Strategic Petroleum Reserve

CLIMATE CHANGE RISK AND RESILIENCE ASSESSMENT

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Executive Summary

Introduction

To protect the United States from severe petroleum shortages and to carry out the United States' obligations under the International Energy Program, the U.S. Department of Energy's (DOE) Strategic Petroleum Reserve (SPR) has a statutory mission to maintain drawdown readiness in order to meet the nation's critical energy goals and provide access to the nation's oil reserves when requested by the president of the United States under the authorities of the Energy Policy and Conservation Act (EPCA). In the Gulf Coast region, where the SPR has multiple sites, climate science indicates that climate conditions are changing and will likely continue to change in the future. These changes could threaten the SPR's ability to carry out its mission. In spring 2016, the SPR volunteered to undergo a climate change risk and resilience assessment to better understand and manage these climate-related risks. Funded by the DOE Sustainability Performance Office (SPO), SPR staff engaged in a year-long effort, working with staff from the National Renewable Energy Laboratory (NREL) and the Southern Climate Impacts Planning Program (SCIPP) to conduct the assessment.

The SPR is currently planning for a second Life Extension project (LE2) that will modernize and enhance the SPR facilities to ensure long-term integrity of SPR assets and the ability of the program to complete its mission. This Climate Change Risk and Resilience Assessment complements LE2 planning by reinforcing planned improvements and identifying new considerations that can be incorporated into the LE2 design.

The goal of the Climate Change Risk and Resilience process is to identify the most pressing climate-related risks that the SPR faces and explore the potential resilience options best suited to reduce those climate-related risks. To accomplish this goal, the assessment first aims to gain an understanding of what is most critical to the SPR in order to carry out its mission, followed by consideration of projected climate changes to those areas of importance. Organizing the assessment in this way, rather than starting with climate change projections, helps to focus thinking and produce targeted mission-related resilience options.

General Findings

Based on the assessment, the SPR's most significant climate-related risks are associated with the resource areas of water (access, quality, and quantity), power, physical space, equipment, workforce, crude oil distribution network, and crude oil inventory. Resilience options that present the greatest potential to reduce these risks include:

- Integrate climate change considerations into future planning and operations
- Provide more flexible degassing capabilities (i.e., portable degassing equipment)
- Identify, evaluate, and consider elevating at-risk equipment (e.g., pumps)
- Identify, evaluate, and consider elevating or reinforcing at-risk buildings/site facilities
- Have Sandia National Laboratories conduct an in-depth subsidence projection for the sites
- Prioritize a list of equipment needing upgrades
- Update annual reviews to go beyond corrective maintenance and include climate change considerations
- Add additional crude oil distribution locations
- Review and update water monitoring temperatures with climate change considerations and add trending

- Review hurricane after-action reports and identify resilience options that could mitigate impacts for climate change
- Continue to evaluate options for maintaining cooling capacity as water temperatures increase (i.e., resize heat exchangers)
- Increase recovery pump exercise (RPX) pumping capabilities
- Add diesel pumps as backups at intake structures to have a non-power drawdown option (meets practical demand only, not statutory)
- Replace old or poorly designed pumps to reduce potential for overheating.

These resilience options fell into the *do now* or *continue evaluating* recommendation category. Many of the recommendations in the *do now* or *continue evaluating* category are action items to study or review and involve minimum associated costs. Implementing the outcomes from those studies or reviews will be more expensive and will likely require additional planning and funding (some of which is already taking place with LE2). Taking the steps now to study, evaluate, and identify the best options will position the SPR when additional funding opportunities present themselves.

A complete list of the SPR's climate-related risks and the associated resilience options are presented in the report.

Project Overview

This project overview presents a combined summary of the two stages of the Strategic Petroleum Reserve's (SPR) Climate Change Risk and Resilience Assessment: the risk assessment (Stage 1) and the resilience options evaluation (Stage 2). The overview concludes with a set of recommended resilience options that can be used to inform SPR management decision making.

Introduction

To protect the United States from severe petroleum shortages and to carry out the United States' obligations under the International Energy Program, the U.S. Department of Energy's (DOE) SPR has a statutory mission to maintain drawdown readiness at all times in order to meet the nation's critical energy goals. The SPR Climate Change Risk and Resilience assessment identifies the SPR's climate-related sensitivities and the associated climate stressors that threaten the SPR's ability to meet its mission. Climate stressors may exacerbate existing challenges with climate-related sensitivities or present new challenges to the SPR. The SPR Climate Change Risk and Resilience assessment explores resilience options to mitigate those challenges. Funded by the DOE Sustainability Performance Office (SPO), SPR staff engaged in a year-long effort working with staff from the National Renewable Energy Laboratory (NREL) and the Southern Climate Impacts Planning Program (SCIPP) to conduct the climate change risk assessment.

Stage 1: Climate Change Risk Assessment Process and SPR's Findings

To identify the climate-related sensitivities that are specific to the SPR, the project team first developed a framework to explore the SPR's unique organizational circumstances. This framework combines four key organizational objectives, based on information from SPR's strategic planning documents and nine key resources that are deemed essential to continued operation of SPR facilities.

SPR's Impacts Framework

	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			
	Power			
	Command and Control System			
	Physical Space			

Key Resources	
	Specialized Equipment
	Physical Site Access
	Workforce
	Crude Oil Transportation Network
	Crude Oil Inventory

The framework provides a structure to guide the project team through discussions about potential sensitivities to the organization connected to each key resource and its relationship to each of the key organizational objectives. The result of the conversations was a comprehensive list of climate-related sensitivities unique to the SPR. These sensitivities were then scored based on the potential impact to the SPR considering the magnitude of consequence.

Climate experts from SCIPP subsequently developed a detailed list of potential climate stressors for the Louisiana and Texas coastal area that could affect SPR sites and scored each stressor based on its potential likelihood of change taking into account the quality and consistency of change observed in the climate models and the degree of agreement between different climate models.

The magnitude of the consequence score for each sensitivity (i.e., the degree to which an affected unit - a process, system, facility, or staff member - faces risk from climate) was then combined with the likelihood score for each of its associated climate stressors to determine a risk score for the sensitivity. The risk scores were used to prioritize SPR's sensitivities by grouping them according to their scores from *high risk* to *low risk*. The Risk Score Matrix illustrates how the consequence and likelihood scores were combined to determine the risk scores. Highest-risk sensitivities are noted in dark purple and the lowest-risk sensitivities are designated dark green.

Risk Score Matrix

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)

- 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

The Consequence, Likelihood and Risk Scores table presents an example of how a sensitivity's consequence was assessed and combined with the likelihood assessment for the associated climate stressors to yield a risk score.

Consequence, Likelihood, and Risk Scores

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	

†For ease of reference, sensitivities are numbered S1-S17 and climate stressors are numbered V1-V28.

Fourteen sensitivities were identified and scored in the assessment. The SPR's Climate Change Related Sensitivity Risk Scores table lists the sensitivities that were selected and scored in the assessment. Highest-risk sensitivities are listed at the top and lowest-risk sensitivities are at the bottom.

SPR's Climate Change Related Sensitivity Risk Scores

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
S6	Ability to maintain necessary raw water quality for disposal of brine to the Gulf of Mexico (i.e., 95%+ salinity, pH levels, etc.)	2
S8	Reliance on a single supplier of commercial power lines 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
S12	Susceptibility to mold in buildings	5
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
S7	Ability to access raw water for flushing of brine strings during fill operations	8
S9	Adequate power required to run the distributed control system (DCS)	6
S10	Command center, single facility for control of pumping stations	6
S14	Wellhead exposure to weather	11

†For ease of reference, sensitivities are numbered S1-S17 and are organized by risk score in this table.

Stage 2: Climate Change Resilience Options Evaluation Process and SPR's Findings

During the second stage of the assessment process a comprehensive list of potential resilience options that could mitigate the sensitivities was developed. Project team members were encouraged to be as comprehensive as possible when identifying the options to explore a range of measures and stimulate innovative thinking. Each of the options was then subjected to an evaluation and scored based on the effectiveness, feasibility, and cost to mitigate the sensitivity. Scores were based on preliminary professional judgement and discussion with the project team using a scale of *good, fair,* or *poor* for each of the evaluation criteria. The Resilience Options Scoring Criteria table illustrates how the resilience options were evaluated and scored.

Resilience Options Scoring Criteria

Assessment 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 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

The last step in the risk and resilience assessment process was to assign each of the resilience options to a category of action recommending an approach for moving forward. One of three recommended approaches was assigned to each resilience option:

- ***Do now*** was assigned for actions that the SPR can reasonably pursue and that may benefit other strategies beyond climate change resilience planning. These strategies provide benefits under current and projected climate conditions. When the SPR spends money on this type of strategy, it will reduce facility risk to current climate stressors, make the SPR more resilient to future climate change, and ensure the investment is worthwhile regardless of the climate future. These strategies may involve some cost that is not fully justified under current climate conditions.

- ***Continue evaluating*** was assigned to resilience actions that require more in-depth analysis to better determine if they could be endorsed as *do now* or *remove from consideration* actions.

- ***Remove from consideration*** was assigned to resilience actions that were untenable for one or more reasons, or because the resilience options address impacts that are beyond current planning horizons.

Summary of Findings – Recommended Approach

The SPR's Scored Resilience Options by Key Resource table summarizes the resilience options. The table also includes the resilience evaluation scores and recommended approaches for each option that the SPR may wish to pursue. These recommendations are preliminary; additional analysis may be necessary to ensure that any selected option best reflects SPR's capabilities and priorities.

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SPR's Scored Resilience Options by Key Resource and Associated Sensitivities

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

Key Resource	No. †	Resilience Options and Associated Sensitivities	LE2	Approach
Multiple	**R1**	**Integrate climate change considerations into future planning and operations**		
	S2	Ability to meet statutory oil quantity requirements	Y	Do Now
	S3	Ability to maintain necessary raw water quality and quantity for drawdown		
	S5	Increased build-up of silt in raw water systems		
	S12	Susceptibility to mold in buildings		
	S13	Large amount of old and fatigued equipment (70% past lifespan design)		
	S14	Wellhead exposure to weather		
	S17	Ability to maintain oil temperature (i.e., increasing raw water temperatures affecting crude oil cooling capability)		
	R2	**Provide more flexible degassing capabilities (i.e., portable degassing equipment)**		
	S2	Ability to meet statutory oil quantity requirements	Y	Do Now
	S17	Ability to maintain oil temperature (i.e., increasing raw water temperatures affecting crude oil cooling capability)		
	R3	**Identify, evaluate, and consider elevating at-risk equipment (e.g., pumps)**		
	S1	Ability to respond if a weather event impacts more than one site at the same time	Y	Do Now
	S4	Ability to conduct process pump seal flushing and bearing cooling		
	S9	Adequate power required to run the DCS		
	S10	Command center, single facility for control of pumping stations		
	S11	Sites elevation and proximity to the ocean		
	S13	Large amount of old and fatigued equipment (70% past lifespan design)		
	R4	**Review hurricane after-action reports and identify resilience options that could mitigate impacts for climate change**		
	S1	Ability to respond if a weather event impacts more than one site at the same time	N	Continue Evaluating
	S11	Sites elevation and proximity to the ocean		
	S12	Susceptibility to mold in buildings		
	S14	Wellhead exposure to weather		
Water	**R5**	**Review the ongoing sediment study (Bryan Mound) and integrate climate change considerations**		
	S5	Increased build-up of silt in raw water systems	N	Continue Evaluating
	S7	Ability to access raw water for flushing of brine strings during fill operations		
	R6	**Continue to evaluate options for maintaining cooling capacity as water temps increase (i.e., resize heat exchangers)**		
	S2	Ability to meet statutory oil quantity requirements	Y	Continue Evaluating
	S3	Ability to maintain necessary raw water quality and quantity for drawdown		
	S4	Ability to conduct process pump seal flushing and bearing cooling		

Key Resource	No. †	Resilience Options and Associated Sensitivities	LE2	Approach
	R7	**Add ILA water wells (like at West Hackberry) to ensure fresh water for process pump flushing**		
	S4	Ability to conduct process pump seal flushing and bearing cooling	Y	Continue Evaluating
	S7	Ability to access raw water for flushing of brine strings during fill operations		
	R8	**Add tanks or covers to brine ponds (specifically at Bayou Choctaw) to protect from rainwater dilution**		
	S6	Ability to maintain necessary raw water quality for disposal of brine to the Gulf of Mexico (i.e., 95%+ salinity, pH levels, etc.)	Y	Continue Evaluating
Power	**R9**	**Increase RPX pumping capabilities**		
	S8	Reliance on a single supplier of commercial power lines to each of the sites	N	Continue Evaluating
	R10	**Add diesel pumps as backups at intake structures to have a non-power drawdown option (meets practical demand only, not statutory)**		
	S8	Reliance on a single supplier of commercial power lines to each of the sites	N	Continue Evaluating
	R11	**Monitor and continue to investigate potential for solar PV systems as efficiency of panels improves**		
	S8	Reliance on a single supplier of commercial power lines to each of the sites	N	Continue Evaluating
	R12	**Add new generators designed to use crude oil in storage (at SPR) as fuel to meet drawdown requirements**		
	S8	Reliance on a single supplier of commercial power lines to each of the sites	N	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)**		
	S8	Reliance on a single supplier of commercial power lines to each of the sites	N	Remove from Consideration
	R14	**Reevaluate the feasibility of dual power feeds (like at Big Hill)**		
	S8	Reliance on a single supplier of commercial power lines to each of the sites	N	Remove from Consideration
Command and Control System	**R15**	**Identify locations where an upgrade to seaworthy, marine-rated cable would be appropriate**		
	S9	Adequate power required to run the DCS	N	Remove from Consideration
	S10	Command center, single facility for control of pumping stations		
Physical Space	**R16**	**Install more-efficient HVAC systems (variable fans, etc.) and consider use of ground water (well) for building cooling to reduce electricity demands**		
	S12	Susceptibility to mold in buildings	N	Do Now
	R17	**West Hackberry - Monitor and assess potential involvement in LA coastal plan hydrologic restoration projects**		

Key Resource	No. †		Resilience Options and Associated Sensitivities	LE2	Approach
		S11	Sites elevation and proximity to the ocean	N	Do Now
	R18		**Add "check for mold" to the Organizational Assessments checklist**		
		S12	Susceptibility to mold in buildings	N	Do Now
	R19		**Identify, evaluate, and consider elevating or reinforcing at-risk buildings/site facilities**		
		S1	Ability to respond if a weather event impacts more than one site at the same time	Y	Do Now
		S11	Sites elevation and proximity to the ocean		
		S12	Susceptibility to mold in buildings		
	R20		**Have Sandia National Laboratories conduct an in-depth subsidence projection for the sites**		
		S2	Ability to meet statutory oil quantity requirements	N	Do Now
		S11	Sites elevation and proximity to the ocean		
Specialized Equipment	**R21**		**Bryan Mound - Review study on brine tanks and integrate climate change information**		
		S13	Large amount of old and fatigued equipment (70% past lifespan design)	Y	Do Now
	R22		**Prioritize list of equipment needing upgrades**		
		S13	Large amount of old and fatigued equipment (70% past lifespan design)	Y	Do Now
	R23		**Replace old or poorly designed pumps to reduce potential for overheating**		
		S13	Large amount of old and fatigued equipment (70% past lifespan design)	Y	Continue Evaluating
	R24		**Update annual reviews to go beyond corrective maintenance and include climate change considerations**		
		S13	Large amount of old and fatigued equipment (70% past lifespan design)	N	Continue Evaluating
Workforce	**R25**		**Adjust schedules and times to account for more climate delays**		
		S15	Outdoor workforce exposed to elements	Y	Do Now
Crude Oil Transportation Network	**R26**		**Add additional distribution locations**		
		S1	Ability to respond if a weather event impacts more than one site at the same time	Y	Do Now
		S16	Availability of distribution systems, pipelines, and terminals in the region that SPR uses to meet mission requirements		
	R27		**Bayou Choctaw and West Hackberry - Add options to move oil by rail and/or truck**		
		S1	Ability to respond if a weather event impacts more than one site at the same time	N	Remove from Consideration
		S2	Ability to meet statutory oil quantity requirements		
		S16	Availability of distribution systems, pipelines, and terminals in the region that SPR uses to meet mission requirements		
	R28		**Review and update water monitoring temperatures with climate change considerations and add trending**		
		S2	Ability to meet statutory oil quantity requirements	N	Do Now

Key Resource	No. †		Resilience Options and Associated Sensitivities	LE2	Approach
Inventory		S17	Ability to maintain oil temperature (i.e., increasing raw water temperatures affecting crude oil cooling capability)		

†For ease of reference, sensitivities are numbered S1-S17 and resilience options are numbered R1-R28. Only sensitivities that relate to each resilience option are listed in this table.

