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An educated approach to resiliency

U.S. Department of Energy Federal Energy Management Program

A Climate Change Risk and Resilience Assessment Process

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August 15, 2017

NREL/PR-3500-70038

NREL Program Portfolio

Broad Range of Clean Energy Solutions






Energy Efficiency
Vehicle Technologies
Building Technologies

Renewable Resources
Wind and Water
Solar
Biomass
Hydrogen
Geothermal

Systems Integration
Grid Infrastructure
– SmartGrid and RE Grid
Battery and
Thermal Storage

International, Tribal, Federal Agencies, States, Local Communities, Private Sector

Foundational Science

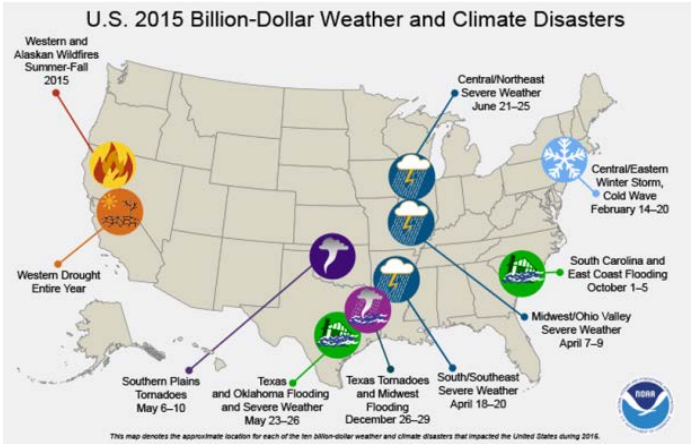
Why Climate Change Resilience Planning?

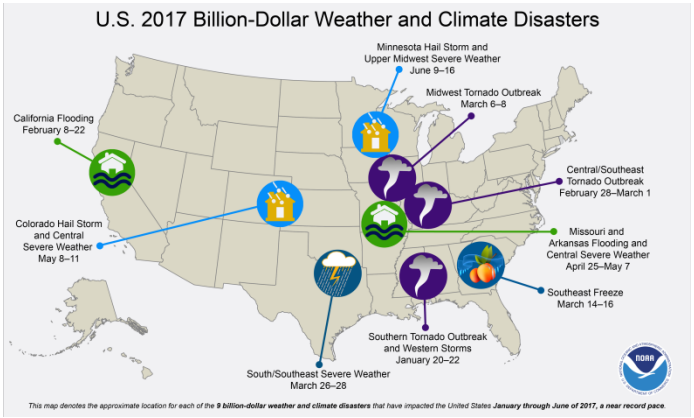
- The business case:

  Extreme weather has already had an impact across the nation. Preparing for and strengthening assets and processes **to lessen impacts and recover quickly** from existing weather-related events and climate change will help ensure viability of the organization.

- EO 13693: *Planning for Federal Sustainability in the Next Decade* (March 2015)

  *"…ensure that **agency operations and facilities prepare for impacts of climate change**." (Section 13)*

