatures can pose challenges to maintaining a comfortable and safe office environment. Climate experts are projecting no average overall increase in relative humidity; however, short-term relative humidity spikes that are caused by convective storms may pose challenges to comfort and safety. NREL could use air conditioners only during periods when evaporative cooling cannot reduce temperatures to a comfortable level; this limited use would help address any concerns that the use of air conditioners could damage NREL's reputation as a sustainable campus (see "Feasibility").

An additional concern about NREL's cooling system is that it relies on water; as described in the vulnerability assessment, water supplies are also vulnerable to climate change. In the event of water curtailments, NREL could reallocate the water it uses for cooling to another use. NREL should use a tiered approach to reduce the cost and improve the feasibility of this action; only essential laboratories and buildings should use backup air conditioners. For example, security buildings at secure-access entrances and climate-sensitive laboratories would have backup air conditioners; the Education Center would not. This action would also reduce a disruption to research that relies on climate-sensitive equipment.

This resiliency action does not address risks from NREL's reliance on evaporative cooling for equipment needs, which were addressed under actions to mitigate disruptions to research that relies on climate-sensitive equipment (Section 3.6).

Effectiveness. Air conditioners effectively maintain comfortable and safe indoor climates and do not rely on water. Thus, backup air conditioners would be more effective than evaporative coolers during periods of extreme heat and increased humidity. Based on these considerations, this action's effectiveness was scored as *good*.

Feasibility. The most important barrier to backup air conditioners is that these systems require increased energy, which may conflict with NREL's mission and ability to remain a sustainable campus. During times of drought, however, this action may improve NREL's sustainability by lowering its water use, and the focus on carefully targeted and limited use helps address this concern. Thus, the feasibility of this action was scored as *fair*.

Cost. The cost to install backup air conditioners is high, but prioritizing a subset of spaces to cool would reduce the cost. Thus, cost was scored as *fair*.

Recommended approach. Based on this evaluation, NREL should continue evaluating the action of backup air conditioners, especially in climate-sensitive laboratories.

3.4 NREL Has Only One Electricity Supplier and Depends on Electricity to Support Mission-Critical Activities, Including IT Connectivity

NREL's reliance on electricity supplied from a single supplier scored as a high-risk vulnerability. NREL's IT infrastructure, buildings and research areas depend on a reliable source of electricity. Two *do now* actions were identified to reduce this vulnerability: **improve demand management** and **install a battery supply**. Both of these actions help NREL increase the diversity of the on-site generation system.

NREL has a number of mission-critical electricity requirements. The two actions were evaluated individually. However, an alternative approach would be to evaluate a portfolio of actions rather than individual actions.

NREL should use a tiered implementation approach to *continue evaluating* the action of **establish a microgrid**.

During the resiliency action review process, an additional resiliency action was suggested to mitigate NREL's electricity supply vulnerability: that NREL evaluate concentrated solar power and any other innovative technologies that may become available.

Table 7 summarizes the actions and recommendations vis-à-vis this vulnerability.

Table 7. NREL Has Only One Electricity Supplier and Depends on Electricity to Support Mission-Critical Activities, Including IT Connectivity*

Action	Description	Evaluation Criteria and Score			Recommended Approach
		Effectiveness	Feasibility	Cost	
Improve demand management	Improve demand management by improving energy efficiency, developing a demand-response program, and developing an energy-shortage contingency plan	Fair	Fair	Good	Do now
Install a battery supply	Install a supply of batteries in which NREL could store either the excess power it generates or the power it purchases from Xcel	Good	Good	Fair	Do now
Establish a microgrid	Establish a microgrid to serve as the primary electricity source and maintain a connection to the grid for use as a backup supply	Good	Fair	Fair	Continue evaluating

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

3.4.1 Improve Demand Management

Work group participants discussed the concept of improving electricity demand management as an action that includes three components. Each component was evaluated individually and assigned collective scores for each evaluation criteria.