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1. Introduction

The U.S. Department of Energy's (DOE) Strategic Petroleum Reserve (SPR), located in Louisiana and Texas, has a statutory mission to maintain drawdown readiness in order to meet the nation's critical energy goals and provide access to the nation's oil reserves at any time when requested by the president of the United States under the authorities of the EPCA.[1] In support of this mission, SPR seeks to better understand the potential effects of climate change on its sites—and therefore on its mission—to ensure its ongoing success. Planning today for a changing climate can reduce SPR's risks and improve resilience to climate-related sensitivities. This report presents a climate change risk and resilience assessment for the SPR. The outcome of the assessment is a list of potential resilience options that can be used to inform future decision making at the SPR.

1.1. Background

The federal government continues to make efforts to better understand, plan for, and adapt to the impacts of climate change. These efforts are implemented through key executive orders,[2] most specifically in Executive Order 13693: *Planning for Federal Sustainability in the Next Decade* (March 2015). Executive Order 13693 requires agencies to ensure that they are (Section 13 (a)):

- Identifying and addressing projected impacts of climate change on mission critical water, energy, communication, and transportation demands
- Considering those climate impacts in operational preparedness planning for major agency facilities and operation.

Executive Order 13693 also requires the Council on Environmental Quality to issue Guiding Principles for new and existing Federal buildings to consider climate resilience (Section 4 (f)) and regional Environmental Protection Agency and Government Services Administration offices to coordinate interagency working groups to ensure that regional agency activities consider and are consistent with climate change preparedness and resilience planning in coordination with state, local, and tribal communities (Section 10 (c)).

The DOE has formally been planning for climate change at a national level since 2011. Efforts include adding climate change as an integral part of its 2014-2018 Strategic Plan,[3] facilitating a Climate Change Adaptation Planning Work Group, producing an agency-wide Climate Adaptation Plan,[4]sponsoring pilot climate change adaptation planning efforts at DOE sites, and developing guidance documents to assist DOE sites in conducting climate change vulnerability screenings and assessments: *Practical Strategies for Climate Change Vulnerability Assessments*[5] and *Climate Change Vulnerability Screening Guidance.*[6]

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[1] United States DOE. SPR. Accessed March 31, 2017. https://energy.gov/fe/services/petroleum-reserves/strategic-petroleum-reserve.

[2]Executive Order 13653: *Preparing the United States for the Impacts of Climate Change* (November 2013) required that each agency develop, implement, and update climate adaptation plans and also requires agencies to report on progress on those plans through the annual Strategic Sustainability Performance Plan scorecard process. While writing the draft report on this assessment's findings, in March 2017, President Trump signed the Executive Order: *Promoting Energy Independence and Economic Growth*, which officially rescinds Executive Order 13653.

[3]United States DOE. DOE/CF-0067. Strategic Plan 2014-2018. April 2014. Accessed https://energy.gov/downloads/2014-2018-strategic-plan.

[4] United States DOE Climate Adaptation Plan 2014. June 2014. Accessed March 31, 2017. https://energy.gov/management/spo/downloads/2014-doe-climate-change-adaptation-plan.

[5] United States DOE Sustainability Performance Office. Practical Strategies for Climate Change Vulnerability Assessments. December 2015. Accessed March 31, 2017. https://powerpedia.energy.gov/w/images/6/6b/Practical_Strategies_for_Climate_Change_Vulnerability_Assessments_12.8.15.pdf.

The SPR has also been evaluating natural phenomena since its foundation under the 1975 EPCA. In 1976 the initial environmental impact statements were completed. These were among the first environmental impact statements completed on a national federal program and addressed the following topics, many of which will be found in this Climate Change Risk and Resilience report:

- Geology (caverns)
- Hydrology
- Meteorology
- Climatology
- Water Quality
- Water Resources
- Water Use
- Brine Disposal
- Dredging.

These early environmental impact statements form the bases of the robust SPR National Environmental Policy Act Program that continues through today.

Early in the SPR development program, natural phenomena impacts were addressed in the following programs:

- SPR Level I, II, III design criteria
- Design Review Procedures
- Safety Analysis and Review Program
- Configuration Management Program
- Engineering design standards and specifications
- National Environmental Policy Act reviews
- Emergency Response procedures and capabilities.

Since its founding, the SPR has continued to review, evaluate and plan for natural phenomena. In 1982, a report was prepared for the SPR, *Incidence of Natural Hazards at the SPR,* prepared by The Aerospace Corporation, Energy and Resources Division. This report addressed the following topics, many of which will be found in this Climate Change Risk and Resiliency report:

- Hydrology (maximum rainfall, flood levels and protection)
- Hurricanes (storm surges, occurrence, hazards)
- Lightning
- Tornadoes
- Subsidence
- Earthquakes
- Tsunamis.

The SPR facilities have been tested by some of the most powerful natural phenomena this region has ever been subjected to, including 2005 hurricanes Katrina and Rita and 2008 hurricanes Ike and Gustav. Within days following these natural disasters, the SPR was able to assume its drawdown mission, supplying oil to industry to make up for the large amount of oil production disrupted by the hurricanes. This was accomplished by a workforce that had been evacuated and who reported to work even though

[6] United States DOE Sustainability Performance Office. DOE Vulnerability Screening Guidance. January 2017. Accessed March 31, 2017. https://powerpedia.energy.gov/w/images/e/e6/DOE_Vulnerability_Screening_Guidance.pdf.

their homes in many cases had been destroyed, suffering no loss of life. Following these major events, the SPR conducted a number of After Action reports.

Since 2006, the SPR has initiated a more formal Natural Phenomena Hazards Program in accordance with DOE Order (DOE O) 420.1B, Facility Safety. The SPR program was expanded to cover the following hazards:

Primary Natural Phenomena Hazards:

- Earthquakes
- Volcanic Events
- Tornadoes
- Hurricanes
- High Winds
- Floods
- Excessive Rains
- Excessive Snow
- Ice Cover
- Lightning
- Forest Fires.

Secondary Natural Phenomena Hazards:

- Drought
- Fog
- Frost
- High Temperatures
- Low Temperatures
- Landslides
- Subsidence
- Surface Collapse
- Uplift
- Storm Surges
- Waterspouts

Tertiary Natural Phenomena Hazards:

- Geo-thermal Warming in Crude Oil Caverns
- Biological (e.g., pandemics)
- Cosmic (e.g. meteors, asteroids, space junk)
- Global Climate Change (including rise in sea level)
- Brine-Laden Atmosphere
- Natural Gas Intrusion into Brine produced during Leaching of Crude Oil Caverns
- Natural Gas Intrusion into Crude Oil Caverns
- Salt Dome Salt Elasticity & Cavern Creep
- Cavern Salt Falls
- Coastal Land Loss due to Natural Processes and Human Activities
- Soil Liquefaction
- Tsunamis
- Rogue Waves

- Solar Flares, Solar Super Flares, electromagnetic pulse (EMP), Nuclear EMP

To facilitate implementation of the federal executive orders, the Office of Management and Budget and the Council on Environmental Quality circulated a joint memo titled *Strengthening Climate Adaptation Planning in Fiscal Year 2016 and Beyond*[7] that outlines specific tasks each agency must track and report in the annual Office of Management and Budget scorecard process. The requirements include conducting a "comprehensive assessment of the climate change-related impacts on and risks to the agency's ability to accomplish its missions, operations, and programs."

Subsequent to the Office of Management and Budget/Council on Environmental Quality memo, the United States Secretary of Energy issued a memo to DOE Program Offices titled *Climate Change Preparedness and Resilience*,[8] which required all program offices to:

- Conduct climate change vulnerability screenings at all DOE sites and offices that manage real property (if the site has not already completed a vulnerability screening or assessment) no later than January 2018
- Identify and prioritize sites that need further assessment (i.e., those with significant vulnerabilities)
- Oversee assessments at sites with mission-critical climate vulnerabilities
- Ensure that project and property managers incorporate climate-resilient design into construction and renovation projects, ongoing facility management activities, and planning processes, including site plans and campus strategies
- Identify funding for resilience actions by including funding requirements in future budget requests, beginning with FY18 requests.

This SPR Climate Change Risk and Resilience Assessment satisfies the DOE mandate, exceeding the minimum requirement for a screening and completing a more comprehensive vulnerability assessment.

Assisting the federal government in achieving the executive order goals is only one driver for building resilience to climate change. Extreme weather has already had an impact on DOE sites. For example, mega-fires and severe flooding at Los Alamos National Laboratory between 2000 and 2013 resulted in significant damage to facilities and disruptions to laboratory operations. Los Alamos National Laboratory decided to be proactive and incorporate resilience strategies into planning and activities after the fires and floods of 2000. These measures helped to reduced impacts from subsequent extreme weather events experienced in 2013.[9] SPR has also been affected by previous extreme weather events, including hurricanes Ike and Katrina, which caused site shutdowns and damage to facilities and equipment. Taking actions to evaluate and build resilience strengthen the organization and its ability to endure now and into the future regardless of the specific climate changes.

1.2. How this Report is Organized

The report begins with a background on the impetus for the assessment, continues with an overview of the process and a summary of the identification and analysis of climate-related sensitivities, and concludes with an evaluation of potential resilience options and recommended approaches for

[7] United States Office of Management and Budget. Memorandum. M-16-09. Strengthening Climate Adaptation Planning in Fiscal Year 2016 and Beyond. April 2016. Accessed March 31, 2017. https://obamawhitehouse.archives.gov/sites/default/files/omb/memoranda/2016/m-16-09.pdf.

[8] United States Department of Energy. 10-21 Incoming Memo From S1 - Climate Change Preparedness and Resilience. October 2016.

[9] Fowler, M. Kim, Josh Silverman, and Denny L. Hjeresen. Climate Change and the Los Alamos National Laboratory: The Adaptation Challenge. Richland, WA: Pacific Northwest Laboratory, 2015. http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-24097.pdf

management consideration. Appendix A is a document created by the project team to support the assessment process. Appendix B and 0 include an overview of the region's latest climate science and a detailed report on historical and projected climate aspects specific to the sites. Appendix D is an Excel workbook developed by the project team to support the risk assessment and resilience evaluation analysis.

1.3. NREL's Process and Participation

In 2015, the National Renewable Energy Laboratory (NREL), a U.S. Department of Energy (DOE) national laboratory located in Golden, Colorado, volunteered to be a pilot site under the auspices of the DOE Sustainability Performance Office (SPO) to conduct its own climate change risk assessment. As a pilot project site, NREL enlisted the support of local climate adaptation experts to help develop and document the process in a way that was replicable by others with a goal of building a foundation for future climate-smart planning and decision making. The resulting risk management process presents a systematic way to look at potential climate-related risks and the potential impact on the ability to meet organizational objectives.

With sponsorship from the DOE SPO, the SPR agreed to utilize the NREL process as a guide to conduct their own assessment under the mentorship of NREL staff and with support from external regional climate change experts to assist with developing climate change projections.

1.4. Project Team

The project team for this assessment consists of key staff members from SPR, NREL, and the Southern Climate Impacts Planning Program (SCIPP). SCIPP is a National Oceanic and Atmospheric Administration Regional Integrated Sciences and Assessments program center for the south-central United States that covers Arkansas, Louisiana, Mississippi, Oklahoma, Tennessee, and Texas. SCIPP is a collaboration of researchers representing multiple disciplines from Oklahoma University, Louisiana State University, Texas A&M, the National Drought Mitigation Center, and Weather Ready Nation. The program center is focused on strengthening the linkage between climate science and societal impacts for decision making purposes. Additional technical and subject matter experts from SPR provided information and support during the assessment, as needed, but were not included in the core project management team. Project management team members and their roles and responsibilities are described in in Table 1.

Table 1. Project Management Team

	Strategic Petroleum Reserve (SPR)	National Renewable Energy Laboratory (NREL)	Southern Climate Impacts Planning Program (SCIPP)
Team Members	• Gabe Adams • Gerald Schroeder • Bob Sevcik • Will Woods	• Suzy Belmont • Lissa Myers • Frank Rukavina	• Alan Black • Barry Keim
Roles and Responsibilities	• Champion the project • Provide technical content to support the assessment • Provide day-to-day project management (SPR) • Coordinate SPR project participants • Liaise with Steering Committee and DOE HQ.	• Provide project advice and counsel • Facilitate project process • Provide day-to-day project management (NREL and subcontractor) • Procure subcontractor • Liaise with DOE SPO and subcontractor • Document project process and results.	• Provide regional climate change science overview • Conduct climate change variable evaluation and integrate climate science information in risk assessment.

1.5. Project Scope

This climate change risk and resilience assessment considers facilities and work activities at the Bryan Mound, Big Hill, West Hackberry, and Bayou Choctaw Storage Sites as well as the New Orleans Office and the Stennis Warehouse in Mississippi. The climate change risk and resilience assessment process considered SPR's crude oil storage and raw water systems including raw water injection pumps; brine disposal systems, involving brine disposal tanks and ponds, brine disposal pipeline, and offshore brine diffusers; and oil distribution systems that involve heat exchangers, crude oil pumps, salt dome storage caverns, storage tanks, and process piping.

In 2014, the Office of Petroleum Reserves conducted a review of its capabilities and infrastructure to compare current operational capability to Level 1 Technical and Performance Criteria and to identify and adjust gaps within the storage site infrastructure and distribution system infrastructure to provide the published delivery rate of 4.4 million barrels per day, now and for the next 25 years. The results indicated that a significant investment in infrastructure and process equipment is critical to ensure the SPR can maintain readiness, meet mission requirements, and operate in an environmentally responsible manner. The SPR Life Extension 2 (LE2) project will address these requirements.[10] This climate change risk and resilience assessment attempts to incorporate relevant information from the LE2 project and includes some resilience options that could strengthen the LE2 project when implemented. Where appropriate in this report, references to LE2 are made to highlight opportunities for integrating the information collected in the assessment into LE2 project decision making.

[10] DRAFT SPR Life Extension Phase 2 Project Execution Plan – June 2016, Deputy Assistant Secretary Office of Petroleum Reserves Office of Fossil Energy, Project ID 001059

2. Climate Change in Louisiana and Texas Coastal Region

Climate science indicates that climate is changing and will continue to change in the future.[11] The SPR sites along the Gulf Coast are likely to experience rising temperatures, changes in precipitation, and changes in extreme weather events. The combination of sea level rise and site subsidence, coupled with projections that show more extreme rains and the potential for stronger hurricanes may result in considerably more flooding at the SPR sites in the future. Sections 2.1 through 2.4 summarize the current state of knowledge about the observed and projected effect of climate change on the SPR sites. For more detail, see Appendix B and 0.

2.1. Observations

Observations from climate experts at SCIPP show the following changes along the Gulf Coast:

- Warming temperatures were most pronounced at West Hackberry, Bryan Mound, New Orleans, and Stennis, with little trend in temperature at Bayou Choctaw and a modest cooling trend at Big Hill.
- No long-term trend in precipitation was found in the region.

2.2. Climate Projections

Projections of future climate rely on climate models.[12] Results of these models vary based on the atmospheric greenhouse gas (GHG) concentration scenarios used. In summary, general circulation model (GCM) projections show the following:

- By 2046 (the 30-year project life of LE2), each site is expected to see temperatures increase by 1.5°–5.5°F relative to the 1971–2000 period for a moderate-emission scenario (representative concentration pathway (RCP) 4.5[13]) and by 2.5°–7.0°F for a high-emission scenario (RCP 8.5).
- For the end-century years 2075 and 2100, temperatures are projected to increase by 2.0°–6.5°F for a moderate emission scenario (RCP 4.5) and by 5.0°–11.0°F for a high-emission scenario relative to the 1971–2000 period.
- An increase in the temperature on the hottest day of the year, and more days with high temperatures over 95°F
- Disagreement in average annual precipitation changes. Precipitation changes ranging from a decrease of 9 inches to an increase of 9 inches of rainfall per year relative to the 1971–2000 period for a moderate-emission scenario (RCP 4.5), and anywhere from a decrease of 13 inches to an increase of 10 inches of rainfall per year for a high-emission scenario (RCP 8.5) are projected by 2046.
- The number of days with rainfall is expected to decrease; however, rainfall is expected to be heavier when it occurs. This will result in more droughts (due to longer rain-free periods) and more flooding (heavier rainfall when rain does occur, leading to flooding).

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[11] IPCC, 2013: Summary for Policymakers. In Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[12] Climate models, or general circulation models (GCMs), are numerical models that simulate the physical processes in the atmosphere, ocean, cryosphere, and land surface. They are the most sophisticated tools available for simulating the response of the global climate system to increasing GHG concentrations A number of models were consulted to explore a range of possible future climate outcomes. The models used were all part of the Coupled Model Intercomparison Project Phase 5 (CMIP5) (Additional detail can be found in 0).

[13] The Representative Concentration Pathways (RCPs) provide various projections of GHG concentrations to be used in climate change analysis and predictions. The four pathways—RCP8.5, RCP6, RCP4.5, and RCP2.6—come from the Intergovernmental Panel on Climate Change Fifth Assessment Report. The numeric values (i.e., 8.5, 4.5) represent the additional planetary warming contributed by GHGs in watts per square meter (W/m^2).