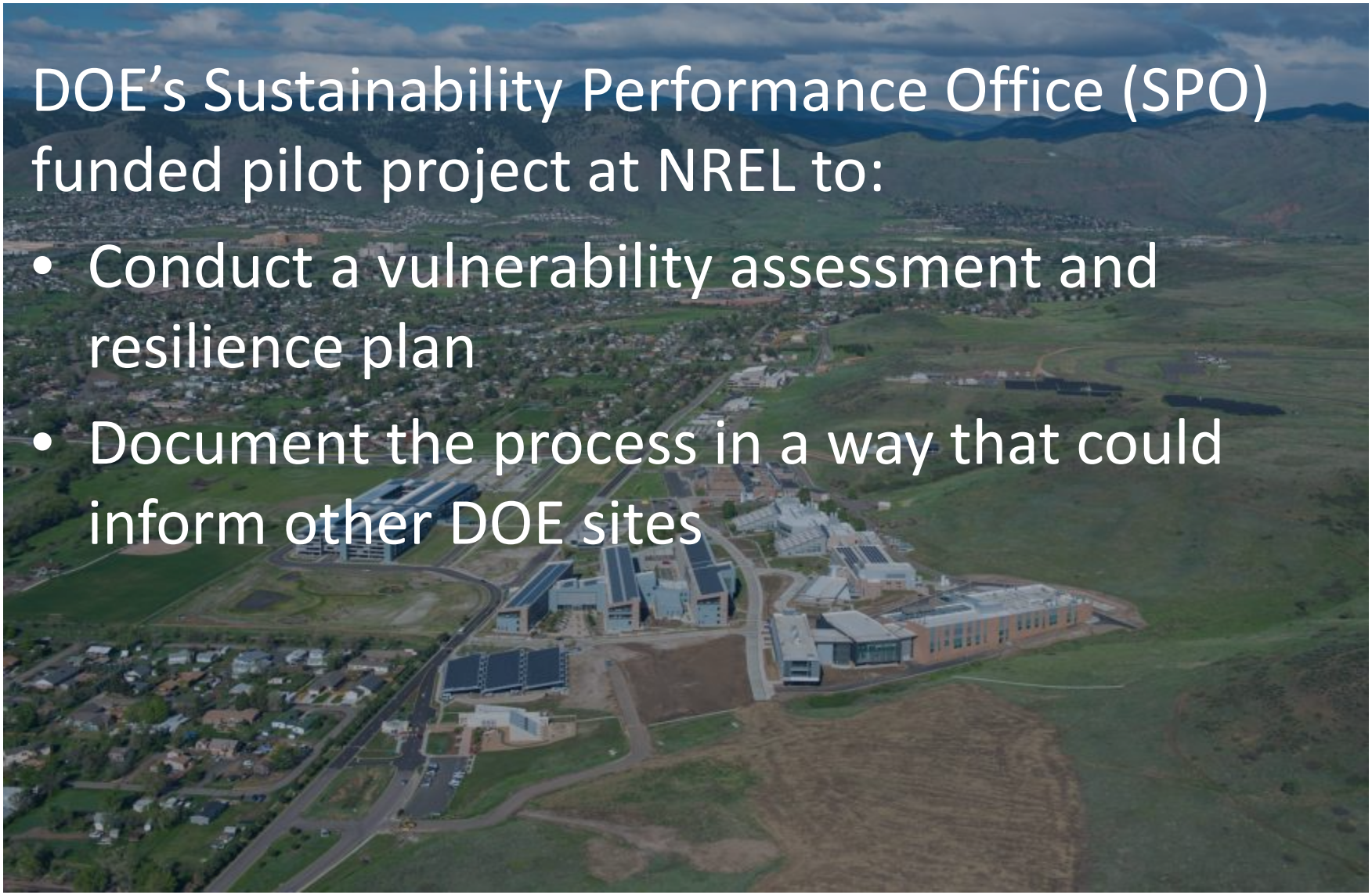




Each year there are multiple weather and climate disaster events with losses exceeding $1 billion each across the United States

[NOAA National Centers For Environmental Information]

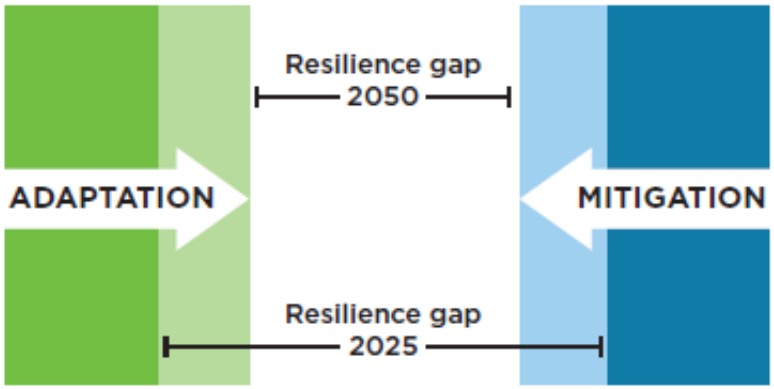
NREL's Climate Resilience Assessment Pilot Project



DOE's Sustainability Performance Office (SPO) funded pilot project at NREL to:

- Conduct a vulnerability assessment and resilience plan
- Document the process in a way that could inform other DOE sites

Project Context



Source: www.ucsusa.org/resilience_principles

Mitigation

Reducing emissions and increasing energy efficiency to minimize contributions to climate change (e.g., renewable electricity and demand management)

Adaptation

Changing what you have, how you operate, or what you do, so enough flexibility exists to adapt to climate changes, while continuing to thrive (e.g., design standards, back-up power generation)

Modified an Established Approach

- U.S. EPA's Climate Ready Estuaries approach as a guide
- Tailored the process more suitable for a site-level assessment
- Sought external assistance to provided credible and actionable climate science info