- ***Improve energy efficiency***. Because NREL is already committed to continuously improving energy efficiency, this action is ongoing. Executive Order 13693 (Federal Register 2015) requires that all new federal buildings larger than 5,000 gross square feet that enter the planning process in 2020 or thereafter achieve net-zero energy by 2030. This is a major driver for energy efficiency and renewable energy.
- ***Develop a demand-response program***. This program would enable NREL to reduce or shift its electricity use during peak periods.
- ***Develop an electricity-shortage contingency plan***. Similar to the water-shortage contingency plan described in Section 3.3, NREL should develop an electricity-shortage contingency plan to systematically reduce demand and prioritize supply if the electricity supply is disrupted. An electricity-shortage contingency plan could also work in conjunction with the installation of a battery supply (Section 3.4.2). The plan could help inform the amount of electricity storage required to sustain essential operations during power outages and suggest ways to prioritize that battery supply during outages and shortages.

Effectiveness

- ***Improve energy efficiency***. NREL is a leader in creating clean energy technologies for the marketplace and in constructing its own facilities to exhibit whole building systems that optimize energy efficiency and integrate renewable energy systems. Of the 999,796 square feet of buildings at the STM, seven Leadership in Energy & Environmental Design Platinum or Gold buildings comprise 69.5% of the campus footprint. Although the efficiency of older facilities can be improved through retrofits, significant further efficiency gains must come from more difficult initiatives such as reducing load growth through active controls and changing the operational requirements of new equipment. Thus, this action scored *fair*.
- ***Develop a demand-response program***. NREL has the capacity to shift its electricity use during peak periods to reduce the likelihood of grid-scale blackouts and power shortages. The effectiveness of a demand-response program would depend on large-scale participation from power customers beyond NREL. Thus, an NREL-specific demand-response program would have little or no effect on the overall reliability of electricity supply from the grid. This action scored *fair*.
- ***Develop an electricity-shortage contingency plan***. This action will mitigate NREL's loss of mission-critical activities that rely on electricity, including IT support, because it will help prioritize use. However, the plan will be effective only if it is implemented in conjunction with install a battery supply (Section 3.4.2) because the battery supply would protect against the risk of energy blackouts. Assuming that NREL implements the battery supply action as recommended, this action scored *good*.

Apart from their operational benefits, demand-response systems would decrease NREL's demands on the electricity grid during shortages. The individual components of improved demand management were assigned mixed scores; thus, this action scored as *fair* for overall effectiveness.

Feasibility. Reducing the use of electricity and demand on power systems is already a priority for NREL. Thus, from an organizational perspective, this action is feasible. The technical feasibility, however, needs further evaluation because demand-response programs require shifts in energy use based on peak demand. For example, NREL research that requires the high-performance computer probably cannot be shifted, but energy demands for cooling might be shifted through chilled water storage. Because of this uncertainty, the feasibility for demand-management efforts was scored as *fair*.

Cost. Xcel Energy offers rate incentives for shifting energy use from peak time through its Energy-EnerNOC Peak Savings Program (EnerNOC undated). These savings may offset the logistical costs of shifting NREL's electricity use and the financial costs of developing demand-management software. Thus, the costs of shifting peak demand and developing and implementing an electricity-shortage contingency plan are low. This action was scored as good.

Recommended approach. This is a no- or low-regrets recommendation, partly because it aligns with NREL's focus on sustainability, and partly because changes to climate are likely to increase the number of power outages. However, NREL needs to ensure a minimum amount of energy during shortages and should consider implementing this action in conjunction with installation of a battery supply (Section 3.4.2). This action was recommended as *do now*.

3.4.2 Install a Battery Supply, South Table Mountain Campus

The STM currently generates approximately 7% of the electricity it uses from onsite photovoltaic systems; and Xcel Energy delivers the rest via the grid. NREL's multiple photovoltaic systems are connected to the grid in one location, and NREL currently consumes all the electricity generated at the STM. Installing batteries in which NREL could store electricity onsite would be an appropriate resiliency action for the vulnerability of relying on a single energy supplier. During grid-based power outages, NREL could use the stored power in its batteries to maintain essential prioritized functions; the facilities that are unaffected by an electricity-supply shortage would depend on the size of the battery system. Given the importance of understanding the demand and priorities for NREL's essential functions, the action of installing battery power is closely related to the action of developing an electricity-shortage contingency plan (Section 3.4.1).

Effectiveness. NREL has conducted a preliminary assessment and determined the amount of battery storage needed to provide enough electricity to support critical needs, although an electricity-shortage contingency plan would help prioritize the allocation of electricity. Thus, the action of installing a battery supply was assigned an effectiveness score of *good.*

Feasibility. The organizational feasibility of this action is good because battery power is in line with NREL's mission to research and use renewable energy. The external feasibility of this action is more complex because of the relationship with Xcel Energy through the power purchase agreement. Nevertheless, this action was scored as *good.*

Cost. NREL has identified battery requirements; preliminary costs seem moderately expensive. Thus, cost was scored as *fair*.