2.3. Extreme Event Projections

Extreme events such as flooding and hurricanes have considerable impacts on SPR operations. However, projections of these events in the future have greater uncertainty because they occur on relatively small scales of space and time compared to the global focus of GCMs. In summary, projections along the Gulf Coast show the following:

- It is expected that there will be more heatwaves and more days with temperatures over 95°F.
- The number of tropical cyclones and hurricanes are expected to decrease globally; however, those that do occur are projected to be stronger.[14] Stronger hurricanes have the potential to produce higher storm surges.
- The number of days per year with thunderstorms is projected to increase.
- There is potential for severe thunderstorms to increase in frequency.
- It is likely that the SPR sites will be at an increased risk from flooding due to a combination of sea level rise, land subsidence, the potential for higher storm surges, and flash flooding or river flooding due to heavier rainfall.

2.4. A Note about Climate Variability

Natural climate variability presently influences weather and climate extremes. Even under the most extreme climate change scenario, it is expected that natural climate variability will continue to influence inter-annual and inter-decadal changes in weather, climate, and extreme events. Examples of natural climate variability include the El Niño Southern Oscillation/La Niña Southern Oscillation, which is related to warming and cooling of the waters of the central and east-central equatorial Pacific Ocean, respectively. Other natural processes include the Pacific Decadal Oscillation and the Atlantic Multi-Decadal Oscillation. Currently, it is difficult to predict cycles of these phenomena at yearly to decadal timescales, and it is unknown how they might be affected by climate change.

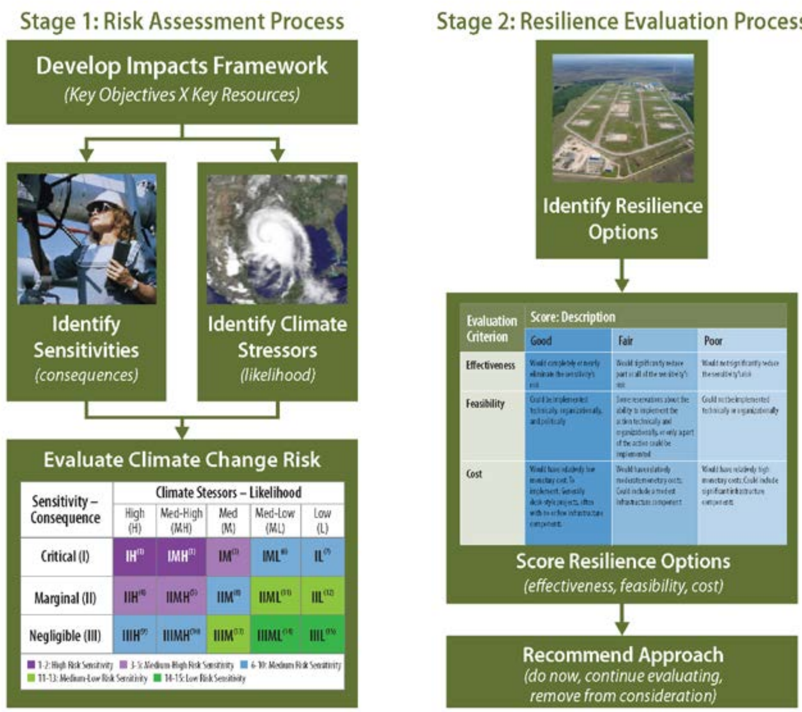
[14] Knutson, T.R., J.L. McBride, J. Chan, K. Emanuel, G. Holland, C. Landsea, I. Held, J.P. Kossin, A.K. Srivastava, and M. Sugi, 2010: Tropical Cyclones and Climate Change. *Nature Geoscience*, 3, 157-163.

3. Stage 1: Climate Change Risk Assessment Process and SPR's Findings

The goal of the risk and resilience process is to identify SPR's highest climate-related risks and evaluate potential resilience options. The process, initiated in spring 2016, has two distinct stages:

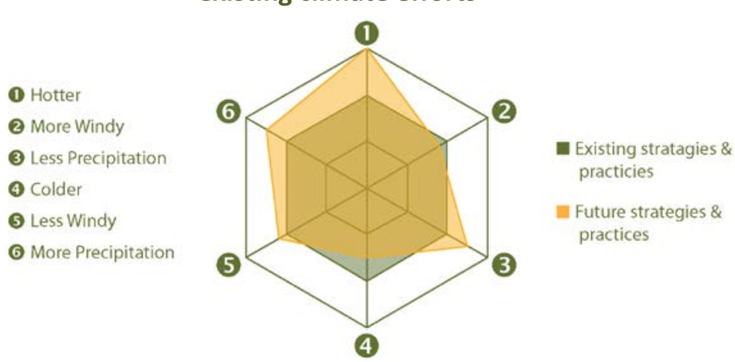
- Stage 1: *Risk Assessment Process* to identify SPR's climate change risks and the aspects of SPR's mission or operations that may be affected by a changing climate, and
- Stage 2: *Resilience Evaluation Process* to explore resilience measures that could mitigate or reduce the potential impacts. Figure 1 provides a snapshot of the process.

Figure 1. Depiction of the risk assessment and resilience evaluation processes



The intent of the risk and resilience assessment is to strengthen SPR's existing strategic and capital improvement planning, operational procedures, and best practices by using a lens of projected climate changes to highlight potential gaps where climate changes could exacerbate challenges and threaten SPR's ability to complete its work. Figure 2 illustrates how this process seeks to build on existing efforts.

Figure 2. Diagram of how this climate change risk and resilience assessment builds on existing climate efforts



3.1. Develop Impacts Framework

Developing the Impacts Framework is the first step in this climate change risk assessment process. The Impacts Framework presents a way to organize information that leads to the identification of climate-related sensitivities that have the greatest potential impact to what is most important to the SPR and its ability to continue its mission. The Impacts Framework seeks to identify the key organizational objectives that the SPR is responsible for executing and the key resources (i.e., systems, infrastructure, and staff) that are required to complete the work.

3.1.1. Identify Key Organizational Objectives and Resources

Through conversations with SPR staff about the SPR's practices and operations, and reviewing various guiding documents including the SPR Strategic Plan, a draft SPR Life Extension Phase 2 Project Execution Plan, a Drawdown and Distribution Management Manual for the SPR (Revision 7), the SPR Annual Report for Calendar Year 2012, and the Long-Term Strategic Review of the United States Petroleum Reserve, the project team selected the following key SPR organizational objectives for the risk assessment:

- **Drawdown Execution** - Readiness to supply oil at a maximum sustained rate for 90 days within 15 days' notice by the president of the United States
    - Maintain oil quality through a wide-ranging quality testing and operations control program
    - Provide effective drawdown systems
    - Provide effective distributions systems with System Test Exercises and Test Sales
    - Provide the most cost effective operations
- **Protect the Nation's Crude Oil Stockpile**
    - Protect the quality and inventory of the crude oil stored on SPR sites
    - Ensure the physical security of the SPR sites and stored oil
- **Maintain SPR's Current Import Protection Level**
    - Maintain the reserve through exchanges that maximize value to the government (e.g., royalty in-kind, government-to-government exchanges, additional return on temporary transfer, etc.)
    - Maintain an effective partnership with Department of Interior/Office of Natural Resources Revenue for oil transfers
- **Promote International Energy Stockpiling and Alliances**
    - Support United States participation in support of the International Energy Agency and Asia-Pacific Economic Corporation and meet commitments for collective action
    - Maintain alliances with stockpiling agencies for the exchange of technical, managerial, and operational information to enhance efficiency.

Several recent acts of Congress have authorized sales of crude from the SPR, including the Bipartisan Budget Act (Section 403 and 404) (2015), the 21st Century Cures Act (2016), and the Fixing America's Surface Transportation Act (2015). A continuing resolution enacted in December 2016 included a provision for DOE to sell up to $375.4 million in crude oil from the SPR. In January 2017, the DOE's Office of Fossil Energy awarded contracts for the first of several sales of crude oil from the SPR. This sale will be the first of several planned sales totaling nearly 190 million barrels during fiscal years 2017 through 2025. These sales will increase drawdown activity at the SPR. Though the sales are not included as a specific key organizational objective identified in the impacts framework, the operations activities required to execute these sales are included in the considerations of this assessment.

The key resources needed to complete SPR's work were also identified through discussions with SPR staff and review of guiding documents. Table 2 lists the SPR's key resources and illustrates how the organizational objectives and resources are related to one another in order to create the Impacts Framework.

Table 2. The SPR's Impacts Framework

	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 Access (site (e.g., roadways and lighting), perimeter security (e.g., detection and fencing)				
Workforce (operations and security)				
Crude Oil Transportation Network (partnerships and physical infrastructure (e.g., pipelines))				
Crude Oil Inventory (quantity and quality)				

3.1.2. Develop Questions to Uncover Potential Sensitivities

The Impacts Framework provides a structure for developing targeted questions aimed at exploring the role that climate factors play in SPR meeting its key organizational objectives in relation to each of the key resources. These questions function as a guide for engaging SPR subject matter experts in dialogue to investigate how each of the key resources contributes to the organizational goals, how the key resource is currently impacted by the climate, and what the impacts would be if the resource was compromised due to a change in the climate. For example, the project team discussed how water contributes to d*rawdown execution* and then considered what would happen if water was no longer available in the same quantity or if the quality of the water degraded. See Appendix A for a complete list of the questions developed and used in the discussions. The answers to the questions collected through the review of the guiding documents and numerous working meetings with SPR staff highlight the areas where SPR is most sensitive to potential changes in climate.

3.2. Identify and Score SPR's Sensitivities

Using the Impacts Framework questions and a high-level overview of how climate may change in the future for the Louisiana and Texas coastal region provided by the SCIPP (see Appendix B for the High Level Climate Projections), the project team engaged in discussions about sensitivities to the organization connected to each key resource and its relationship to each of the key organizational objectives. From these conversations a comprehensive list of sensitivities emerged. Subsequent conversations with SPR staff focused on scoring the consequence of the climate-related sensitivities based on the potential impact to the SPR.

3.2.1. Score Sensitivities by Magnitude of Consequence

The project team discussed and assigned a consequence score of critical, marginal, or negligible to each sensitivity considering the magnitude of potential impact to SPR from that sensitivity.

When determining a consequence score the project team considered:

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

For example, the sensitivity S3: *Ability to maintain necessary raw water quality and quantity for drawdown* received a critical score. Water is an essential resource for the SPR. If raw water is not available, or if the temperature of the raw water increases substantially, then the impacts to the SPR would be high. Raw water is required to complete drawdown and fill (e.g., string flushing) functions and cool the crude oil for delivery as well as routine maintenance of equipment and crude oil inventory. Therefore, a lack of water, inconsistent access to water, or high raw water temperatures would have serious implications for SPR's ability to achieve its key objectives. Table 3 lists all the sensitivities and their consequence scores that resulted from the discussions.

Consequence Scoring Criteria
Consequence is defined as the impact on the key objectives, should the key resource 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.

Table 3. SPR's Climate-Related Sensitivities and Consequence Scores

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.)	Critical (I)
	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 lines 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)
	S12	Susceptibility to mold in buildings	Marginal (II)
Specialized Equipment	S13	Large amount of old and fatigued equipment (70% past lifespan design)	Critical (I)
	S14	Wellhead exposure to weather	Negligible (III)
Workforce	S15	Outdoor workforce exposed to elements	Critical (I)
Crude Oil Transportation Network	S16	Availability of distribution systems, pipelines, and terminals in the region that SPR uses to meet mission requirements	Critical (I)
Crude Oil Inventory	S17	Ability to maintain oil temperature (i.e., increasing raw water temperatures affecting crude oil cooling capability)	Marginal (II)

[†]For ease of reference, sensitivities are numbered S1-S17.

3.3. Identify and Score SPR's Climate Stressors

Having identified the sensitivities and determined the potential impacts to the SPR, climate experts from SCIPP developed a comprehensive and detailed list of potential climate stressors for the Louisiana and Texas coastal area that could affect SPR sites. In addition, the SCIPP identified the potential likelihood that these climate stressors would change based on the quality and consistency of change observed in the climate models and the degree of agreement between different climate models.[15]

For example, climate stressor V1: *Increased annual average temperatures,* received a likelihood score of *high* as models consistently indicate a significant increase in temperature for all SPR sites. Table 4 lists the potential climate stressors identified in this assessment and their associated likelihood scores. (See tab Climate Stressor Likelihood (L) in Appendix D for the rationale for the likelihood scores.)

Scoring Climate Stressors by Likelihood of Change

Climate experts from the Southern Climate Impacts Planning Program (SCIPP) assigned a score for the likelihood that specific climate stressors will change based on current projected climate changes for the Louisiana and Texas coastal region (Table 4).

A stressor was assigned a higher likelihood of occurrence if the climate models demonstrated strong agreement about its direction and a high degree of change. A stressor was 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.

[15] Additional detail about the models used in this analysis can be found in 0.

Table 4. SPR's Climate Stressors and Associated Likelihood Scores

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

[†]For ease of reference, climate stressors are numbered V1-V28.

Utilizing the comprehensive list of potential climate stressors and their likelihood scores developed by SCIPP, the project team members then discussed and identified the climate stressors that are related to (or have the potential to impact) each sensitivity. Most sensitivities are associated with more than one climate stressor. For example, for the sensitivity S3: *Ability to maintain necessary raw water quality and quantity for drawdown*, the project team identified the climate stressors having to do with air temperature, raw water temperature, precipitation, and drought. Table 5 illustrates how this information is organized. (See tab "Risk Score Calc" in Appendix D for a complete list of each sensitivity and its relevant climate stressors.)

Table 5. Example of Relevant Climate Stressors

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

3.4. Evaluate SPR's Climate Change Risks

The final step of Stage 1 is to evaluate each sensitivity's risk. The risk score is based on the combination of the sensitivity's consequence score and the combination of applicable climate stressors' likelihood scores. A risk score is assigned to each sensitivity based on the risk matrix in Table 6. The risk matrix provides a structure for combining these scores in a meaningful way that enables analysis and ranking of the risks. The outcome of this step is a ranked listing of SPR's climate-related sensitivities.

Table 6 illustrates how scores are combined to identify an overall risk score for each climate-related sensitivity based on the sensitivity's consequence score and the related climate stressors' scores. Final risk scores were grouped into five categories based on scoring criteria and the numbers listed in the table; scores of 1-2 were identified as *High Risk Sensitivities*, scores of 3-5 were identified as *Medium-High Risk Sensitivities*, 6-10 were identified as *Medium Risk Sensitivities*, 11-13 were identified as *Medium-Low Risk Sensitivities*, and 14-15 were identified as *Low Risk Sensitivities*.

Table 6. Risk Score Matrix

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)

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

The sensitivity's consequence score was combined with all the likelihood scores for each climate stressor identified as related to that sensitivity. The combined scores were then averaged to calculate an overall risk score for that sensitivity. Table 7 provides an example of this process for sensitivity S3: *Ability to maintain necessary raw water quality and quantity for drawdown.* S3 was identified as a *High Risk* Sensitivity. See the tab "Risk Score Calc" in Appendix D for a complete worksheet with all SPR sensitivities and associated risk scoring.

Table 7 Consequence, Likelihood, and Risk Scores

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	

Sensitivities were ranked according to the identified risk level from 1 to 15 (see Table 6) and grouped by *high, medium-high, medium, medium-low*, and *low* risk characterization. Table 8 lists each of the SPR climate-related sensitivities and their associated risk scores.

Table 8. SPR's Climate Change Related Sensitivity Risk Scores

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
S6	Ability to maintain necessary raw water quality for disposal of brine to the Gulf of Mexico (i.e., 95%+ salinity, pH levels, etc.)	2
S8	Reliance on a single supplier of commercial power lines 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

No.	Sensitivity	Risk Score
S11	Sites elevation and proximity to the ocean	3
S12	Susceptibility to mold in buildings	5
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
S7	Ability to access raw water for flushing of brine strings during fill operations	8
S9	Adequate power required to run the distributed control system (DCS)	6
S10	Command center, single facility for control of pumping stations	6
S14	Wellhead exposure to weather	11

3.5. SPR's Risk Assessment Narrative Summary

Sections 3.5.1 through 3.5.10 highlight the results from the risk analysis for each of the sensitivities grouped by key resource (identified in the Impacts Framework). The narrative in this section provides a summary description of the consequence scores, likelihood scores and the combined risk scores for each of the sensitivities related to each key resource identified.

Note that two of the sensitivities are associated with virtually all of the key resources and are thus discussed as a group referred to as Multiple Key Resources. The remainder of the sensitivities are organized by the main key resource that they are associated with. Some of the sensitivities are associated with more than one key resource, but those key resources are not as important or directly tied to that sensitivity. For example, with sensitivity S3: *Ability to maintain necessary raw water quality and quantity for drawdown* the main key resource is water. The key resources of physical space and crude oil transportation network are also associated with this sensitivity and were identified as secondary key resources during the assessment. Secondary key resources may involve climate stressors not related to the main key resource for that sensitivity. Comprehensive tables detailing how each of these sensitivities were scored, and taking into account the climate stressors related to the secondary key resources, are provided in tab "Risk Score Calc" of Appendix D.