Collaborative Stakeholder-Driven Participatory Process

Resilience Assessment Process Overview

Stage 1: Risk Assessment Process

Develop Impacts Framework
(Key Objectives X Key Resources)

Identify Sensitivities
(consequences)

Identify Climate Stressors
(likelihood)

Evaluate Climate Change Risk

Sensitivity – Consequence	Climate Stessors – Likelihood				
	High (H)	Med-High (MH)	Med (M)	Med-Low (ML)	Low (L)
Critical (I)	IH[1]	IMH[1]	IM[3]	IML[6]	IL[7]
Marginal (II)	IIH[4]	IIMH[5]	IIM[8]	IIML[11]	IIL[12]
Negligible (III)	IIIH[9]	IIIMH[10]	IIIM[13]	IIIML[14]	IIIL[15]

1-2: High Risk Sensitivity; 3-5: Medium-High Risk Sensitivity; 6-10: Medium Risk Sensitivity; 11-13: Medium-Low Risk Sensitivity; 14-15: Low Risk Sensitivity

Stage 2: Resilience Evaluation Process

Identify Resilience Options

Evaluation Criterion	Score: Description		
	Good	Fair	Poor
Effectiveness	Would completely or nearly eliminate the sensitivity's risk	Would significantly reduce part or all of the sensitivity's risk	Would not significantly reduce the sensitivity's risk
Feasibility	Could be implemented technically, organizationally, and politically	Some reservations about the ability to implement the action technically and organizationally, or only a part of the action could be implemented	Could not be implemented technically or organizationally
Cost	Would have relatively low monetary cost. To implement; Generally desk-style projects, often with no or few infrastructure components	Would have relatively moderate monetary costs; Could include a modest infrastructure component	Would have relatively high monetary costs; Could include significant infrastructure components

Score Resilience Options
(effectiveness, feasibility, cost)

Recommend Approach
(do now, continue evaluating, remove from consideration)

Stage 1: Impacts Framework

Explore role that climate stressors play in organization's ability to meet its key organizational objectives (in relation to the key resources needed to meet those objectives).

	Key Organizational Objectives			
	I Drawdown Execution	II Protect the Nation's Crude Oil Stockpile	III Maintain SPR's Current Import Protection Level	IV Promote International Energy Stockpiling & Alliances
Key Resources				
Water	(quantity, quality, and access)			
Power	(quantity, quality, and access)			
Command and Control System	(communications systems)			
Physical Space	(caverns, land, facilities, site infrastructure (e.g., perimeter fencing))			
Specialized Equipment	(pumps, terminals, brine tanks, disposal wells, etc.)			
Physical Site	(site (e.g., roadways and lighting), perimeter security (e.g., detection and fencing)			
	operations and security)			
	partnerships and physical infrastructure (e.g., pipelines))			
	quantity and quality)			

SPR's Impacts Framework

Key Objectives	Key Resources					
	Water (quality & quantity)	Energy utilities (electricity, gas, steam)	HVAC	Physical space (land, building, storage, facilities, site infrastructure)	Site Access (internet connectivity, external roadways, worksite/transportation)	Workforce
Research, Analysis & Deployment Execution - Advance science and technology research - Conduct credible and objective analysis - Develop partnerships to accelerate commercialization of technologies and solutions and deliver deployment outcomes (PEMP Goals 1.0, 4.0, 5.0)	*Questions 3-6*	*Questions 9-15*	*Questions 17-20*	*Questions 22-26*	*Questions 28-30*	*Questions 32-36*
Facility Stewardship Manage each major facility to maintain its relevance, value, and impact to ensure mission fulfillment (PEMP Goal 2.0)	*Question 7*	*Question 16*	*Question 21*	*Question 27*	*Question 31*	*Question 37*
Sustaining Laboratory Operations Support the delivery of NREL's mission. - Provide a campus that is: secure, safe, healthy, and environmentally sound - Develop, operate, and maintain: business systems, workplace connectivity, infrastructure, and site operations (PEMP Goals 6.0, .0, 8.0, 9.0)	*Questions 3-5, 8*	*Questions 9-15*	*Questions 17-20*	*Questions 22-26*	*Questions 28, 30*	*Questions 32-36, 38*

NREL's Impacts Framework

Stage 1: Identifying & Scoring Vulnerabilities

*Utilize the **impacts framework***

*Create a list of **potential climate-related vulnerabilities***

*Assign a **consequence score** for each vulnerability.*

Sample considerations when assigning consequence scores:

- The health effects on staff, including worker safety
- 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 (award fee) caused by the climate change impact
- The number of staff affected
- The environmental effects, including the release of toxic materials, effects on biodiversity, changes to the area's ecosystem, and impacts on historic sites.