Recommended approach. Based on the evaluation, this action was recommended as *do now*.

3.4.3 Establish a Microgrid, South Table Mountain Campus

A microgrid is a segment of the power grid that can generate and manage energy. Microgrids normally operate while connected to the grid, but they can disconnect from the traditional grid and operate autonomously during power outages or similar events. A switch can separate the microgrid from the main grid to allow the systems to be automatically or manually connected or disconnected.

Establishing a microgrid at the STM would reduce the site's vulnerability to a single electricity supply by providing a backup electricity option. Currently, the STM generates approximately 7% of the electricity that it consumes. Thus, a microgrid system could enable prioritized facilities to operate isolated components for mission-critical uses. NREL is currently in the process of establishing a pilot-scale microgrid at the Vehicle Testing and Integration Facility. The experience from the pilot-scale microgrid could help inform the strengths and drawbacks of developing a full-scale microgrid to serve the entire STM.

Effectiveness. The STM currently relies on the grid to distribute its electricity and to provide the minimal base power load. The microgrid would deliver islanding capabilities to enable the STM to operate independently of the grid and would provide a backup supply of electricity during power outages to power essential operations such as IT connectivity and the supercomputing facility.

The effectiveness of this action, like the action of installing battery power, is related to implementing an electricity-shortage contingency plan; such a plan would help prioritize use and provide infrastructure to implement those priorities. Assuming NREL implements an electricity-shortage contingency plan; this action's effectiveness was scored as *good*.

As a cobenefit, if NREL were to have a microgrid system that enabled autonomy, the laboratory would have a significant operational asset.

Feasibility. This action aligns well with NREL's mission as a leader in clean energy technologies. All photovoltaic systems, whether they are governed by power purchase agreements or are NREL-owned, need to be installed with a switching mechanism to transition from grid to island condition. NREL does not currently have the switches in place. NREL also has not initiated agreements with Xcel to install a microgrid, although such agreements appear to be feasible. Based on these two potential obstacles, this action was scored as *fair* for feasibility.

Cost. Although a detailed cost estimate is outside the scope of this analysis, this action scored as *fair.* NREL has a good understanding of system requirements and believes there is potential for industry partnering to cost-share; however, the costs of the required large infrastructure installments and retrofits are high.

Recommended approach. Despite the concerns about the feasibility and cost of developing a microgrid for the STM, this action was recommended as c*ontinue evaluating*. The strong alignment with NREL's mission and its potential for effectiveness warrant further exploration.

3.5 Site Flooding May Occur because the South Table Mountain Campus Has Poor Drainage; Landslides May Occur because the South Table Mountain Campus Buildings are Close to the Mesa Slope

As described in the vulnerability assessment, NREL has two high-risk vulnerabilities that pertain to physical space: (1) the STM's proximity to the mesa slope, which presents a high overall risk of landslides; and (2) its poor drainage, which presents a medium-to-high overall risk of site flooding. For this plan, these vulnerabilities have been combined into one discussion because the associated resiliency actions have considerable overlap.

The primary resiliency action that the work groups discussed to mitigate these vulnerabilities was to redesign and retrofit the site's drainage. Improving drainage and overall storm water management would mitigate NREL's risk of flooding and landslides. A project of this size and complexity would require two phases: (1) develop a master plan to evaluate a redesign of site drainage, and (2) retrofit the campus based on the plan. For this analysis, these two actions have been combined into a single action: **evaluate and redesign the site to improve drainage and**

slope stability. As Table 8 shows, this action was placed in the *do now* category. Because the two phases are consecutive, the effectiveness, feasibility, and costs of specific projects that are yet to be identified through the master plan cannot be evaluated at this time.