3.5.1. Multiple Key Resources

Two of SPR's sensitivities identified in the assessment are associated with virtually all of the key resources with relatively equal importance. They include:

- S1: Ability to respond if a weather event impacts more than one site at the same time
- S2: Ability to meet statutory oil quantity requirements.

Existing mitigations
SPR currently employs several mitigation strategies that reduce the potential impacts to these two sensitivities as follows:

- Maintain multiple basic ordering agreements (BOAs) and backup supplies to meet requirements for drawdown situations
- Use raw-water-cooled, crude-oil heat exchangers to control oil delivery temperatures

- Use equipment and staff able to quickly respond to emergencies on a site by site basis
- Maintain multiple caverns at four different sites to increase crude oil storage capacity

Sensitivity consequence scores
Based on discussions with SPR staff and taking into account mitigations already in place, sensitivities S1 and S2 both received a consequence score of *critical* because of their high importance to the SPR's key objectives.

Climate stressors
Climate experts scored 11 climate stressors that can affect all of the key resources. Four of the climate stressors scored a *high* likelihood of occurring:

- V1: Increased annual average temperatures
- V2: Increases in magnitude of hottest annual temperature
- V3: Increase in the number of days with temperatures >= 95°F per year
- V5: Increased sea level.

Five climate stressors scored a *medium-high* likelihood of occurring:

- V8: Increased intensity of hurricane winds
- V9: Higher storm surge due to hurricanes
- V10: Increased raw water temperature
- V14: Subsidence – increase with sea level rise
- V15: Coastal land loss – increase.

One climate stressor scored a *medium* likelihood of occurring:

- V17: Increased chance of drought/low water levels.

One climate stressor scored a *med-low* likelihood of occurring:

- V25: Increase in tornadoes.

Most of the related climate stressors have to do with increases in air temperature, both in duration and intensity, as well as increase of intensity in storm events such as tornadoes and hurricanes and their related impacts (e.g., storm surge). Storm events in particular are exacerbated by sea level rise and coastal land loss. These climate stressors have the potential to directly affect the SPR's ability to continue and sustain operations, especially if a single event like a hurricane impacts more than one site at a time, which can negatively impact the ability of the SPR to meet statutory oil requirements.

Risk scores
As a result of these consequence and likelihood scores, sensitivity S1: *Ability to respond if a weather event impacts more than one site at the same time* and S2: *Ability to meet statutory oil quantity requirements* both received *high* risk scores.

3.5.2. Water

Water is an essential resource for the SPR. Most of the SPR's fill, storage, and drawdown activities require extensive amounts of raw water, which is used to do fill and drawdown operations. Industrial, landscaping and agricultural (ILA) and potable water usage include operations such as process pump flushing and cool-down of pumps during operations. In FY2015, 82.5 million gallons of raw, potable, and ILA water was used from all sites. In a drawdown situation, the SPR would require a much higher volume of raw, ILA, and potable water. Nearly 30.7 billion gallons of raw water and substantial increases in ILA and potable water would be required due to the increased level of equipment operation. Access to raw and potable water is critical, and the water must maintain a specific quality (i.e., temperature, sediment level, salinity level, pH, etc.) at all times in order to meet key mission objectives. The SPR water sources are as follows:

- Bryan Mound - City of Freeport (potable) and the Brazos River Diversion Channel (raw)
- Big Hill - Trinity Bay Conservation District (potable) and the Gulf Intracoastal Waterway (raw)
- West Hackberry - two Cameron Parish Waterworks Districts (potable), on site well (ILA water), and the Gulf Intracoastal Waterway (raw)
- Bayou Choctaw - Iberville Parish (potable) and Cavern Lake on site (raw).

Water-related sensitivities

The five most significant water-related sensitivities identified in the assessment are:

- S3: Ability to maintain necessary raw water quality and quantity for drawdown
- S4: Ability to conduct process pump seal flushing and bearing cooling
- S5: Increased build-up of silt in raw water systems
- S6: Ability to maintain necessary raw water quality for disposal of brine to the Gulf of Mexico (i.e., 95%+ salinity, pH levels, etc.)
- S7: Ability to access raw water for flushing of brine strings during fill operations.

Existing water-related mitigations

SPR currently employs several mitigation strategies that reduce the potential impacts to water-related sensitivities as follows:

- Periodic monitoring of raw water quality to ensure requirements are met
- Regular dredging in water ways near the SPR to reduce silting and improve water flow
- Capability to run water or put ice over pumps to cool them in extreme situations
- Contracts in place at Bryan Mound with Brazos River Authority to ensure access to potable water even in cases of drought.

Water-related sensitivity consequence scores

Based on discussions with SPR staff and taking into account water-related mitigations already in place, sensitivities S3, S4, S5, and S6 received *critical* consequence scores, and sensitivity S7 received a *marginal* consequence score because of their relative importance to SPR's key objectives.

Water-related climate stressors

Climate experts scored 19 climate stressors that can affect water supply and water quality. Five of the climate stressors scored a *high* likelihood of occurring:

- V1: Increased annual average temperatures
- V2: Increases in magnitude of hottest annual temperature (increasing cooling water temperatures)
- V3: Increase in the number of days with temperatures >= 95°F per year
- V4: Increased rainfall amounts on days with rain
- V5: Increased sea level.

Six climate stressors scored *medium-high* likelihood:

- V7: Increased number of days with heavy rainfall
- V8: Increased intensity of hurricane winds

- V9: Higher storm surge due to hurricanes
- V10: Increased raw water temperature
- V14: Subsidence – increase with sea level rise
- V15: Coastal land loss – increase.

Three climate stressors scored *medium* likelihood:

- V16: Increased chance of flooding/high water levels
- V17: Increased chance of drought/low water levels
- V18: Increased annual rainfall.

Four climate stressors scored *medium-low* likelihood:

- V21: Changes in raw water quality – increase sediment
- V22: Changes in raw water quality – increase salinity
- V23: Changes in raw water quality – pH
- V25: Increase in tornadoes.

Increases in average air temperatures and increases in the intensity and duration of higher air temperatures could potentially result in higher raw water temperatures that could reduce the effectiveness and efficiency of SPR's ability to adequately cool oil for delivery in drawdown operations. Increases in rainfall amounts on days with rain could impact raw water availability by promoting siltation at raw water intake structures that would decrease the quantity of raw water for drawdown activities and increase the need for dredging activities. Increases in saltwater intrusion from sea level rise could lead to increased corrosion of field mounted electrical distribution and control system components and other exposed equipment.

Water-related risk scores

As a result of these consequence and likelihood scores, sensitivities S3: *Ability to maintain necessary raw water quality and quantity for drawdown* and S6: *Ability to maintain necessary raw water quality for disposal of brine to the Gulf of Mexico (i.e., 95%+ salinity, pH levels, etc.)* received a *high* risk score. Sensitivities S4: *Ability to conduct process pump seal flushing and bearing cooling* and S5: *Increased build-up of silt in raw water systems* received a *medium-high* risk score, and sensitivity S7: *Ability to access raw water for flushing of brine strings during fill operations* received a risk score of *medium*.

3.5.3. Power

The SPR depends on a consistent and reliable supply of power to execute nearly all of the SPR's key objectives. The amount of electrical power necessary varies. To execute a full drawdown requires a substantial amount of power—more than 67 MW for all sites combined. Significantly less power—approximately 6MW—is required for daily operations when no drawdown is being executed. Regardless, a constant supply of electricity is necessary to maintain storage activities, command and control and security systems, and occupant comfort in buildings, particularly in the summer months when temperature and humidity levels are high.

The SPR currently receives all of its electricity from a single source at each of the sites. All sites receive power from their local utility. There are no onsite renewable power options at any site. The SPR does have on-site backup diesel generator capacity to maintain emergency operations and safely support shutdown processes. If diesel fuel is available, then the generators can sustain this minimal operation for an indefinite period of time.

Portable diesel-driven pumps are available to provide additional backup capacity for limited drawdown operations. However, this backup capacity is not sufficient to meet statutory drawdown requirements and necessitates continued access to diesel fuel. If the SPR's electricity supply were compromised for an extended period of time, particularly at more than one site at the same time or if repeated brownout conditions occurred, it would be a challenge to meet the SPR's mission.

Power-related sensitivities

SPR's reliance on a single provider of electrical power with no on-site renewable power generation capabilities was identified as the power-related sensitivity:

- S8: Reliance on a single supplier of commercial power lines to each of the sites

Existing power-related mitigations

The SPR currently employs several mitigation strategies that reduce the potential impacts to power-related sensitivities, as follows:

- Backup diesel generators to maintain emergency loads at each site
- BOAs in place for required diesel delivery to maintain diesel generators if required
- Portable equipment that can be transported to sites in order to perform reduced drawdown operations without the availability of commercial power.

Power-related sensitivity consequence scores

While the SPR does have existing mitigations that reduce potential impacts, none of the mitigations would enable the SPR to operate at drawdown capacity and meet statutory requirements. Diesel backup generators provide some capacity for emergency shutdown operations and life safety systems. However, these systems rely on a consistent supply of diesel fuel, which may not be available.

Based on conversations with SPR staff and taking into account current SPR mitigation strategies that reduce the impact of power-related sensitivities, sensitivity S8 received a consequence score of *critical*.

Power-related climate stressors

Climate experts scored 13 climate stressors that could affect the supply of electrical power. Four of the climate stressors scored a *high* likelihood:

- V1: Increased annual average temperatures
- V2: Increases in magnitude of hottest annual temperature
- V3: Increase in the number of days with temperatures >= 95°F per year
- V5: Increased sea level.

Six of the climate stressors scored a *medium-high* likelihood:

- V6: Decreased annual rainfall
- V7: Increased number of days with heavy rainfall
- V8: Increased intensity of hurricane winds
- V9: Higher storm surge due to hurricanes
- V12: Increased number of days with thunderstorms/lightning
- V14: Subsidence – increase with sea level rise.

Two of the climate stressors scored *medium* likelihood:

- V16: Increased chance of flooding/high water levels
- V19: Increase in severe thunderstorms

One of the climate stressors scored *medium-low* likelihood:

- V25: Increase in tornadoes.

Increases in average air temperatures as well as increases in the intensity and duration of high air temperatures, storm frequency and intensity, and flooding could result in brownouts or other grid interruptions that would disrupt the SPR's ability to execute a drawdown and conduct regular operations. This could reduce the ability of SPR to maintain building occupant safety and comfort, particularly throughout the summer season.

Power-related risk score

As a result of these consequence and likelihood scores, Sensitivity S8: *Reliance on a single supplier of commercial power lines to each of the sites* received a *high* risk score.

3.5.4. Command and Control Systems

The SPR's command and control system—the distributed control system (DCS)—allows for remote operations of pumps, valves, and other essential pieces of the crude oil storage and drawdown system. This communication system is an essential part of maintaining sustained operations that have the ability to meet all key objectives. These systems use the same software at each SPR site, and the systems are isolated from internet and other external access. Each site does have an alternate operating location for the DCS that could serve as a command and control room if required.

The command and control system resides both inside and outside the central control room and through physical wiring infrastructure throughout the sites. The wiring of these systems is subject to all manner of weather events and climate and is only impacted when it's within a facility that is impacted (i.e., flooding).

Command and control system-related sensitivities

Two sensitivities related to the command and control system were identified in the assessment:

- S9: Adequate power required to run the DCS
- S10: Command center single facility for control of pumping stations.

Existing command and control system-related mitigations

SPR currently employs several mitigation strategies that reduce the potential impacts to command and control system-related sensitivities as follows:

- During storm events, sensitive indoor command and control system equipment is covered with plastic to avoid system loss from water leaks
- "Green room" exercises are conducted annually and include a prioritization of improvements to command center facilities
- Backup diesel generators to maintain emergency loads at each site (includes critical processes for the DCS)
- SPR systems can be manually accessed and controlled if required
- SPR has multiple layers of redundancy in staff and training, including expertise in running the DCS from an alternate site location
- Control room exterior windows at each site have been recently upgraded
- DCS is connected to an uninterruptable power supply (UPS) system at each site and alternative locations of operation can be established if required.

Command and control system-related sensitivity consequence scores

Based on discussions with SPR staff and taking into account command and control system-related mitigations already in place, sensitivities S9 and S10 received *marginal* consequence scores because of their relative importance to SPR's key objectives.

Command and control system-related climate stressors
Climate experts scored 11 climate stressors that could affect the SPR's command and control system. One of the climate stressors scored a *high* likelihood:

- V4: Increased rainfall amounts on days with rain.

Six of the climate stressors scored *medium-high* likelihood:

- V7: Increased number of days with heavy rainfall
- V8: Increased intensity of hurricane winds
- V9: Higher storm surge due to hurricanes
- V12: Increased number of days with thunderstorms/lightning
- V14: Subsidence – increase with sea level rise
- V15: Coastal land loss – increase.

Three of the climate stressors scored *medium* likelihood:

- V16: Increased chance of flooding/high water levels
- V18: Increased annual rainfall
- V19: Increase in severe thunderstorms.

One climate stressor scored *medium-low* likelihood:

- V25: Increase in tornadoes.

Increases in average air temperatures, the intensity and duration of high air temperatures, storm frequency and intensity, as well as increases in high waters or flooding could result in power disruptions or building and equipment malfunction. This could limit SPR's ability to appropriately control pumping activities through the command and control systems.

Command and control system-related risk scores
As a result of these consequence and likelihood scores, sensitivities S9: *Adequate power required to run the DCS* and S10: *Command center, single facility for control of pumping stations* received *medium* risk scores.

3.5.5. Physical Space

Physical space, including caverns, land, facilities, and site infrastructure such as roadways and perimeter fencing are all necessary for the SPR to operate in a way that meets mission requirements. Physical space is necessary to store the crude oil and provide staging for brine water disposal, shelter for staff and equipment, access to pumping stations and buildings, and physical site security. The SPR sites were located where they are because of the inherent physical space characteristics and access to oil distribution networks.

Each of the SPR storage sites includes a number of salt dome caverns where crude oil is stored. The salt domes are naturally formed; the manmade caverns require ongoing structural monitoring and maintenance to reduce cavern creep as oil sits for a sustained period of time. Each site also has buildings for security, laboratory space for testing oil quality, and the command and control center. Additional physical space includes brine ponds and storage tanks. An office complex in New Orleans houses SPR staff and Maintenance & Operations headquarters operations and records. The facility in Stennis, MS, includes a warehouse and offices with backup equipment for the SPR sites.

Physical space-related sensitivities
Two physical space-related sensitivities were identified in the assessment:
- S11: Sites elevation and proximity to the ocean
- S12: Susceptibility to mold in buildings.

Existing physical space-related mitigations
The SPR currently employs several mitigation strategies that reduce the potential impacts to physical space-related sensitivities as follows:
- Building specs have been updated to reflect the need to build at or above the 100-year flood plain
- Windows were recently upgraded in multiple facilities at multiple sites
- New materials are investigated on an ongoing basis to prevent damage from mold and corrosion
- Leaks are prioritized when building improvements are made.

Physical space-related sensitivity consequence scores
Based on conversations with SPR staff and taking into account current SPR mitigation strategies that reduce the impact of physical space-related sensitivities, sensitivity S11 received a *critical* score and sensitivity S12 received a *marginal* score because of their relative importance to the key objectives.

Physical space-related climate stressors
Climate experts scored the likelihood of 16 climate stressors that could affect physical space. Five of the climate stressors scored a *high* likelihood:
- V1: Increased annual average temperatures
- V2: Increases in magnitude of hottest annual temperature
- V3: Increase in the number of days with temperatures >= 95°F per year
- V4: Increased rainfall amounts on days with rain
- V5: Increased sea level.

Five of the climate stressors scored *medium high* likelihood:
- V 7: Increased number of days with heavy rainfall
- V8: Increased intensity of hurricane winds
- V9: Higher storm surge due to hurricanes
- V14: Subsidence – increase with sea level rise
- V15: Coastal land loss – increase.

Three of the climate stressors scored *medium* likelihood:
- V16: Increased chance of flooding/high water levels
- V18: Increased annual rainfall
- V20: Increase in vector-borne diseases.

Two of the climate stressors scored *medium-low* likelihood:
- V21: Changes in raw water quality – increase sediment
- V22: Changes in raw water quality – increase salinity.

One climate stressors scored a *low* likelihood:
- V 28: Increase in relative humidity.