Consequence: Impact on the key objective, should the key resource(s) be affected by climate changes

Negligible - Low magnitude of consequence. The key objectives would either experience no major effect or an in-place backup system would resolve the failure.

Marginal - Medium magnitude of consequence. The key objectives would be somewhat affected.

Critical - High magnitude of consequence. The key objectives would be significantly affected. Impacts would hinder almost every staff member's work and have serious implications for the ability to achieve key objectives.

Stage 1: Example Climate-Related Vulnerabilities

Impacts Framework > Vulnerabilities > Climate Stressors > Risk Evaluation > Identify Options > Score Options > Recommend Approach

Main Key Resource	No.	Sensitivity	Consequence Score
Multiple	S1	Ability to respond if a weather event impacts more than one site at the same time	Critical (I)
	S2	Ability to meet statutory oil quantity requirements	Critical (I)
Water	S3	Ability to maintain necessary raw water quality and quantity for drawdown	Critical (I)
	S4	Ability to conduct process pump seal flushing and bearing cooling	Critical (I)
	S5	Increased build-up of silt in raw water systems	Critical (I)
	S6	Ability to maintain necessary raw water quality for disposal of brine to the Gulf of Mexico (i.e., 95%+ salinity, pH levels, etc.)	Marginal (II)
	S7	Ability to access raw water for flushing of brine strings during fill operations	Marginal (II)
Power	S8	Reliance on a single supplier of commercial power line to each of the sites	Critical (I)
Command and Control System	S9	Adequate power required to run the DCS	Marginal (II)
	S10	Command center, single facility for control of pumping stations	Marginal (II)
Physical Space	S11	Sites elevation and proximity to the ocean	Critical (I)

Sample of SPR's Scored Climate-Related Sensitivities

Stage 1: Identifying & Scoring Climate Stressors

No.	Potential Climate Stressor	Likelihood
V1	Increased annual average temperatures	High
V2	Increases in magnitude of hottest annual temperature	High
V3	Increase in the number of days with temperatures >= 95°F per year	High
V4	Increased rainfall amounts on days with rain	High
V5	Increased sea level	High
V6	Decreased annual rainfall	Med-High
V7	Increased number of days with heavy rainfall	Med-High
V8	Increased intensity of hurricane winds	Med-High
V9	Higher storm surge due to hurricanes	Med-High
V10	Increased raw water temperature	Med-High
V11	Decrease in wind speed	Med-High
V12	Increased number of days with thunderstorms/lightning	Med-High
V13	Decrease in relative humidity	Med-High
V14	Subsidence – increase with sea level rise	Med-High
V15	Coastal land loss – increase	Med-High
V16	Increased chance of flooding/high water levels	Medium
V17	Increased chance of drought/low water levels	Medium
V18	Increased annual rainfall	Medium
V19	Increase in severe thunderstorms	Medium
V20	Increase in vector-borne diseases	Medium
V21	Changes in raw water quality – increase sediment	Med-Low
V22	Changes in raw water quality – increase salinity	Med-Low
V23	Changes in raw water quality – pH	Med-Low
V24	Increase in wind speed	Med-Low
V25	Increase in tornadoes	Med-Low
V26	Decreased number of days with heavy rainfall	Med-Low
V27	Increase in wildfire occurrence	Med-Low
V28	Increase in relative humidity	Low

SPR's Scored Climate Stressors

Scoring Climate Stressors by Likelihood of Change

A stressor is assigned a h**igher likelihood of occurrence** if the climate models demonstrated strong agreement about its direction and a high degree of change.

A stressor is assigned a **lower likelihood of occurrence** if the models showed less agreement and a lower degree of change.

Scores include low, medium-low, medium, medium-high, and high.