Table 8. Site Flooding and Landslides May Occur at the STM*

Action	Description	Evaluation Criteria and Score			Recommended Approach
		Effectiveness	Feasibility	Cost	
Evaluate and redesign the site to improve drainage and slope stability	Develop a plan to evaluate, plan, and potentially redesign part of the site drainage to allow water to be moved from the mesa slope and the STM	Good	Good	Fair	Do now

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

3.5.1 Evaluate and Redesign the Site to Improve Drainage and Slope Stability

The work group discussions that pertained to drainage centered on evaluating and redesigning drainage at the STM; NREL may also eventually retrofit the site's drainage and stabilize the steeper slopes around the west side of the campus. NREL should create a master storm water site plan so it can evaluate and prioritize projects to improve site drainage and stabilize the slope. A common theme for the site flooding work group was that multiple rain events and single, large-disaster scenarios must be considered. Examples of potential retrofit projects include:

- Resize the culverts and storm water pipelines to handle large precipitation events.
- Construct additional detention ponds to capture and slowly drain storm water and melted snow.
- Evaluate conveyance via swales.
- Use sustainable practices to maximize the use of porous materials in hardscape areas throughout the campus.
- Install small, in-series detention basins or other storm water drainage runoff improvements to enhance and promote the stability of the steep slopes that surround the mesa top.

NREL's recent construction of multiple facilities at the STM required NREL staff to design innovative and effective drainage systems to mitigate significant storm water events. These systems sustained back-to-back substantial rain events in September 2013.

Effectiveness. Evaluating and redesigning the drainage system for the STM will not entirely mitigate NREL's risks of landslides or flooding. However, such planning is a necessary first step. NREL has engineers on staff with a strong understanding of the issues posed by poor drainage and proximity to the mesa slope. With the high level of internal knowledge and capability, coupled with this action's status as a necessary first step, its effectiveness was scored as *good*.

Feasibility. Even without climate change, the STM is currently at risk of site flooding and landslides. Therefore, developing a drainage evaluation and redesign plan is a no- or low-regrets action that NREL should do in any case. NREL's in-house expertise in restoration ecology will enable it to address these concerns. Evaluating and redesigning drainage are common and therefore technically feasible; given the importance of the STM to NREL's mission, the organizational feasibility of such planning would be strong. Thus, the action was scored as *good.*

Cost. Because the issue is relatively complex, the cost of doing the initial evaluation and redesign is anticipated to be *fair*; however, the action would involve a large assessment and study, and the work could be done internally by staff who already possess a great deal of the necessary knowledge.

Recommended approach. As Table 8 indicates, this action was recommended as *do now*—with some caveats. It does not directly mitigate the risks posed by climate change; NREL's ability to mitigate this risk, however, directly depends on completing this action. Thus, this action is imperative.

3.6 Damage to Climate-Sensitive Equipment May Disrupt Research

The vulnerability discussed in this section—Damage to climate-sensitive equipment may disrupt research—would be particularly appropriate for the cross-cutting action **integrate climate considerations into current operations and practices** (section 3.1). This action is attractive for this vulnerability because climate variables can affect research equipment in a variety of ways; this action was recommended as *do now*.

The work groups discussed the following specific applicable components of this resiliency action:

- Incorporate climate change projections into the *process for purchasing and upgrading equipment* (e.g., add climate-type questions to infrastructure checklists).
- Update laboratory procedure templates to *require or recommend climate change considerations when updating laboratory-level procedures*.
- Include climate change considerations in facility designs.

One additional action, **retrofit climate-sensitive equipment**, was also identified and evaluated Table 9 shows that this action was recommended as *continue evaluating.*

Table 9. Damage to Climate-Sensitive Equipment May Disrupt Research[a]

Action	Description	Evaluation Criteria and Score			Recommended Approach
		Effectiveness	Feasibility	Cost	
Integrate climate considerations into current operations and practices[b]	Provide a framework to integrate climate considerations into current operations and practices, including facility management plans, laboratory plans, laboratory operating procedures, and equipment purchases	Good	Good	Fair	Do now
Retrofit climate-sensitive equipment	Redesign HVAC or laboratory layouts to minimize potential hazards associated with climate change	Fair[c]	Fair	Fair[c]	Continue evaluating[c]

[a] See Box 1 and Box 2 for details about scoring methodology.
[b] This action is described and evaluated in Section 3.1.1.
[c] The effectiveness and cost of this action have a reciprocal relationship: if effectiveness is *good*, cost will be *poor*; if effectiveness is *poor*, cost will be *good*. For this plan, a moderately effective and moderately costly implementation was chosen and score as *fair* for both.