Increases in air temperature, precipitation intensity frequency and intensity of storms, and sea level rise with resulting coastal land loss and subsidence all have the ability to affect physical space and therefore the operations at the SPR. Flooding of site infrastructure and buildings could become more frequent. Increased intensity of precipitation events, salt water intrusion or increased sediment from storm activity could affect brine storage ponds. Increased subsidence could affect cavern integrity. All of these stressors could affect the effectiveness of the SPR process and require additional maintenance activities such as dredging, roadway repairs, or mold abatement. Multiple stressors happening at the same time exacerbate those impacts and threaten the SPR's ability to meet its key objectives.

Physical space-related risk scores

As a result of these consequence and likelihood scores, sensitivities S11: *Sites elevation and proximity to the ocean* and S12: *Susceptibility to mold in buildings* received a *medium-high* risk score.

3.5.6. Specialized Equipment

In order to meet mission objectives, the SPR maintains a number of essential systems through the use of specialized equipment including crude oil storage systems, raw water systems, brine disposal systems, and oil distribution systems. Specialized equipment and components of this system include heat exchangers, raw water injection pumps, crude oil pumps, brine disposal pipeline and offshore brine diffusers, process piping, and brine settling ponds. SPR is required to meet drawdown requirements with defined-quality crude oil supplies when called upon by the president of the United States. This requires equipment to be maintained in a functional state. Equipment is tested on a regular basis and critical infrastructure is backed up with redundant equipment.

Specialized Equipment-related sensitivities

The two sensitivities related to specialized equipment identified in the assessment are:

- S13: Large amount of old and fatigued equipment (70% past lifespan design)
- S14: Wellhead exposure to weather.

Existing specialized equipment-related mitigations

The SPR currently employs several mitigation strategies that reduce potential impacts to specialized-equipment-related sensitivities as follows:

- Maintains a detailed and periodic corrosion inspection process to ensure equipment is functional
- Maintains equipment redundancy for critical needs and emergencies
- Well heads on salt domes are located in higher areas of the local terrain
- Designates staff and equipment so that pumps and motors can be maintained as needed
- Uses totally enclosed fan-cooled (TEFC) rated motors that are resistant to water intrusion
- Uses pumps designed for sea water service and made of corrosion-resistant material.

Specialized-equipment-related sensitivity consequence scores

Based on discussions with SPR staff and taking into account specialized-equipment-related mitigations already in place, sensitivity S13 received a *critical* consequence score and sensitivity S14 received a *negligible* consequence score because of their relative importance to SPR's key objectives.

Specialized-equipment-related climate stressors

Climate experts scored 20 climate stressors that can affect specialized equipment. These scores focused on the likelihood of change for these specific climate stressors. Five of the climate stressors scored a *high* likelihood:

- V1: Increased annual average temperatures
- V2: Increases in magnitude of hottest annual temperature
- V3: Increase in the number of days with temperatures >= 95°F per year
- V4: Increased rainfall amounts on days with rain
- V5: Increased sea level.

Seven climate stressors scored *medium-high* likelihood:

- V7: Increased number of days with heavy rainfall
- V8: Increased intensity of hurricane winds
- V9: Higher storm surge due to hurricanes
- V10: Increased raw water temperature
- V12: Increased number of days with thunderstorms/lightning
- V14: Subsidence – increase with sea level rise
- V15: Coastal land loss – increase.

Three climate stressors scored *medium* likelihood:

- V16: Increased chance of flooding/high water levels
- V18: Increased annual rainfall
- V19: Increase in severe thunderstorms.

Four climate stressors scored *medium-low* likelihood:

- V22: Changes in raw water quality – increase salinity
- V23: Changes in raw water quality – pH
- V24: Increase in wind speed
- V25: Increase in tornadoes.

One climate stressor scored *low* likelihood:

- V28: Increase in relative humidity.

Increased air temperatures, rain events, sea level rise and storm surge can wear on outdoor equipment, requiring more replacement of essential pieces and potentially stalling operations until necessary parts can be replaced. The majority of the SPR's essential specialized equipment is under shelter, protected from sun and rainfall. Power and control system equipment is enclosed in appropriately weather-hardened enclosures. Increases in subsidence and coastal land loss can potentially affect specialized equipment and access to that equipment. Increased storms, flooding, hurricane surge, and winds can potentially increase the exposure of these systems and components to water, specifically salt water that can increase corrosion and system failures. Raw water quality also affects piping systems and increases in salinity and variable pH can both potentially lead to failures.

Specialized-equipment-related risk scores

Based on these consequence and likelihood scores, sensitivity S13: *Large amount of old and fatigued equipment (70% past lifespan design)* received a *high* risk score. Sensitivity S14: *Wellhead exposure to weather* received a *low* risk score.

3.5.7. *Physical Site Access*

SPR sites are distributed across multiple areas near the coast of the Gulf of Mexico in both Texas and Louisiana. Each of these sites has one main access road. A couple of sites also have secondary roads that can access the sites. All sites have perimeter security systems and secure site access. In order to perform drawdown functions and meet other key operational objectives, the SPR sites must be manned by on-site staff and secured. Physical site access is an essential part of ensuring the access, security, and safety of on-site staff and the ability of SPR to meet its operational mission and objectives.

Physical site access-related sensitivities
The SPR has multiple mitigations currently in place to address sensitivities around physical site access. In addition, both sensitivities identified as relating to multiple key resources included considerations of physical site access. Based on discussion with SPR staff and experts, no specific physical site access-related sensitivities were identified.

Existing physical site access-related mitigations
SPR has extensive mitigations and redundancy to ensure secure physical site access to all sites. These include:

- Ability to get staff to sites by any means possible including but not limited to; helicopter, boats, and high water vehicles
- Many sites can be accessed through rivers, or intercostal waterways if required.

Physical site access risk scores
During the course of the project, the project team determined that site access is a subcomponent of the key resource of physical space and that any sensitivities associated with this key resource were being addressed in the physical space discussions. Therefore, for the remainder of the project, this key resource was removed as a distinct resource and does not appear in any of the following tables or narrative.

3.5.8. *Workforce*

The SPR's workforce is an essential resource required to meet the SPR's key organizational objectives. In order to perform necessary activities for drawdown operations, a number of staff members are required to work outdoors on a regular basis or to perform crucial tasks. SPR staff is also trained extensively on operations of equipment and systems throughout each site. The SPR recognizes the essential roles of its workforce and ensures working conditions create a safe and productive space to meet the SPR's mission.

Workforce-related sensitivities
One workforce-related sensitivity was identified by the assessment, S15: *Outdoor workforce exposed to elements.*

Existing workforce-related mitigations
The SPR ensures the safety and productivity of its workforce through a number of current mitigation strategies including:

- Maintain and continue development of an exemplary heat stress monitoring program to ensure the safety of its workers
- Regular spraying of outdoor areas on site to reduce mosquito populations
- Maintain redundancy in overall workforce to provide backup both at each site and between sites.

Workforce-related sensitivity consequence scores
Based on discussions with SPR staff and taking into account workforce-related mitigations already in place, sensitivity S15 received a *critical* consequence score.

Workforce-related climate stressors
Climate experts scored 15 climate stressors that can affect the workforce. These scores focused on the likelihood of change for these specific climate stressors. Three of the climate stressors scored *high* likelihood:

- V2: Increases in magnitude of hottest annual temperature
- V3: Increase in the number of days with temperatures >= 95°F per year
- V4: Increased rainfall amounts on days with rain.

Four climate stressors scored *medium-high* likelihood:

- V7: Increased number of days with heavy rainfall
- V8: Increased intensity of hurricane winds
- V9: Higher storm surge due to hurricanes
- V12: Increased number of days with thunderstorms/lightning.

Five climate stressors scored *medium* likelihood:

- V16: Increased chance of flooding/high water levels
- V17: Increased chance of drought/low water levels
- V18: Increased annual rainfall
- V19: Increase in severe thunderstorms
- V20: Increase in vector-borne diseases.

Two climate stressors scored *medium-low* likelihood:

- V25: Increase in tornadoes
- V27: Increase in wildfire occurrence.

One climate stressor scored *low* likelihood:

- V28: Increase in relative humidity.

Increases in air temperature can slow or even stop work so that a safe working environment for outdoor workforce is ensured. Increases in rain and thunderstorms can also increase schedule delays and reduce productivity at the SPR. Vector-borne disease can have harmful impacts on the outdoor workforce if new diseases impact large portions of the SPR's workforce and team. Increased flooding due to hurricanes, storm surge, and rain events can create unsafe working environments both indoor and outdoor. This can reduce the capacity and effectiveness of SPR's staff to complete mission-essential functions. Increased wildfires can also create unsafe outdoor working environments mostly due to smoke.

Workforce-related risk scores
Based on these consequence and likelihood scores, sensitivity S15: *Outdoor workforce exposed to elements* received a *medium-high* risk score.

3.5.9. Crude Oil Transport Network

In order to move oil to meet drawdown requirements and other key operational objectives, the SPR is connected to an extensive crude oil transportation network in the region. This network includes both physical infrastructure such as pipelines and various terminals, as well as relational infrastructure that involves various partnerships, agreements, and contracts with multiple entities across the Gulf Coast. This network of physical assets and partnerships is essential to maintaining access to the crude oil transportation network that moves crude oil from the SPR to where it is needed.

Crude oil transportation network-related sensitivities
The essential requirements of the crude oil transportation network were identified as the crude oil transportation network-related sensitivity, S16: *Availability of distribution systems, pipelines, and terminals in the region that SPR uses to meet mission requirements.*

Existing crude oil transportation network-related mitigations
The SPR's current mitigation strategy related to the crude oil transportation network is to resume DOE operation of the St. James terminal, presently under lease, which would increase options for transporting crude oil by sea. This effort is part of LE2.

Crude oil transportation network-related sensitivity consequence scores
Based on discussions with SPR staff and taking into account the crude oil transportation network-related mitigation already in place, sensitivity S16 received a *critical* consequence score.

Crude oil transportation network-related climate stressors
Climate experts scored eleven climate stressors that can affect the crude oil transportation network. These scores focused on the likelihood of change for these specific climate stressors. Four of the climate stressors scored *high* likelihood:

- V1: Increased annual average temperatures
- V2: Increases in magnitude of hottest annual temperature
- V3: Increase in the number of days with temperatures >= 95°F per year
- V5: Increased sea level.

Four climate stressors scored *medium-high* likelihood:

- V8: Increased intensity of hurricane winds
- V9: Higher storm surge due to hurricanes
- V10: Increased raw water temperature
- V12: Increased number of days with thunderstorms/lightning.

Two climate stressors scored *medium* likelihood:

- V16: Increased chance of flooding/high water levels
- V17: Increased chance of drought/low water levels.

One climate stressors scored 'medium-low' likelihood:

- V25: Increase in tornadoes.

Increases in air temperature can lead to quicker deterioration of the physical aspects of the crude oil transportation network. Increased sea level, higher storm surge, and winds during hurricanes and tornadoes can also lead to the possible loss or shut down of key elements of the crude oil transportation network, which could limit overall access. In addition, this could lead to strains on contracts and partnerships as efforts to move crude oil are made more difficult through the loss of systems. Increased drought can also limit water sources necessary to transport oil.

Crude oil transportation network-related risk scores
Based on these consequence and likelihood scores, sensitivity S16: *Availability of distribution systems, pipelines, and terminals in the region that SPR uses to meet mission requirements* received a *high* risk score.

3.5.10. Crude Oil Inventory

At the core of the SPR's mission is the quality and quantity of the crude oil inventory. High quality crude oil is essential to meeting the organizational mission and objectives. Most importantly, moderate temperatures are required to effectively and efficiently cool crude oil at the time of delivery to reduce the crude oil bubble point before entering the crude oil transportation network. This key resource is also dependent upon all other key resources previously discussed.

Crude oil inventory-related sensitivities
In order to meet the quality and quantity requirements of crude oil at the SPR, the crude oil inventory-related sensitivity identified was S17: *Ability to maintain oil temperature (i.e., increasing raw water temperatures affecting crude oil cooling capability).*

Existing crude oil inventory-related mitigations
The SPR current mitigation strategies related to the crude oil inventory include:

- Has an extensive amount of systems and equipment in place to monitor crude oil
- Conducts ongoing laboratory testing of crude oil to determine oil attributes and identify any concerns
- Conducts degassing to manage crude oil temperature.

Crude oil inventory-related sensitivity consequence scores
Based on discussions with SPR staff and taking into account crude oil inventory-related mitigations already in place, sensitivity S17 received a *marginal* consequence score.

Crude oil inventory -related climate stressors
Climate experts scored one specific climate stressor that can affect crude oil inventory *medium-high* likelihood, focusing on the likelihood of change:

- V10: Increased raw water temperature

Since the crude oil inventory is mainly stored in salt caverns, many climate stressors had limited to no impact on the crude oil inventory itself. In particular, the crude oil temperature is determined by the cavern temperatures, how long the crude oil has been stored in the caverns, and whether or not those caverns have been degassed recently. To maintain moderate crude oil temperature for transportation the SPR requires an optimal range of raw water temperature to cool down the oil. Increases in raw water temperature (as little as two degrees above 2017 temperatures) would substantially impact heat exchangers and could reduce the deliverability of the SPR's crude oil by violating regulatory mandates to excessive delivery temperatures.

Crude oil inventory-related risk scores
Based on these consequence and likelihood scores, sensitivity S17: *Ability to maintain oil temperature (i.e., increasing raw water temperatures affecting crude oil cooling capability)* received a *medium-high* risk score.

4. Stage 2: Climate Change Resilience Options Evaluation Process and SPR's Findings

> ***Definition of Resilience***
>
> *The capacity of the SPR to prevent, withstand, respond to, and recover from a disruption.*

Stage 2, the resilience evaluation process, aims to identify and evaluate potential resilience options that could reduce the potential impacts from climate change on the identified sensitivities to inform the SPR's future planning and decision making.

For the purposes of this assessment, the SPR team discussed and identified a common definition for resilience. The definition selected (modified slightly) originated from the National Oceanic and Atmospheric Administration's United States Climate Resilience Toolkit.[16]

There are three steps to the resilience evaluation process: (1) identify the potential resilience options, (2) score the resilience options at a high level based on key criteria, and (3) prioritize the options by recommending an approach for each of the options.

4.1. Identify Resilience Options

The goal of this step is to develop a range of options that could reduce the potential consequence to the SPR of each sensitivity. Using the definition of resilience, the project team brainstormed potential resilience options for each of the sensitivities identified using the related climate stressors and the potential impacts identified previously.

To generate some innovative ideas, the project team was encouraged to be as comprehensive and unrestrained as possible in developing these options. During a subsequent step in the process these options were evaluated based on specific criteria to help ground or truth-test the options.

The questions below helped guide the brainstorming discussions about ideas that may reduce the sensitivity's risk and how the risk would be reduced:

- New (or enhanced) processes?
- New (or enhanced) codes or standards?
- New (or changes to existing) policies or procedures?
- Site or facility physical improvements?
- Additional or new site infrastructure or facilities?
- New (or upgrades to existing) equipment?
- External partnerships?

[16] United States federal government. "Resilience." United States Climate Resilience Toolkit. Steps to Resilience glossary. Last modified July 15, 2016. Accessed March 31, 2017. https://toolkit.climate.gov/content/glossary.

4.2. Score Resilience Options

Having discussed and created a list of resilience options, the project team then subjected each option to a high level assessment based on key criteria: effectiveness, feasibility, and cost. Scores of good, fair, and poor were assigned according to the descriptions in Table 9.

Note that these assessments are based on conversations and professional judgements from project team participants. No additional analysis was conducted to identify specific costs or feasibility for a particular resilience measure as that is beyond the scope of the project. Resilience options may require additional study or analysis of a particular measure that emerged from this process.

Effectiveness is the capacity of the resilience option to reduce the sensitivity'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.

Table 9. Resilience Options Scoring Criteria

Assessment 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 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

4.3. Recommend an Approach

Using the assessments for each resilience option, the project team then assigned a recommended approach of *Do Now, Continue Evaluating,* or *Remove from Consideration* according to the descriptions provided:

- ***Do now*** was assigned actions that the SPR can reasonably pursue and that may benefit other strategies beyond climate change resilience planning. These strategies provide benefits under current and projected climate conditions. When the SPR spends money on this type of strategy, it will reduce facility risk to current climate stressors, make the SPR more resilient to future climate change, and ensure the investment is worthwhile regardless of the climate future. These strategies may involve some cost that is not fully justified under current climate conditions.

- ***Continue evaluating*** was assigned to resilience actions that require more in depth analysis to better determine if they could be endorsed as *do now* actions or removed from consideration.

- ***Remove from consideration*** was assigned to resilience actions that were untenable for one or more reasons, or because the resilience options address impacts that are beyond current planning horizons.

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.

Based on the resilience options evaluation discussions the project team identified, scored and selected a recommended approach for each resilience option organized by key resource as noted in Table 10.