Climate Stressor	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

NREL's Scored Climate Stressors

Stage 1: Selecting Climate Stressors for Each Vulnerability

*Utilized comprehensive **list of potential climate stressors** and their **likelihood scores** developed by climate experts*

*Discussed and identified climate stressors related to (or have the potential to impact) **each vulnerability**.*

Potentially Relevant Climate Variable	Potential vulnerability: NREL has only one electricity supplier and depends on electricity to support mission-critical activities (e.g. power to buildings, IT connectivity).
Increased annual average temperatures	✓
Increased extreme heat events	✓
Earlier peak stream flows	
Increased likelihood of fire and longer fire season	✓
Increased minimum nighttime temperatures	
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	
Increased pollen count	
Landslides	
Increased likelihood of ice storms	✓
Shifts in annual and seasonal precipitation amounts	
Changes in total annual stream flows	
Changes in wind patterns	✓

Example of selecting relevant climate stressors for a particular vulnerability from NREL's study

Stage 1: Evaluating Climate-related Risks

Impacts Framework › Vulnerabilities › Climate Stressors › **Risk Evaluation** › Identify Options › Score Options › Recommend Approach

The risk score is based on:

- *vulnerability's* ***consequence score***
- *all applicable climate stressors'* ***likelihood scores****.*

The risk matrix provides a structure for combining these scores in a meaningful way that enables analysis and ranking of the risks.

The outcome:

- *ranked listing of climate-related risks.*

Sensitivity - Consequence	Climate Stressors - Likelihood				
	High (H)	Med-High (MH)	Medium (M)	Med-Low (ML)	Low (L)
Critical (I)	IH (1)	IMH (2)	IM (3)	IML (6)	IL (7)
Marginal (II)	IIH (4)	IIMH (5)	IIM (8)	IIML (11)	IIL (12)
Negligible (III)	IIIH (9)	IIIMH (10)	IIIM (13)	IIIML (14)	IIIL (15)

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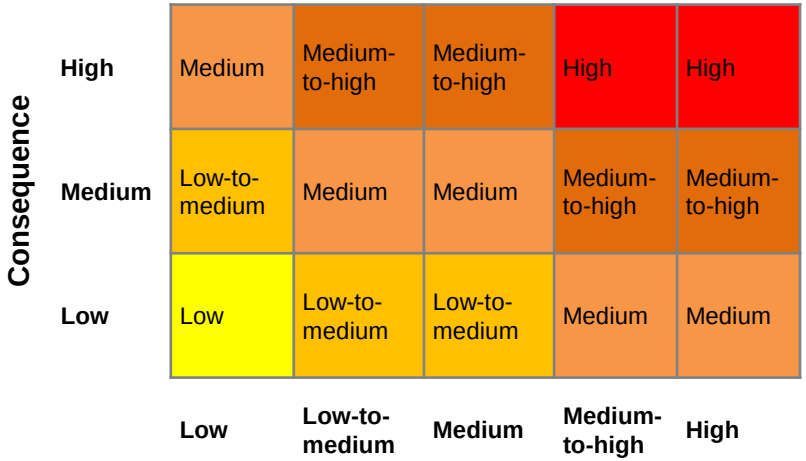
3-5 - Medium-High Risk Sensitivity
6-10 - Medium Risk Sensitivity
11-13 - Medium-Low Risk Sensitivity
14-15 - Low Risk Sensitivity

SPR's Risk Matrix



NREL's Risk Matrix

Stage 1: Example Risk Evaluation

No.	Sensitivity	Consequence (C)	No.	Climate Stressor	Likelihood (L)	C + L Score		Risk Score
S3	Ability to maintain necessary raw water quality and quantity for drawdown	Critical (I)	V2	Increases in magnitude of hottest annual temperature	High	IH	1	2
			V4	Increased rainfall amounts on days with rain	High	IH	1	
			V7	Increased number of days with heavy rainfall	Med-High	IMH	2	
			V10	Increased raw water temperature	Med-High	IMH	2	
			V16	Increased chance of flooding/high water levels	Medium	IM	3	
			V17	Increased chance of drought/low water levels	Medium	IM	3	
			V21	Changes in raw water quality – increase sediment	Med-Low	IML	6	

SPR example risk evaluation for a particular sensitivity

*Each vulnerability's **consequence score** is combined with **all the likelihood scores** for the climate stressors identified.*

*The combined scores are then averaged to calculate an **overall risk score** for that vulnerability.*

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 example risk evaluation for a particular vulnerability