3.6.1 Retrofit Climate-Sensitive Equipment

The work group participants identified specific equipment that is sensitive to water and that sits directly under or close to chilled water lines, which sweat and drip during periods of high humidity. Although climate experts predict decreased average relative humidity along the Front Range, relative humidity spikes are likely. Chilled water lines were identified as an issue in particular; however, other equipment climate sensitivities are possible. This action was recommended as *continue evaluating*.

To mitigate the specific risk of chilled water lines, NREL should redesign HVAC or laboratory layouts to minimize potential hazards. For example, when laboratory personnel determine equipment locations, they should consider that chilled water lines could damage nearby equipment. Alternatively, NREL could consider moving chilled water lines or even creating mini-environments that could be individually climate controlled to avoid damage to sensitive equipment. As an initial step, this action would require a scoping exercise to identify the locations of such potential hazards. Similar actions would be required for other equipment sensitivities.

Effectiveness. This action would directly mitigate—and perhaps entirely eliminate—the risk of HVAC damaging sensitive equipment. However, the effectiveness and cost of this action have a reciprocal relationship: if effectiveness is *good*, cost will be *poor*; if effectiveness is *poor*, cost will be *good*. For this plan, a moderately effective and moderately costly implementation was assumed; both effectiveness and cost were scored *fair*. Other equipment climate sensitivities would likely face similar tradeoffs.

Feasibility. The technical feasibility of redesigning or relocating chilled water lines and mechanical and electrical equipment will depend on individual laboratory layouts. NREL has limited annual funding allocated to facility improvements; the laboratory uses a competitive process to allocate funds internally, so feasibility will depend on the submission of other maintenance activities. Thus, a *fair* feasibility score was assigned to this action. Other equipment climate sensitivities would likely face similar feasibility challenges.

Cost. The uncertain level of effort needed to implement this action, paired with its technical complexity, made determining cost a challenge for the work group. Cost and effectiveness for this action have a reciprocal relationship. For this plan, a moderately effective and moderately costly implementation led to a score of *fair*. Other equipment climate sensitivities would likely face similar tradeoffs.

Recommended approach. Given the strong potential for this action and despite the drawbacks, NREL should *continue evaluating* this action.

3.7 Staff May Not Be Able to Conduct Outdoor Research and Other Outdoor Activities

Several cross-cutting resiliency actions were recommended (Section 3.1). The vulnerability discussed in this section—Staff may not be able to conduct outdoor research and other outdoor activities—would be particularly appropriate for the cross-cutting action of **integrate climate considerations into current operations and practices**. This action was recommended as *do now*.

The work groups discussed the following specific applicable components of this resiliency action:

- Continue to update safety plans.
- Add climate-related questions to project plans.
- Incorporate climate change projections into the process for purchasing and upgrading outdoor equipment.

The second cross-cutting resiliency action, **create and implement a climate monitoring and communication system** (Section 3.1.2) would also help mitigate the risk of outdoor research and activities, specifically through an alert to warn outdoor workers of hazardous conditions. This action was recommended as *do now.* Both actions are described in Table 10.

Table 10. Staff May Not Be Able to Conduct Outdoor Research and Other Outdoor Activities[a]

Action	Description	Evaluation Criteria and Score			Recommended Approach
		Effectiveness	Feasibility	Cost	
Integrate climate considerations into current operations and practices[b]	Incorporate climate change projections into the process for purchasing and upgrading equipment, update laboratory procedure templates to require or recommend climate change considerations when updating laboratory-level procedures, include climate change considerations in facility designs	Good	Good	Fair	Do now
Create and implement a climate monitoring and communication system[c]	Create and implement a system to monitor and communicate indoor and outdoor climate variables, including building temperatures so staff can dress accordingly and lightning; make accurate outdoor temperature predictions to ensure safety	Fair	Fair	Fair	Do now
Install outdoor structures for protection from hazardous weather events	Provide workers with additional shelters to allow them to seek shelter from unexpected weather events	Poor	Poor	Fair	Remove from consideration
Relocate the ReFuel Facility to the STM	Relocate the ReFuel Facility to a new indoor facility at the STM from its current location	Fair	Fair	Poor	Remove from consideration

[a] See Box 1 and Box 2 for details about scoring methodology.
[b] See Section 3.1.1.
[c] See Section 3.1.2.