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Table 10. SPR's Scored Resilience Options by Key Resource

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 Choctaw) 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

Command and Control System	R15	Identify locations where an upgrade to sea-worthy, marine-rated cable would be appropriate	Fair	Fair	Poor	Remove from Consideration
Physical Space	R16	Install more-efficient HVAC systems (variable fans, etc.) and consider use of ground water (well) for building cooling to reduce electricity demands	Good	Good	Good	Do Now
	R17	West Hackberry - Monitor and assess potential involvement in LA coastal plan hydrologic restoration projects	Good	Good	Good	Do Now
	R18	Add "check for mold" to the Organizational Assessments checklist	Good	Good	Good	Do Now
	R19	Identify, evaluate, and consider elevating or reinforcing at-risk buildings/site facilities	Good	Good	Fair	Do Now
	R20	Have Sandia National Laboratories conduct an in-depth subsidence projection for the sites	Good	Good	Fair	Do Now
Specialized Equipment	R22	Prioritize list of equipment needing upgrades	Good	Good	Good	Do Now
	R23	Replace old or poorly designed pumps to reduce potential for overheating	Good	Good	Poor	Continue Evaluating
	R24	Update annual reviews to go beyond corrective maintenance and include climate change considerations	Good	Fair	Fair	Continue Evaluating
Workforce	R25	Adjust schedules and times to account for more climate delays	Good	Good	Good	Do Now
Crude Oil Transportation Network	R26	Add additional distribution locations	Good	Good	Poor	Do Now
	R27	Bayou Choctaw and West Hackberry - Add options to move oil by rail and/or truck	Poor	Poor	Poor	Remove from Consideration
Crude Oil Inventory	R28	Review and update water monitoring temperatures with climate change considerations and add trending	Good	Good	Good	Do Now

4.4. SPR's Resilience Evaluation Narrative Summary

The remainder of Section 4 provides narrative description about the resilience options that were identified for each of the sensitivities grouped by key resource. Each section includes a table that describes the resilience options, their scores using the evaluation criteria, and the recommended approach.

4.5. Cross-Cutting

Several cross-cutting resilience options emerged during the assessment that could mitigate multiple sensitivities and serve as overarching mechanisms to address climate change.

Table 11. Cross-Cutting Resilience Options

	No.	Resilience Options	LE2	Effectiveness	Feasibility	Cost	Approach
	R1	Integrate climate change considerations into future planning and operations	Y	Good	Good	Good	Do Now
	R2	Provide more flexible degassing capabilities (i.e., portable degassing equipment)	Y	Good	Good	Fair	Do Now
	R3	Identify, evaluate, and consider elevating at-risk equipment (e.g., pumps)	Y	Good	Good	Fair	Do Now
	R4	Review hurricane after-action reports and identify resilience options that could mitigate impacts for climate change	N	Fair	Fair	Good	Continue Evaluating

4.5.1. *Cross-cutting resilience options to* do now

Three resilience options were assigned *do now*:

- R1: Integrate climate considerations into future planning operations
- R2: Provide more flexible degassing capabilities (i.e., portable degassing equipment)
- R3: Identify, evaluate, and consider elevating at-risk equipment (e.g., pumps).

These resilience options address potential impacts related to the key resources of water, specialized equipment, physical space, command and control system, and crude oil inventory. All three options are also being considered as part of LE2.

R1: Integrate climate considerations into future planning operations
Establishing an ongoing process to institutionalize consideration of climate changes into current operations and planning emerged as a theme in many of the project team discussions. Conditions will change as the understanding of climate change improves and as policy preferences, SPR objectives, and climate events occur. Periodic review and updates will ensure that the SPR continuously practices adaptive management as it pursues resilience and integrates information into preparedness efforts.

Independent research has also shown that other federal agencies have evaluated and recommended integrating climate considerations into current practices. For example, according to the U.S. Department of Defense 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."[17]

- Effectiveness: *Good*
  Changes that result from these considerations are expected to be effective. As climate and climate change projections continue to evolve, this action will provide additional catalysts and targeted mechanisms through which the SPR can integrate climate considerations without developing a separate decision-making process.

- Feasibility: *Good*
  Technically and organizationally this option is quite feasible, as the SPR already reviews and updates operating procedures, health and safety plans, design criteria, etc. at regular intervals; adding climate change considerations should be straightforward. One potential barrier is that current climate projections must be considered and assessed. The SPR does not currently have this expertise in-house. However, relationships with climate experts developed as part of this assessment may be used in the future to support updates.

- Cost: *Good*
  Outside of the potential costs to subcontract with external climate experts to assess and update climate stressors, the direct cost of integrating climate considerations into current and future operations and planning activities is minimal. Action items that stem 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 selection of new equipment purchases. However, taking a proactive approach can lead to long-term cost savings because the SPR may purchase more effective and longer lasting equipment.

R2: Provide more flexible degassing capabilities

- Effectiveness: *Good*
  Expanding capacity of portable degassing equipment would enable SPR to more efficiently and effectively address degassing needs at the sites.

- Feasibility: *Good*
  Technically and organizationally this option is feasible and is already being considered as part of LE2.

- Cost: *Fair*
  New degassing equipment would be moderately expensive, requiring substantial initial investment. However, the investment in the new equipment could potentially decrease operating costs in the long-run.

[17] United States Department of Defense, *2014 Climate Change Adaptation Roadmap*, 2014. http://ppec.asme.org/wp-content/uploads/2014/10/CCARprint.pdf.

R3: Identify, evaluate, and consider elevating at-risk equipment (e.g., pumps)

- Effectiveness: *Good*
  Elevating at-risk equipment would minimize or eliminate equipment malfunction or damage due to flooding and corrosion.

- Feasibility: *Good*
  Technically and organizationally this option is feasible and is already being considered as part of LE2.

- Cost: *Fair*
  Depending on the volume and type of equipment identified for potential design modifications, the cost could be substantial. However, the identification and evaluation of the equipment needing to be elevated would not require a substantial investment other than staff time. Some of the equipment is already being considered as part of LE2.

4.5.2. *Cross-cutting resilience options to* continue evaluating

One resilience option, R4: *Review hurricane after-action reports and identify resilience options that could mitigate impacts for climate change,* was assigned *continue evaluating*.

This resilience option addresses potential impacts related to the key resource of physical space and specialized equipment.

R4: Review hurricane after-action reports and identify resilience options that could mitigate impacts for climate change.

- Effectiveness: *Fair*
  During hurricanes events sites can be impacted by wind, flooding, and other damage. The after-action hurricane reports provide good suggestions for hardening assets and infrastructure to similar-type events. Not all the actions suggested in the reports have been implemented so a review of the reports would help identify new mitigation steps the SPR could take.

- Feasibility: *Fair*
  This option is technically feasible; however, organizationally it will require staff time and expertise to review the documents and evaluate them. Many of the suggested improvements in the hurricane reports were previously not selected for implementation.

- Cost: *Good*
  The cost to review the reports and look for improvements that would support climate change resilience is low because it does not rely on expensive infrastructure or equipment investments.

4.6. Water

Table 12. Water Resilience Options

	No.	Resilience Options	LE2	Effectiveness	Feasibility	Cost	Approach
	R5	Review the ongoing sediment study (Bryan Mound) and integrate climate change considerations	N	Fair	Good	Good	Continue Evaluating
	R6	Continue to evaluate options for maintaining cooling capacity as water temps increase (i.e., resize heat exchangers)	Y	Fair	Fair	Fair	Continue Evaluating
	R7	Add ILA water wells (like at West Hackberry) to ensure fresh water for process pump flushing	Y	Good	Good	Fair	Continue Evaluating
	R8	Add tanks or covers to brine ponds (specifically at Bayou Choctaw) to protect from rainwater dilution	Y	Good	Fair	Poor	Continue Evaluating

4.6.1. Water-related resilience options to continue evaluating

Four resilience options related to water were assigned as *continue evaluating*. These included:

- R5: Review the ongoing sediment study (Bryan Mound) and integrate climate change considerations
- R6: Continue to evaluate options for maintaining cooling capacity as water temps increase (i.e., resize heat exchangers)
- R7: Add ILA water wells (like at West Hackberry) to ensure fresh water for process pump flushing
- R8: Add tanks or covers to brine ponds (specifically at Bayou Choctaw) to protect from rainwater dilution.

These resilience options propose a range of actions from relatively low cost options such as reviewing existing studies to look for opportunities to integrate climate change information from this assessment to more substantial and costly infrastructure upgrades such as adding ILA wells for ground water cooling or tanks to protect brine quality. These resilience options impacted sensitivities S3: *Ability to maintain necessary raw water quality and quantity for drawdown*, S4: *Ability to conduct process pump seal flushing and bearing cooling*, S5: *Increased build-up of silt in raw water systems,* S6: *Ability to maintain necessary raw water quality for disposal of brine to the Gulf of Mexico (i.e., 95%+ salinity, pH levels, etc.)*, and S7: *Ability to access raw water for flushing of brine strings during fill operations.*

R5: Review the ongoing sediment study (Bryan Mound) and integrate climate change considerations

- Effectiveness: *Fair*

Reviewing the Bryan Mound sediment study and integrating climate change considerations would reduce—but not eliminate—water-related sensitivities associated with sediment buildup in raw water systems. Action items with targeted measures identified in doing the review, if implemented, would further reduce the potential impacts.

- Feasibility: *Good*
  Reviewing the Bryan Mound sediment study would be technically and organizationally feasible. Even without the pressures of climate change, the Bryan Mound sediment study is investigating options for monitoring and making improvements that benefit the SPR operations.

- Cost: *Good*
  The cost to review a study and integrate climate change considerations is low because it does not rely on expensive infrastructure or equipment investments.

R6: Continue to evaluate options for maintaining cooling capacity as water temps increase (i.e., resize heat exchangers)

- Effectiveness: *Fair*
  As water temperatures increase, having additional options for maintaining cooling capacity will reduce—but may not necessarily eliminate—the water-related sensitivities associated with the ability to maintain water quality for drawdown and process pump flushing activities to meet statutory oil requirements. Action items identified in the evaluations, if implemented would further reduce the potential impacts.

- Feasibility: *Fair*
  The feasibility of this option is uncertain and depends on the application. Detailed evaluation of the various options may require external support.

- Cost: *Fair*
  The cost of this action would vary depending on the timing and various options investigated. At the low end, costs to continue to monitor and look for opportunities for improvement are marginal. At the high end, detailed engineering analysis may require more research and possible external technical expertise.

R7: Add ILA water wells (like at West Hackberry) to ensure fresh water for process pump flushing

- Effectiveness: *Good*
  Adding ILA water wells would provide backup options for raw water for pump flushing.

- Feasibility: *Good*
  West Hackberry already has an ILA well for process pump flushing. This is technically and organizationally feasible at the other SPR locations.

- Cost: *Fair*
  The cost to install ILA wells is relatively moderate. Prioritizing the sites and installing over time would reduce the initial cost.

R8: Add tanks or covers to brine ponds (specifically at Bayou Choctaw) to protect from rainwater dilution

- Effectiveness: *Good*
  Adding tanks or covers to existing brine ponds will reduce substantially or eliminate potential impacts to the ability to maintain necessary water quality for disposing of brine to brine disposal wells.

- Feasibility: *Fair*
  Covers have not been used for brine ponds at the SPR. Design, construction, and operation of covers have not previously been tested and wind resistance requirements present engineering challenges. Brine tanks have worked well with brine disposal wells at West Hackberry demonstrating good feasibility if selected as the preferred solution.

- Cost: *Poor*
  Depending on the solution the costs to cover the brine ponds or add tanks could be high.

4.7. Power

Table 13. Power Resilience Options

	No.	Resilience Options	LE2	Effectiveness	Feasibility	Cost	Approach
	R9	Increase RPX pumping capabilities	N	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)	N	Fair	Fair	Fair	Continue Evaluating
	R11	Monitor and continue to investigate potential for solar PV systems as efficiency of panels improves	N	Good	Poor	Poor	Continue Evaluating
	R12	Add new generators designed to use crude oil in storage (at SPR) as fuel to meet drawdown requirements	N	Good	Poor	Poor	Remove from Consideration
	R13	Install a non-fossil fuel option (battery) to provide an alternative source for recovery pumps if diesel is not available (backup only, not drawdown)	N	Poor	Poor	Poor	Remove from Consideration
	R14	Reevaluate the feasibility of dual power feeds (like at Big Hill)	N	Poor	Fair	Poor	Remove from Consideration

4.7.1. Power-related resilience options to continue evaluating

Three resilience options related to power sensitivities were assigned *continue evaluating*:

- R9: Increase RPX pumping capabilities
- R10: Add diesel pumps as backups at intake structures to have a non-power drawdown option (meets practical demand only, not statutory)
- R11: Monitor and continue to investigate potential for solar PV systems as efficiency of panels improves.

These resilience options all address the sensitivity S8: *Reliance on a single supplier of commercial power lines to each of the sites.*

R9: Increase RPX pumping capabilities

- Effectiveness: *Good*
  Increasing the number of RPX pumps will provide the SPR with the ability to deliver more crude oil from more sites if electrically driven pumping operations are lost due to a storm or other event. The demand for crude is typically high after hurricanes, which damage power lines and disrupt commercial oil production and transmission (especially commercial offshore production).

- Feasibility: *Fair*
  The technology is well demonstrated at the SPR and is technically feasible. However, in the aftermath of hurricanes, the most likely event for this need, the ability to transport RPX pumps may be hindered by lack of access to the sites due to flooding. By the time the equipment is brought on site, power may be restored, eliminating the need for this option.

- Cost: *Fair*
  This is an expensive option. Lead time is needed to design and acquire the mobile pump/generators, and cost is incurred for maintaining, testing, exercising, and transporting this equipment.

R10: Add diesel pumps as backups at intake structures to have a non-power drawdown option (meets practical demand only, not statutory)

- Effectiveness: *Fair*
  Adding diesel pumps as backups at intake structures would allow for a non-power drawdown option. However, it would not be possible to install enough diesel pumps to meet drawdown capabilities which would inhibit the SPR from meeting some of its key objectives.

- Feasibility: *Fair*
  This option is technically feasible but would require significant organizational support, which could be difficult to obtain.

- Cost: *Fair*
  There would be some initial costs to implementing this resilience option through the purchase of additional diesel pumps.

R11: Monitor and continue to investigate potential for solar PV systems as the efficiency of panels improves

- Effectiveness: *Good*
  This option would provide an alternate, self-sufficient power source onsite, supporting climate change resilience efforts and potentially reducing SPR's fossil-fuel energy use and electricity costs in the long-run.

- Feasibility: *Poor*
  At present, the size and number of solar panels required would not be technically feasible, requiring too much land coverage and providing too little power. However, the solar industry is continually making improvements and at some point the efficiency of solar panels will likely increase, improving the feasibility in the future.

- Cost: *Poor*
  The cost to purchase and install solar panels to meet even a portion of SPR's power requirements is substantial. As efficiency of the solar panels improves, the costs for this option will improve as well.

4.7.2. *Power-related resilience options to* remove from consideration

Three resilience options were assigned *remove from consideration*:

- R12: Add new generators designed to use crude oil in storage (at SPR) as fuel to meet drawdown requirements
- R13: Install non-fossil fuel option (battery) to provide an alternative source for recovery pumps if diesel is not available (backup only, not drawdown)
- R14: Reevaluate the feasibility of dual power feeds (like at Big Hill).

These resilience options all address the potential impacts from sensitivity S8: *Reliance on a single supplier of commercial power lines to each of the sites.*

R12: Add new generators designed to use crude oil in storage (at SPR) as fuel to meet drawdown requirements

- Effectiveness: *Good*
  Being able to utilize the fuel that is already on site would be very effective in providing a backup supply of electricity to all the sites.

- Feasibility: *Poor*
  The SPR has previously inquired about the possibility of obtaining diesel generators able to use crude oil as fuel. In that inquiry, the SPR could not find manufacturers to sell those types of generators. It is unclear if this technology is currently available.

- Cost: *Poor*
  In order to meet drawdown requirements, the SPR would need to purchase a large number of backup generators. This would be extraordinarily expensive as the power requirements for drawdown are extensive.

R13: Install non-fossil fuel option (battery) to provide an alternative source for recovery pumps if diesel is not available (backup only, not drawdown)

- Effectiveness: *Poor*
  Even if a battery could be sized to meet temporary needs for the recovery pumps

this does not reduce the impacts from the sensitivity of a single power supplier to meet drawdown activities.

- Feasibility: *Poor*
  The SPR's electricity requirements are so substantial that a battery would need to be enormous to power all drawdown activities. The technical and organizational requirements of this resilience option are not currently feasible.

- Cost: *Poor*
  Because the battery would need to be extremely large to meet the SPR's electricity needs, the cost for the battery would be significant.

R14: Reevaluate the feasibility of dual power feeds (like at Big Hill)

- Effectiveness: *Poor*
  Even if SPR could implement dual power feeds, this option would not reduce the impacts of reliance on a single supplier for electricity.

- Feasibility: *Fair*
  The SPR already has a dual power feed at Big Hill so it is technically feasible. However, organizationally there would be little support for this option.

- Cost: *Poor*
  The cost to implement dual power feeds is substantial.