Stage 1: Climate Related Risks

No.	Sensitivity	Risk Score
S1	Ability to respond if a weather event impacts more than one site at the same time	2
S2	Ability to meet statutory oil quantity requirements	2
S3	Ability to maintain necessary raw water quality and quantity for drawdown	2
S8	Reliance on a single supplier of commercial power line to each of the sites	2
S13	Large amount of old and fatigued equipment (70% past lifespan design)	2
S16	Availability of distribution systems, pipelines, and terminals in the region that SPR uses to meet mission requirements	2
S4	Ability to conduct process pump seal flushing and bearing cooling	3
S5	Increased build-up of silt in raw water systems	3
S11	Sites elevation and proximity to the ocean	3
S15	Outdoor workforce exposed to elements	3
S17	Ability to maintain oil temperature (i.e., increasing raw water temperatures affecting crude oil cooling capability)	5
S6	Ability to maintain necessary raw water quality for disposal of brine to the Gulf of Mexico (i.e., 95%+ salinity, pH levels, etc.)	6
S7	Ability to access raw water for flushing of brine strings during fill operations	8
S9	Adequate power required to run the DCS	6
S10	Command center, single facility for control of pumping stations	6
S12	Susceptibility to mold in buildings	10
S14	Wellhead exposure to weather	11

SPR example risk evaluation for a particular sensitivity

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
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.

NREL example risk evaluation for a particular vulnerability

Stage 2: Resilience Evaluation Process

(1) **Identify** the potential resilience options

(2) **Score** the resilience options at a high level based on key criteria

(3) Prioritize the options by **recommending an approach** for each of the options

Resilience: The capacity to prevent, withstand, respond to, and recover from a disruption.

*modified from the *National Oceanic and Atmospheric Administration's U.S. Climate Resilience Toolkit.*

Stage 2: Scoring Resilience Options

Effectiveness **-** the capacity of the resilience option to reduce the vulnerability's overall risk.

Feasibility - is a measure of whether the option could be implemented—technically, organizationally, and politically.

Cost - is the estimated monetary outlay price of the resilience option.

Assessment 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	Some reservations about the ability to implement the action technically and organizationally, or only a part of the action could be implemented	Could not be implemented technically or organizationally
Cost	Would have relatively low monetary cost to implement; generally desk-style projects, often with no or few infrastructure components.	Would have relatively moderate monetary costs; could include a modest infrastructure component	Would have relatively high monetary costs; could include significant infrastructure components

Stage 2: Recommending an Approach

In exploring recommended approaches, the project team utilized the following:

- Best professional judgement and site-specific knowledge relative to each evaluation criterion and not an average of the three evaluation criteria
- Information that emerged during the project team discussions. When the available information was uncertain or could significantly alter the viability of an option, that option was assigned to continue evaluating
- Consideration of each resilience option independently (not compared to each other) to determine a recommended approach.

Do now

- actions that can reasonably pursue
- may benefit other strategies beyond climate change resilience planning
- reduce facility risk to current climate stressors
- investment is worthwhile regardless of the climate future
- may involve some cost that is not fully justified under current climate conditions

Continue evaluating

- require more in depth analysis to better determine
  - If *do-now* actions
  - If *remove from consideration*

Remove from consideration

- untenable for one or more reasons
- resilience options address impacts beyond current planning horizons.

Stage 2: Examples Resilience Options and Recommended Approaches

Impacts Framework → Vulnerabilities → Climate Stressors → Risk Evaluation → Identify Options → Score Options → Recommend Approach

Vulnerability	Overall Risk Score	Resiliency Actions	Reco Ap
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
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	Continu evaluat
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	Continu evaluat
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	Continu evaluat
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	Continu evaluating
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]
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