NREL should *remove from consideration* two actions: **install outdoor structures for protection from hazardous weather events** at various locations at NREL and **relocate the ReFuel Facility to the STM**. Install outdoor structures was removed because it would not effectively mitigate the vulnerability; specifically, if staff members seek shelter, they would not be conducting outdoor research. The relocation of the ReFuel Facility was removed because such a large infrastructure project—which scored *poor* for cost and *fair* for effectiveness and feasibility—would probably be unwarranted given current climate change projections.

4 Next Steps

Table 11 summarizes the resiliency actions, categorized by vulnerability and key resource that NREL might pursue in the next stage of this project. The table does not include actions that came up late in the process, in parallel with the production of this plan. These actions are noted briefly in Section 3.2 and Section 3.3; NREL should include those actions and explore others as they arise during its subsequent analysis.

Table 11. Vulnerabilities, Resiliency Actions, and High-Level Scores[a]

Key Resource	Vulnerability	Overall Risk Score[b]	Resiliency Actions	Recommended Approach[b]
Multiple	Cross-cutting solutions identified to mitigate across multiple vulnerabilities	Not applicable	Integrate climate considerations into current operations and practices	Do now
			Create and implement a climate monitoring and communication system	Do now
Water	NREL has only one water supplier for each campus and no backup options	High	Develop a water-shortage contingency plan	Do now
			Connect the NWTC to a public water system	Continue evaluating
	NREL may not be able to continue to rely on evaporative cooling and chillers	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 IT 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 STM	High/medium-to-high	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 current operations and practices	Do now
			Retrofit climate-sensitive equipment	Continue evaluating
Site access[c]	Key staff may not be able to access NREL's sites to respond to emergencies and to conduct research; some situations requiring staff redundancy[c]	Medium-to-high	No resiliency action proposed because NREL is already addressing this issue[c]	No recommended approach beyond current NREL efforts[c]
Workforce	Staff may not be able to conduct outdoor research and other outdoor activities	Medium-to-high	Integrate climate considerations into current operations and practices	Do now
			Create and implement a climate monitoring and communication system	Do now

[a] This table presents only medium-to-high and high risk vulnerabilities that fell in the mitigate category and received a *do now* or *continue evaluating* recommendations. For related information, see Section 2 and Box 1.

[b] See Box 1 and Box 2 for information about the *overall risk score* and the *recommended approach*.

[c] The project team did not convene a resiliency action plan work group to discuss this vulnerability because NREL is already addressing this issue through its Emergency Preparedness Continuity of Operations Organizational Specific Plan.

As detailed in Box 2, the recommended approach scores in Table 11 should be viewed as preliminary: the recommendations were based on the information that emerged during the work group discussions.

The rationale behind making only preliminary recommendations was that NREL should internally reevaluate the resiliency actions to ensure that any selected actions align with NREL's specific priorities. Depending on NREL's priorities among the three evaluation criteria of effectiveness, feasibility, and cost, the laboratory could recommend a different approach for each resiliency action. NREL may change the weighting of the criteria or how the results are combined to determine the most advantageous approach. No priorities were set across the three criteria; they were effectively weighted equally. Furthermore, only initial fact-checking was conducted on the information generated through the work group discussions. Those facts should be evaluated further, especially for any proposed large-scale investments. Resiliency actions that have substantial factual uncertainties were generally recommended as *continue evaluating*.

NREL may consider the follow suggestions as it considers the information in the vulnerability assessment report and in this resiliency action plan. These adaptation principles borrow from a large body of work about best practices in the field of climate change adaptation; these were tailored to NREL's specific needs.

- ***Establish an ongoing process to institutionalize the project.*** Beyond exploring and implementing the actions listed in Table 11, NREL needs to find ways to internalize and institutionalize the processes of vulnerability assessment and resiliency action planning. Conditions will change as the understanding of climate variability and change improves and as policy preferences, NREL's mission and objectives, and climate conditions along the Front Range change. Periodic reviews and updates will ensure that NREL continuously practices adaptive management as it pursues resiliency and integrates changing information and conditions into its preparedness efforts.
- ***Mainstream resiliency into NREL's decision-making processes (Section 3.1.1).*** Integrating resiliency planning into current processes is generally more efficient and effective than isolating adaptation in a separate top-down initiative. As part of this effort, NREL or the U.S. Department of Energy may have policies that could undermine efforts to mainstream climate considerations into NREL operations and decision making; NREL should be aware of that possibility and be ready to pursue updates as needed.
- ***Learn from within.*** Continue to look within NREL for departments or groups that are already considering climate in their work. For example, the Security and Emergency Preparedness group may have insights into NREL's current policies as they relate to extreme climate events. Some NREL researchers and analysts have national and international climate change and emergency preparedness experience. The steering committee that was engaged in this planning process could provide expertise in climate change impacts and adaptation and should be viewed as a resource. NREL should bring these internal stakeholders into resiliency action planning.
- ***Develop a process to remain up-to-date on developments in climate science that can affect NREL.*** Climate science is continuously evolving; some areas of vulnerability for NREL may involve climate variables on which the science is uncertain—such as changes