4.8. Command and Control System

Table 14. Command and Control System Resilience Options

	No.	Resilience Options	LE2	Effectiveness	Feasibility	Cost	Approach
	R15	Identify locations where an upgrade to sea-worthy marine-rated cable would be appropriate	N	Fair	Fair	Poor	Remove from Consideration

4.8.1. *Command and control system-related resilience options to* continue evaluating

One resilience option, R15: *Identify locations where an upgrade to sea-worthy, marine-rated cable would be appropriate*, was assigned *remove from consideration*.

This resilience option specifically impacts sensitivities S9: *Adequate power required to run the DCS* and S10: *Command center, single facility for control of pumping stations*. Upgrading to marine-rated cabling specifically protects any cabling needed for the DCS in the command center from the possibility of impacts of flooding from rain events and storm surge.

R15: Identify locations where an upgrade to sea-worthy, marine-rated cable would be appropriate

- Effectiveness: *Fair*
  Replacing cable coverings with marine-rated cable might be able to further protect cabling from water and flooding events at the SPR. However, it is not clear that there are any advantages beyond the cables that the SPR already uses.

- Feasibility: *Fair*
  Upgrading cabling would require further discussion about the cable covering currently in place at the SPR and many changes. There is not any organizational support that could be garnered for this possible solution. Technically this resilience option is possible to execute.

- Cost: *Poor*
  The replacement of cabling across the SPR sites would have a high monetary cost.

4.9. Physical Space

Table 15. Physical Space Resilience Options

	No.	Resilience Options	LE2	Effectiveness	Feasibility	Cost	Approach
	R16	Install more-efficient HVAC systems (variable fans, etc.) and consider use of ground water (well) for building cooling to reduce electricity demands	N	Good	Good	Good	Do Now
	R17	West Hackberry - Monitor and assess potential involvement in LA coastal plan hydrologic restoration projects	N	Good	Good	Good	Do Now
	R18	Add "check for mold" to the Organizational Assessments checklist	N	Good	Good	Good	Do Now
	R19	Identify, evaluate, and consider elevating or reinforcing at-risk buildings/site facilities	Y	Good	Good	Fair	Do Now
	R20	Have Sandia National Laboratories conduct an in-depth subsidence projection for the sites	N	Good	Good	Good	Do Now

4.9.1. Physical space-related resilience options to do now

Five resilience options were assigned *do now*:

- R16: Install more-efficient HVAC systems (variable fans, etc.) and consider use of ground water (well) for building cooling to reduce electricity demands
- R17: West Hackberry - Monitor and assess potential involvement in LA coastal plan hydrologic restoration projects
- R18: Add "check for mold" to the Organizational Assessments checklist
- R19: Identify, evaluate, and consider elevating or reinforcing at-risk buildings/site facilities
- R20: Have Sandia National Laboratories conduct an in-depth subsidence projection for the sites.

These resilience options specifically impact sensitivities S1: *Ability to respond if a weather event impacts more than one site at the same time*, S11: *Sites elevation and proximity to the ocean* and S12: *Susceptibility to mold in buildings*. One of these options, R19, is already being considered in LE2. All these resilience options build resilience in the SPR's physical infrastructure and assets to create facilities more resistant to mold and flooding concerns.

R16: Install more-efficient HVAC systems (variable fans, etc.) and consider use of ground water (well) for building cooling to reduce electricity demands

- Effectiveness: *Good*
  Installing more efficient HVAC systems would have a number of benefits to physical space and would also impact other resources such as water and power. By ensuring HVAC systems are more efficient and properly sized, the SPR can reduce the likelihood of mold development in facilities while reducing energy consumption and improving overall building air quality.

- Feasibility: *Good*
  A number of facilities require upgrades to HVAC systems due to age and functionality. By focusing on replacing these systems first and then eventually replacing other systems throughout the SPR, this option is both technically and organizationally feasible.

- Cost: *Good*
  Although there would be some up-front costs to replacing HVAC equipment, these projects also have the potential to save the SPR money on utility costs and overall building management and mitigation costs, as well as avoiding costs associated with recordable illnesses due to mold.

R17: West Hackberry - Monitor and assess potential involvement in L.A. coastal plan hydrologic restoration projects

- Effectiveness: *Good*
  The Louisiana Coastal Plan is moving forward with hydrologic restoration projects along the Louisiana coast. The SPR should remain aware of ongoing projects and how they will impact the SPR and make decisions in the future about whether or how to engage with these projects.

- Feasibility: *Good*
  These projects are already moving forward.

- Cost: *Good*
  These projects are paid for through state and federal funding and do not cost anything to the SPR directly.

R18: Add "check for mold" to the Organizational Assessments checklist

- Effectiveness: *Good*
  Proactively addressing mold concerns can ensure the SPR has the capacity to intervene in problem buildings and facilities before mold becomes a large concern requiring a larger initiative.

- Feasibility: *Good*

Adding this check onto an existing checklist makes this a feasible option. In addition, the SPR has recently had issues with mold in some facilities so this check would have organizational support.

- Cost: *Good*
  This would add minimal additional effort to the Organizational Assessments that already occur and therefore only a small amount of additional staff time would be required. Additional costs for this effort would be minimal and it should provide long-term cost savings.

R19: Identify, evaluate, and consider elevating or reinforcing at-risk buildings/site facilities

- Effectiveness: *Good*
  By identifying and evaluating the best course forward to build resilience in facilities, the SPR can effectively respond to flooding risks from rain events, sea level rise, and other weather and climate impacts.

- Feasibility: *Good*
  This option is already being considered in LE2 so it has organizational feasibility. In addition, this is a first-step option focused on identifying and evaluating what facilities require elevation or reinforcements, which is a technically feasible solution.

- Cost: *Fair*
  There may be some costs associated with identifying the risks in these facilities and taking the next steps to implement any changes could have high monetary costs. In creating a prioritized list of facilities to address the SPR can effectively allocate future resources for these projects.

R20: Have Sandia National Laboratories conduct an in-depth subsidence projection for the sites

- Effectiveness: *Good*
  With more accurate projections of possible subsidence at the sites the SPR can better prepare for impacts to site facilities and caverns. Having advanced notice will allow the SPR to be more prepared and more effective in responding to any subsidence situations.

- Feasibility: *Good*
  Sandia National Laboratories has worked with the SPR in the past to develop information about subsidence at each of the sites.

- Cost: Good
  There will be some costs associated with the creation of these projections and evaluations. However, this will not require any new data acquisition, only analysis. Sandia has been the entity reviewing the data for decades.

4.10. Specialized Equipment

Table 16. Specialized Equipment Resilience Options

	No.	Resilience Options	LE2	Effectiveness	Feasibility	Cost	Approach
	R21	Bryan Mound - Review the study on tanks and integrate climate change information	Y	Fair	Good	Fair	Do Now
	R22	Prioritize list of equipment needing upgrades	Y	Good	Good	Good	Do Now
	R23	Replace old or poorly designed pumps to reduce potential for overheating	Y	Good	Good	Poor	Continue Evaluating
	R24	Update annual reviews to go beyond corrective maintenance and include climate change considerations	N	Good	Fair	Fair	Continue Evaluating

4.10.1. Specialized equipment-related resilience options to do now

Two resilience options R21: *Bryan Mound - Review study on tanks and integrate climate change information* and R22: *Prioritize list of equipment needing upgrades* were assigned *do now*. These resilience options specifically impact sensitivity S13: *Large amount of old and fatigued equipment (70% past lifespan design).* Resilience option R21 suggests that the study on brine tanks at Bryan Mound should be reviewed and updated with climate-related information from this assessment, if not already integrated. Resilience option R22 suggests developing a prioritized list of specialized equipment in need of upgrades. Both options are currently being considered in the LE2.

R21: Bryan Mound - Review study on tanks and integrate climate change information

- Effectiveness: *Fair*
  Reviewing the study on brine tank design and integrating climate change considerations would reduce-- but not eliminate—specialized-equipment sensitivities associated with storing brine water for disposal. Action items identified in doing the review, if implemented, would further reduce the potential impacts.

- Feasibility: *Good*
  This resilience option is already a consideration in the LE2 process and thus already has organizational support. Technically, this task would not be difficult to implement since a study on the tanks is already underway. The SPR has the technical capabilities to complete this task.

- Cost: *Fair*
  The financial cost of this resilience option is relatively minimal. It will involve some

staff time to review and integrate information and it could require additional analysis if modifications to tank design, materials, or location are identified.

R22: Prioritize list of equipment needing upgrades

- Effectiveness: *Good*
  This resilience option would effectively support the SPR in addressing the large amount of old and fatigued equipment by prioritizing future upgrades. With a prioritized list, the SPR can effectively allocate resources to replace the most critical equipment first in order to both replace equipment past its lifespan design as well as install new equipment better able to withstand risks from a changing climate.

- Feasibility: *Good*
  This resilience option is already a consideration in the LE2 process and thus already has organizational support. Technically this is a task that would benefit areas beyond climate change risks and would not be difficult to implement.

- Cost: *Good*
  The cost of this resilience option is minimal. It may involve some initial staff time to develop but once the prioritized list is created it can be updated on a regular basis with only a small impact to staff.

4.10.2. Specialized equipment-related resilience options to 'continue evaluating'

Two resilience options related to specialized equipment were assigned *continue evaluating*. These include:

- R23: Replace old or poorly designed pumps to reduce potential for overheating
- R24: Update annual reviews to go beyond corrective maintenance and include climate change considerations.

These resilience options propose the replacement of old and poorly designed pumps throughout the SPR system of equipment, specifically focused on pumps required for process pumping. In addition, annual reviews conducted on specialized equipment could include climate change considerations and go above and beyond current corrective maintenance practices. These resilience options impact sensitivity S13: *Large amount of old and fatigued equipment (70% past lifespan design).*

R23: Replace old or poorly designed pumps to reduce potential for overheating

- Effectiveness: *Good*
  By replacing old and poorly designed pumps the possibility of overheating would greatly decrease, reducing the SPR's sensitivity and risk to increases in air temperature and other climate changes. This would be effective in ensuring the SPR remained on the cutting edge of specialized equipment.

- Feasibility: *Good*
  Since pumps are an essential part of meeting drawdown requirements, replacing pumps would be both technically and organizationally feasible. There are already some parts of LE2 that plan to address this resilience option and replace some pumps and equipment.

- Cost: *Poor*
  Replacement of these pumps would be extremely expensive.

R24: Update annual reviews to go beyond corrective maintenance and include climate change considerations

- Effectiveness: *Good*
  Including considerations in annual reviews that go above and beyond corrective action and address climate change considerations would help to mitigate risks of equipment specifically impacted by weather and weather events.

- Feasibility: *Fair*
  DOE makes the final decisions about what is included in the annual reviews. It is not clear how organizationally feasible it currently is to ask DOE to consider adding climate change considerations into these annual review processes. This resilience option would require some education and negotiation.

- Cost: *Fair*
  In order to adjust the annual review process, some costs may be required.

4.11. Workforce

Table 17. Workforce Resilience Options

	No.	Resilience Options	LE2	Effectiveness	Feasibility	Cost	Approach
	R25	Adjust schedules and times to account for more delays	Y	Good	Good	Good	Do Now

4.11.1. Workforce-related resilience options to do now

One resilience option, R25: *Adjust schedules and times to account for more delays,* was assigned *do now*. This resilience option specifically impacts sensitivity S15: *Outdoor workforce exposed to elements*. In order to address increased delays that may impact outdoor work such as heat, flooding, heavy rain, or storm events, it is recommended that the SPR build in these delays to the scheduling process. By allowing for delays in original schedules the SPR can ensure safe working conditions for outdoor workforce, have realistic expectations for project completion, and meet mission requirements. This option is currently being considered in the LE2.

R25: Adjust schedules and times to account for more delays

- Effectiveness: *Good*
  This resilience option would be effective in ensuring the SPR's outdoor workforce has adequate time and is safely completing outdoor activities. Increasing schedule times and accounting for known and possible delays will ensure that the SPR both meets mission objectives and expectations while maintaining a strong workforce.

- Feasibility: *Good*
  The SPR is already incorporating this resilience option into LE2 in order to address potential heat stress with workers and improve expectations and future planning.

- Cost: *Good*
  This resilience option is low to no cost and could save money by ensuring that

adequate time periods and delays are planned for in projects therefore reducing time spent behind schedule.

4.12. Crude Oil Transportation Network

Table 18. Crude Oil Transportation Network Resilience Options

No.	Resilience Options	LE2	Effectiveness	Feasibility	Cost	Approach
R26	Add additional distribution locations	Y	Good	Good	Poor	Do Now
R27	Bayou Choctaw and West Hackberry - Add options to move oil by rail and/or truck	N	Poor	Poor	Poor	Remove from Consideration

4.12.1. Crude oil transportation network-related resilience options to do now

One resilience option, R26: *Add additional distribution locations*, was a crude oil transportation network-related option assigned *do now*. This resilience option specifically impacts sensitivities S1: *Ability to respond if a weather event impacts more than one site at the same time* and S16: *Availability of distribution systems, pipelines, and terminals in the region that SPR uses to meet mission requirements*. By adding additional distribution locations for moving crude oil the SPR can be more resistant to climate changes that impact the crude oil transportation network. This option is already being considered in LE2.

R26: Add additional distribution locations

- Effectiveness: *Good*
  Adding additional distribution locations means that in a storm or weather event the SPR has more choices about where and how to move crude oil to meet mission objectives.

- Feasibility: *Good*
  The SPR is already incorporating this resilience option into LE2 and therefore it is an organizationally and technically feasible option.

- Cost: *Poor*
  This resilience option has a high cost associated with it. Adding new distribution locations means additional equipment and infrastructure which come with a high monetary price.

4.12.2. Crude oil transportation network-related resilience options to remove from consideration

One resilience option, R27: *Bayou Choctaw and West Hackberry - Add options to move oil by rail and/or truck*, related to crude oil transportation network was assigned *remove from consideration*. This resilience option specifically impacts sensitivities S1: *Ability to respond if a weather event impacts more than one site at the same time*, S2: *Ability to meet statutory oil quantity requirements*, and S16: *Availability of distribution systems, pipelines, and terminals in the region that SPR uses to meet mission requirements*. The SPR would increase resilience by adding a different option to move crude oil in addition to pipeline networks. However, this resilience option would require an entirely new infrastructure to be connected to the sites and only Bayou Choctaw and West Hackberry have the capacity and location to make this resilience option viable.

R27: Bayou Choctaw and West Hackberry - Add options to move oil by rail and/or truck

- Effectiveness: *Poor*
  Although trucking or rail would allow the SPR to move oil in a different way, it is not clear how effective these options would be overall. If a weather event or climactic change made moving oil by pipeline not possible there's a low likelihood that moving oil by rail or truck would be a more feasible option because it would also require intact infrastructure.

- Feasibility: *Poor*
  This option is only feasible at two sites, Bayou Choctaw and West Hackberry. Technically this resilience option would involve a great deal of infrastructure development, and negotiation that may not even be possible in these rural areas. Additionally, the project team did not believe this would be an organizationally feasible option because this is such a large project to undertake.

- Cost: *Poor*
  This resilience option has a substantial cost associated with it. Adding in a rail system or building out roadways to handle large truck loads of crude oil would be extremely expensive.

4.13. Crude Oil Inventory

Table 19. Crude Oil Inventory Resilience Options

	No.	Resilience Options	LE2	Effectiveness	Feasibility	Cost	Approach
	R28	Review and update water monitoring temperatures with climate change considerations and add trending	**N**	Good	Good	Good	Do Now

4.13.1. Crude oil inventory-related resilience options to do now

One resilience option related to crude oil inventory, R28: *Review and update water monitoring temperatures with climate change considerations and add trending*, was assigned *do now*. This resilience option is directly related to sensitivities S2: *Ability to meet statutory oil quantity requirements* and S17: *Ability to maintain oil temperature (i.e., increasing raw water temperatures affecting crude oil cooling capability)*.

In order to cool down crude oil inventory for transportation the SPR requires certain water temperatures from the raw water system. By monitoring and trending information about water temperatures, the SPR can be better prepared to address crude oil temperature concerns as they arise.

R28: Review and update water monitoring temperatures with climate change considerations and add trending

- Effectiveness: *Good*

Trending water temperatures ensures the SPR is aware and able to proactively address any increases in water temperatures that may occur due to climate change. This enables a response from the SPR to address these concerns before water is required to cool down crude oil ready to be transported in order to meet mission objectives.

- Feasibility: *Good*
  The SPR already takes some water measurements so adding information and trending that information would be both technically and organizationally feasible.

- Cost: *Good*
  This resilience option would only cost a small amount of staff time in both obtaining temperature information and trending the data.