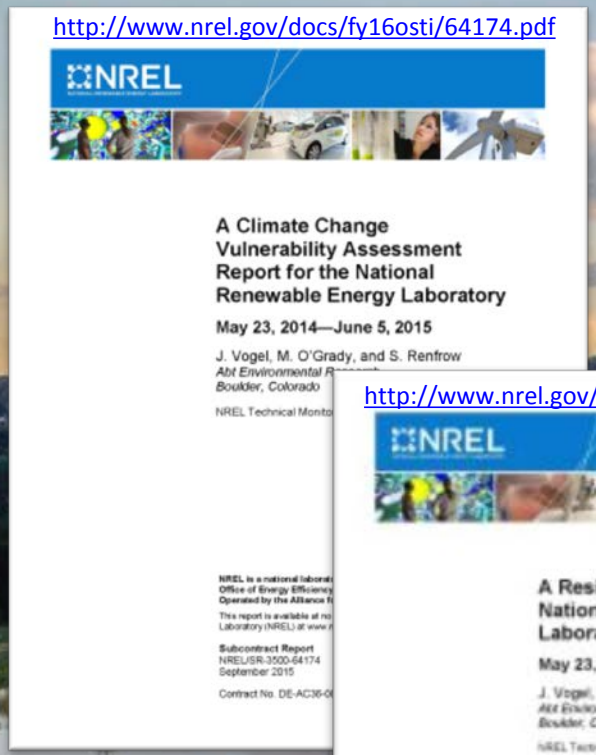
NREL example

Key Resource	No.	Resilience Options	Effectiveness	Feasibility	Cost	Approach
Multiple	R1	Integrate climate change considerations into future planning and operations	Good	Good	Good	Do Now
	R2	Provide more flexible degassing capabilities (i.e., portable degassing equipment)	Good	Good	Fair	Do Now
	R3	Identify, evaluate, and consider elevating at-risk equipment (e.g., pumps)	Good	Good	Fair	Do Now
	R4	Review hurricane after-action reports and identify resilience options that could mitigate impacts for climate change	Good	Fair	Good	Continue Evaluating
Water	R21	Bryan Mound - Review study on tanks and integrate climate change information	Good	Good	Fair	Do Now
	R5	Review the ongoing sediment study (Bryan Mound) and integrate climate change considerations	Fair	Good	Good	Continue Evaluating
	R6	Continue to evaluate options for maintaining cooling capacity as water temps increase (i.e., resize heat exchangers)	Fair	Fair	Fair	Continue Evaluating
	R7	Add ILA water wells (like at West Hackberry) to ensure fresh water for process pump flushing	Good	Good	Fair	Continue Evaluating
	R8	Add tanks or covers to brine ponds (specifically at Bayou Chodaw) to protect from rainwater dilution	Good	Fair	Poor	Continue Evaluating
Power	R9	Increase RPX pumping capabilities	Good	Fair	Fair	Continue Evaluating
	R10	Add diesel pumps as backups at intake structures to have a non-power drawdown option (meets practical demand only, not statutory)	Fair	Fair	Fair	Continue Evaluating
	R11	Monitor and continue to investigate potential for solar PV systems as efficiency of panels improves	Good	Poor	Poor	Continue Evaluating
	R12	Add new generators designed to use crude oil in storage (at SPR) as fuel to meet drawdown requirements	Good	Poor	Poor	Remove from Consideration
	R13	Install non-fossil fuel option (battery) to provide an alternative source for recovery pumps if diesel is not available (backup only, not drawdown)	Poor	Poor	Poor	Remove from Consideration
	R14	Reevaluate the feasibility of dual power feeds (like at Big Hill)	Poor	Fair	Poor	Remove from Consideration

SPR example

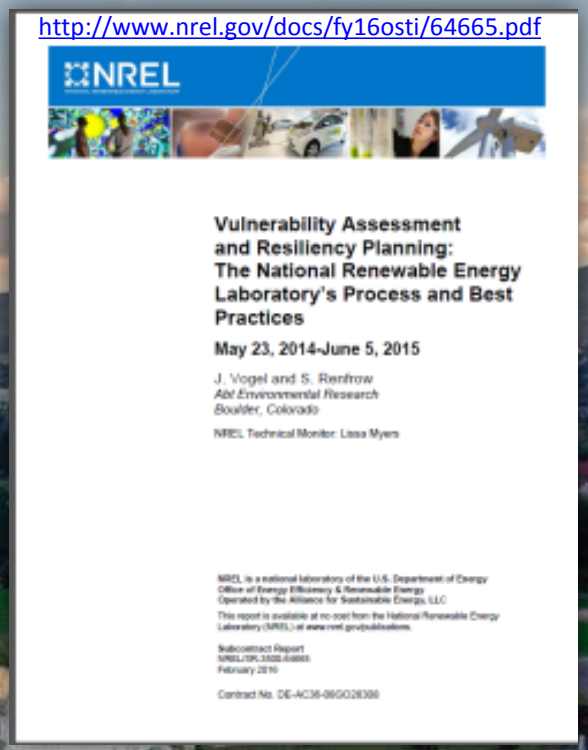
NREL's Climate Change Resilience Study and Process Description Documents