in average precipitation. Treating the likelihood scoring in the vulnerability assessment as subject to revision would be worthwhile as the science evolves. This could change the highest risk vulnerabilities in future rounds of resiliency planning. Routine consultations with local climate experts will help NREL staff stay abreast of the latest developments in climate science. With a wealth of university- and government-based scientists in the Denver-Golden-Boulder-Fort Collins area, NREL is in an excellent position to cultivate relationships in support of this goal.

- ***Ask the "climate question."*** Whenever NREL leadership considers long-term investments, particularly infrastructure improvements on its two campuses, it should ask how climate variability and change could affect near- and long-term decisions.
- ***Prepare for uncertain futures***. As part of NREL's ongoing resiliency action planning, the laboratory should avoid the appeal of planning around a single-scenario climate future. Understanding and preparing for an array of possible "climate futures" will ensure that NREL selects the most beneficial resiliency actions, even when observational climate trends are unclear or projections conflict.
- ***Look for resiliency actions that are no- or low-regrets strategies***. Section 3 outlines a number of these win-win resiliency actions that are specific to NREL's vulnerabilities and operational environment. Such measures will provide immediate benefit to NREL and even greater benefit as the climate changes.
- ***Look for and take advantage of any opportunities that climate change provides***. Do not assume that all change is bad for NREL operations; climate change may provide NREL with new opportunities to test equipment and technologies in shifting climate conditions. Taking advantage of these possibilities could benefit NREL's research as the laboratory leads innovation to improve the energy future.
- ***Continue to identify near- and long-term actions.*** Adaptation to a changing climate may not require that all resiliency actions be instituted now; some actions may need more study. Some may not be needed now but may be needed in the future as conditions change. Contingency plans may be put in place, and implementation may depend on results from monitoring or analysis of climate variables.
- ***Cooperate with other Front Range government-based entities and organizations***. Differentiate between decisions NREL can make internally and those that will require cooperation with external entities. Some resiliency actions—such as creating a cross-cutting climate monitoring and communication system—are "self-contained"; NREL can pursue these actions internally. However, other actions—such as establishing a microgrid—will depend heavily on strong partnerships with external entities such as Xcel Energy. NREL leaders will want to consider these realities as they determine priorities.
- ***Learn from others***. Learn from outside organizations about how they are building on current best practices and following up on their own vulnerability assessments and resiliency action planning. For example, NREL might contact Boulder County concerning its 2012 *Boulder County Climate Change Preparedness Plan* (Boulder County 2012) or the Boulder Resilience Officer about the City's Resilience Plan, the State of Colorado concerning its 2015 *Colorado Climate Change Vulnerability Study*

(Colorado Energy Office 2015) and follow-on work, and the City of Denver and Jefferson County, who have reportedly begun climate adaptation efforts.

- ***Collaborate with other organizations and entities as they adapt to climate change***. NREL can help its neighbors leverage each other's efforts, learn from and network with each other, and collaborate when possible. For example, utilities are beginning to reach out to climate scientists to better understand climate change through the Water Utility Climate Alliance; NREL and other local entities could similarly collaborate as a group to leverage resources and knowledge.

In conclusion, the overarching key lesson from the NREL CCRP project is that understanding vulnerabilities and planning resiliency actions to mitigate their risk is not a linear process. Maintaining resiliency must be a continuous process. No single, standalone resiliency action will entirely eliminate a vulnerability, and even a comprehensive planning effort will not stand the test of time—and the test of climate change—if it does not become part of a larger, ongoing process. Adapting to change will require NREL's continued attention. NREL plans to reevaluate its vulnerabilities and resiliency actions at least annually, or as new information is revealed. With support from the U.S. Department of Energy and its other stakeholders, NREL will be able to adopt a proactive stance and lead the way toward strong organizational resiliency in the face of climate change.

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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