http://www.nrel.gov/docs/fy16osti/64174.pdf

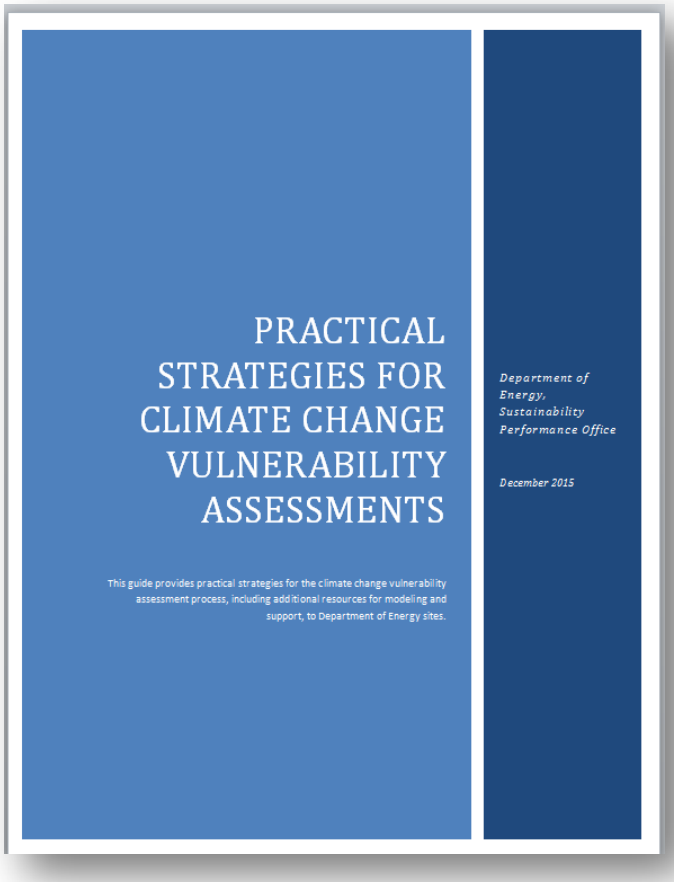


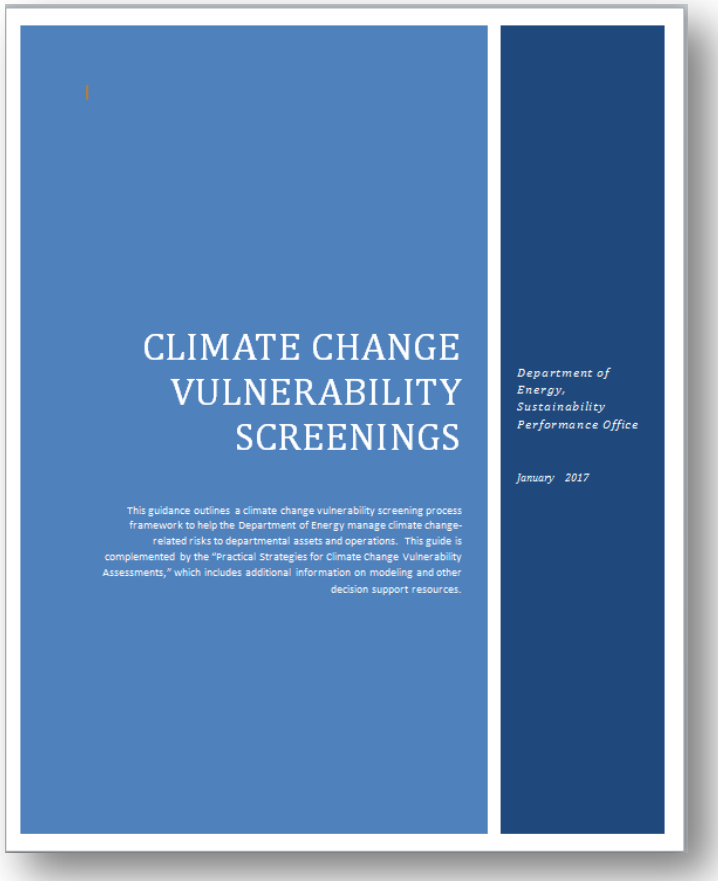
http://www.nrel.gov/docs/fy16osti/64175.pdf

http://www.nrel.gov/docs/fy16osti/64665.pdf



DOE Guidance Documents





Other Go-to Resources

- National Climate Assessment (Regional Reports)

http://nca2014.globalchange.gov/

- U.S. Climate Resilience Toolkit

https://toolkit.climate.gov/

- NASA/DOI Interagency Forum on Climate Change Impacts and Adaptations

https://www.fedcenter.gov/programs/greenhouse/ccforum/

Thank you!

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