Table 20. SPR's Scored Resilience Options by Key Resource and Associated Sensitivities

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

Key Resource	No. †		Resilience Options and Associated Sensitivities	LE2	Approach
Multiple	**R1**		**Integrate climate change considerations into future planning and operations**		
		S2	Ability to meet statutory oil quantity requirements	Y	Do Now
		S3	Ability to maintain necessary raw water quality and quantity for drawdown		
		S5	Increased build-up of silt in raw water systems		
		S12	Susceptibility to mold in buildings		
		S13	Large amount of old and fatigued equipment (70% past lifespan design)		
		S14	Wellhead exposure to weather		
		S17	Ability to maintain oil temperature (i.e., increasing raw water temperatures affecting crude oil cooling capability)		
	R2		**Provide more flexible degassing capabilities (i.e., portable degassing equipment)**		
		S2	Ability to meet statutory oil quantity requirements	Y	Do Now
		S17	Ability to maintain oil temperature (i.e., increasing raw water temperatures affecting crude oil cooling capability)		
	R3		**Identify, evaluate, and consider elevating at-risk equipment (e.g., pumps)**		
		S1	Ability to respond if a weather event impacts more than one site at the same time	Y	Do Now
		S4	Ability to conduct process pump seal flushing and bearing cooling		
		S9	Adequate power required to run the DCS		
		S10	Command center, single facility for control of pumping stations		
		S11	Sites elevation and proximity to the ocean		
		S13	Large amount of old and fatigued equipment (70% past lifespan design)		
	R4		**Review hurricane after-action reports and identify resilience options that could mitigate impacts for climate change**		
		S1	Ability to respond if a weather event impacts more than one site at the same time	N	Continue Evaluating
		S11	Sites elevation and proximity to the ocean		
		S12	Susceptibility to mold in buildings		
		S14	Wellhead exposure to weather		
Water	**R5**		**Review the ongoing sediment study (Bryan Mound) and integrate climate change considerations**		
		S5	Increased build-up of silt in raw water systems	N	Continue Evaluating
		S7	Ability to access raw water for flushing of brine strings during fill operations		
	R6		**Continue to evaluate options for maintaining cooling capacity as water temps increase (i.e., resize heat exchangers)**		

		S2	Ability to meet statutory oil quantity requirements	Y	Continue Evaluating
		S3	Ability to maintain necessary raw water quality and quantity for drawdown		
		S4	Ability to conduct process pump seal flushing and bearing cooling		
	R7	**Add ILA water wells (like at West Hackberry) to ensure fresh water for process pump flushing**			
		S4	Ability to conduct process pump seal flushing and bearing cooling	Y	Continue Evaluating
		S7	Ability to access raw water for flushing of brine strings during fill operations		
	R8	**Add tanks or covers to brine ponds (specifically at Bayou Choctaw) to protect from rainwater dilution**			
		S6	Ability to maintain necessary raw water quality for disposal of brine to the Gulf of Mexico (i.e., 95%+ salinity, pH levels, etc.)	Y	Continue Evaluating
Power	**R9**	**Increase RPX pumping capabilities**			
		S8	Reliance on a single supplier of commercial power lines to each of the sites	N	Continue Evaluating
	R10	**Add diesel pumps as backups at intake structures to have a non-power drawdown option (meets practical demand only, not statutory)**			
		S8	Reliance on a single supplier of commercial power lines to each of the sites	N	Continue Evaluating
	R11	**Monitor and continue to investigate potential for solar PV systems as efficiency of panels improves**			
		S8	Reliance on a single supplier of commercial power lines to each of the sites	N	Continue Evaluating
	R12	**Add new generators designed to use crude oil in storage (at SPR) as fuel to meet drawdown requirements**			
		S8	Reliance on a single supplier of commercial power lines to each of the sites	N	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)**			
		S8	Reliance on a single supplier of commercial power lines to each of the sites	N	Remove from Consideration
	R14	**Reevaluate the feasibility of dual power feeds (like at Big Hill)**			
		S8	Reliance on a single supplier of commercial power lines to each of the sites	N	Remove from Consideration
Command and Control System	**R15**	**Identify locations where an upgrade to seaworthy, marine-rated cable would be appropriate**			
		S9	Adequate power required to run the DCS	N	Remove from Consideration
		S10	Command center, single facility for control of pumping stations		

Physical Space	**R16**	**Install more-efficient HVAC systems (variable fans, etc.) and consider use of ground water (well) for building cooling to reduce electricity demands**			
		S12	Susceptibility to mold in buildings	**N**	Do Now
	R17	**West Hackberry - Monitor and assess potential involvement in LA coastal plan hydrologic restoration projects**			
		S11	Sites elevation and proximity to the ocean	**N**	Do Now
	R18	**Add "check for mold" to the Organizational Assessments checklist**			
		S12	Susceptibility to mold in buildings	**N**	Do Now
	R19	**Identify, evaluate, and consider elevating or reinforcing at-risk buildings/site facilities**			
		S1	Ability to respond if a weather event impacts more than one site at the same time	**Y**	Do Now
		S11	Sites elevation and proximity to the ocean		
		S12	Susceptibility to mold in buildings		
	R20	**Have Sandia National Laboratories conduct an in-depth subsidence projection for the sites**			
		S2	Ability to meet statutory oil quantity requirements	**N**	Do Now
		S11	Sites elevation and proximity to the ocean		
Specialized Equipment	**R21**	**Bryan Mound - Review study on brine tanks and integrate climate change information**			
		S13	Large amount of old and fatigued equipment (70% past lifespan design)	**Y**	Do Now
	R22	**Prioritize list of equipment needing upgrades**			
		S13	Large amount of old and fatigued equipment (70% past lifespan design)	**Y**	Do Now
	R23	**Replace old or poorly designed pumps to reduce potential for overheating**			
		S13	Large amount of old and fatigued equipment (70% past lifespan design)	**Y**	Continue Evaluating
	R24	**Update annual reviews to go beyond corrective maintenance and include climate change considerations**			
		S13	Large amount of old and fatigued equipment (70% past lifespan design)	**N**	Continue Evaluating
Workforce	**R25**	**Adjust schedules and times to account for more climate delays**			
		S15	Outdoor workforce exposed to elements	**Y**	Do Now
Crude Oil Transportation Network	**R26**	**Add additional distribution locations**			
		S1	Ability to respond if a weather event impacts more than one site at the same time	**Y**	Do Now
		S16	Availability of distribution systems, pipelines, and terminals in the region that SPR uses to meet mission requirements		
	R27	**Bayou Choctaw and West Hackberry - Add options to move oil by rail and/or truck**			

		S1	Ability to respond if a weather event impacts more than one site at the same time	**N**	Remove from Consideration
		S2	Ability to meet statutory oil quantity requirements		
		S16	Availability of distribution systems, pipelines, and terminals in the region that SPR uses to meet mission requirements		
Crude Oil Inventory	**R28**	**Review and update water monitoring temperatures with climate change considerations and add trending**			
		S2	Ability to meet statutory oil quantity requirements	**N**	Do Now
		S17	Ability to maintain oil temperature (i.e., increasing raw water temperatures affecting crude oil cooling capability)		

[†]For ease of reference, sensitivities are numbered S1-S17 and resilience options are numbered R1-R28. Only sensitivities that relate to each resilience option are listed in this table.

5. Next Steps

5.1. General Resilience Suggestions for the SPR

The recommended approaches in Table 9 should be viewed as preliminary. These recommendations are based on the information that emerged from discussions during the assessment. SPR staff may need to reevaluate individual resilience options to ensure that they align with the SPR's priorities. For example, adjustments to the resilience option scores for effectiveness, feasibility, and cost may be necessary based on decisions made in the execution of LE2. The SPR may also elect to change the weighting of the criteria or how the three scores combine to determine the most advantageous approach. No priorities were set across the three criteria; they were more or less weighted equally. Furthermore, large-scale investments will need additional evaluation and analysis of return on investment to confirm their scores or to move them from *continue evaluating* to *do now*.

The SPR may consider the following additional suggestions as it reviews this climate change risk and resilience assessment and determines next steps. These principles borrow from NREL's climate change vulnerability assessment process and from a larger body of work about best practices in the field of climate change adaptation and resilience planning.

Learn from within. The SPR should continue to utilize the expertise of its own staff. Many groups within the SPR are already considering climate in their work. Staff from Engineering, Security and Emergency Preparedness, and Environmental, Safety and Health groups may have insights and directives that relate to climate. For example, the 2014 Natural Phenomena Hazards Assessment Report was completed per 420.1C, Facility Safety. These types of efforts should be integrated with resilience planning to avoid duplication of effort and conflicting policies and procedures. The staff that engaged in this assessment could provide expertise in identifying potential climate change impacts and resilience strategies and should be viewed as a resource.

Develop a process to remain up-to-date on developments in climate science that can affect the SPR. Climate science continues to evolve. Some of the SPR's sensitivities are related to climate stressors where the science is uncertain—such as changes in precipitation. The likelihood scoring for the climate stressors in this assessment should be subject to revision as the science matures. This could change the resulting risks scores in future resilience assessments and planning. Routine consultations with local climate experts like those from the SCIPP and Louisiana State University will help SPR staff stay abreast of latest developments.

Prepare for uncertain futures. As part of the SPR's ongoing resilience planning, it should avoid the appeal of planning for a single-scenario climate future. Understanding and preparing for an array of possible climate futures, and utilizing a risk management approach like the one used in this assessment, would help SPR select the most beneficial resilience strategies, even when observational climate trends are unclear or projections conflict.

Look for and take advantage of opportunities that climate change provides. Do not assume that all climate change is bad for the SPR. Climate change may provide the SPR opportunities to try new equipment and technologies in shifting climate conditions. Taking advantage of these possibilities to identify additional efficiencies or effectiveness could benefit the SPR beyond building climate resilience.

Continue to identify near- and long-term resilience strategies and actions. Adapting to a changing climate may not require that all resilience actions be implemented immediately. Some options may not be needed now, but may be needed in the future as conditions change. Planning and establishing trending analysis can be done now. Ongoing monitoring can alert the SPR when specific options in the future need to be set into action.

Collaborate with other organizations and entities as they adapt to climate change. Differentiate between decisions that the SPR can make internally and those that require and would benefit from cooperation with external entities. The SPR can help its regional partners leverage each other's efforts, learn from and network with each other, and collaborate when possible. Some resilience options such as increasing recovery capabilities are wholly internal to SPR operations. However, some of the options related to sea level rise and subsidence would benefit from participation and cooperation with surrounding community organizations and entities like the Louisiana Costal Protection and Restoration Authority.

In conclusion, the major lesson from this assessment is that identifying and understanding the SPR's climate-related sensitivities and the resilience options available to mitigate those risks is not a linear process. No single, stand-alone resilience option will entirely eliminate a sensitivity, and even a comprehensive planning process will not remain viable if it does not become part of a larger, ongoing process. Given this, SPR should consider updating this report on a 5-year basis or more frequently for measurable climate changes that threaten the SPR Program objectives, facilities, and operations.

These updates are anticipated to be made by SPR scientists and engineers, as well as professionals included as members of the Environmental Advisory Committee. In the event of more specialized issues (e.g., use of global climate models), outside help could be sought from universities and organizations such as SCIPP/Louisiana State University, Sandia National Laboratories, and NREL.

In SPR's commitment to integrating climate-relevant thinking into existing practices and operations and reevaluating the sensitivities and climate science on an ongoing basis, the SPR will be adopting a proactive stance leading the way toward strong organizational resilience in the face of climate change.

Sections 5.2 through 5.11 outline specific activities where SPR staff has identified opportunities for integrating climate considerations into existing practices as immediate next steps.

5.2. Incorporate into SPR Natural Phenomena Hazards Worksheets evaluated by Process Hazard Analysis (PHA) Revalidation Teams

Every 5 years at a minimum, SPR Process Hazard Analysis Teams evaluate the Natural Phenomena Hazard (NPH) worksheets. These reviews/analyses include climate change hazards and the development of resiliency action recommendations. These recommendations are tracked by Process Safety Engineering until completion. The schedules of these 5-year PHA Revalidations are:

- Degas Plant 2017
- Bryan Mound 2018
- West Hackberry 2019
- Big Hill 2020
- West Hackberry 2020.

5.3. Incorporate into SPR Natural Phenomena Hazards Worksheets evaluated by PHA Teams for LE 2 and other New Projects

Before a new or major revision to process facilities can proceed, the SPR Process Hazard Analysis Team needs to perform PHAs. These include the evaluation of the NPH worksheets. These reviews/analyses include climate change hazards and the development of resiliency action recommendations. These recommendations are tracked by Process Safety Engineering until completion. No new PHAs are currently scheduled. However, it is anticipated that several will be conducted as part of the SPR LE2 Program.

5.4. Incorporate into SPR Natural Phenomena Hazards Assessment

Every ten years the SPR is obligated per the DOE Order 420.1C Facility Safety, to update its NPH assessment. The next revision is due in 2024. This can be advanced at the wishes of SPR management. The NPH assessment report contains all the worksheets developed by the PHA Teams. The report is updated with all new climatological information available.

5.5. Incorporate into SPR Life Extension 2 Program Planning, Design, and Implementation

As an initiative, the SPR Engineering Community has already begun to incorporate the preliminary findings of this report. As LE2 Design proceeds these initiative may become more formalized. This may include revision to the SPR Level 3 Design Criteria and Standard Specifications.

5.6. Incorporation into SPR Resilience and Sustainability Programs

SPR Sustainability will incorporate, to the extent practical, resiliency strategies and projects into the SPR Sustainability Program in support of the objectives and goals of the SPR and DOE. The Sustainability Program will be monitored for project status and completion for those resiliency options chosen to be implemented by DOE SPR Project Management Office and Maintenance & Operations contractor.

5.7. Continued Monitoring of Climatological Data and Projections

SPR scientists and engineers will continue monitor climatological data and projects applicable to the SPR operational region. Significant changes will be coordinated with the SPR Environmental Advisory Committee and briefed to SPR Management.

5.8. Possible Incorporation into SPR Risk Matrix

As an initiative, Flour Federal Petroleum Operators (FFPO) is currently working to revise the SPR Risk Coding Matrix. This revision is expected to take the matrix from 4 x 4 to 5 x 5. The definitions of some severities and frequency may be changed. This provides the opportunity to add climate hazards if they can be defined concisely.

5.9. Possible Incorporation into SPR Work Order System Matrix

The SPR Work Order System Matrix may have to be revised based on the outcome of the SPR Risk Matrix revision. These two matrices currently overlap. The definitions of some severities and frequency may be changed. This provides the opportunity to add climate hazards if they can be defined concisely.

5.10. Possible Incorporation into FFPO Enterprise Risk Assessment

FFPO currently performs Enterprise Risk and Opportunity Management (EROM) assessments on a quarterly basis. These reviews consist of the input from senior level management and other subject matter experts. The primary purpose of the EROM is to identify all catastrophic risks that pose a threat to the core mission of the SPR and its operations; the assessment also identifies mitigation strategies to minimize their impact. These reviews are for the benefit of FFPO executive management and the senior management team of the DOE. The EROM identifies risks related to natural disasters, safety, cyber security, physical security, environmental hazards, and equipment failure, as well as many other threats that pose a risk to the mission of the SPR. The EROM matrix already addresses catastrophic climate issues deriving from natural disasters. However, there may be an opportunity to add more climate risks if they can be defined concisely and meet the criteria set forth by FFPO's Risk Management Team.

6. Glossary

Adaptation	Adjustment in natural or human systems to a new or changing environment that exploits beneficial opportunities or moderates negative effects.[1]
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.[2]
Climate change	Denotes a significant change in average conditions or 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 stressors 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 *Resilience*.
Climate stressors	Measurable aspects of climate. Examples include temperature, precipitation, wind, humidity, extreme events, drought, and flooding.
Consequence	A measure of the impact on a key organizational objective should a key resource be affected by climate changes.
Likelihood	A measure of the possibility that a climate stressor will change.
Recovery Pump Exercise (RPX)	A SPR term that refers to a complement of transportable diesel-driven pumps that can partially replace lost drawdown capability.
Resilience	The capacity to prevent, withstand, respond to, and recover from a disruption (adapted from the National Oceanic and Atmospheric Administration's U.S. Climate Resilience Toolkit 2016).[3]
Risk	Threats to life, health, safety, the environment, economic well-being, etc. Evaluated in terms of how likely an event is (probability) and the damages that would result (consequences).[1]

[1] U.S. Global Change Research Program 2015. "Glossary," accessed May 17, 2017. http://www.globalchange.gov/climate-change/glossary.
[2] World Meteorological Organization. 2015. "Frequently Asked Questions." World Meteorological Organization, accessed May 17, 2017. www.wmo.int/pages/prog/wcp/ccl/faqs.html.
[3] U.S. Federal Government, 2014: U.S. Climate Resilience Toolkit. Accessed May 17, 2017. http://toolkit.climate.gov.

Site	A geographic entity comprising land, buildings, and other facilities required to perform program objectives. Generally, an organization's site has all the required facility management functions (i.e., it is not a satellite of some other site).[4]
Sensitivity	The degree to which an affected unit (person, facility, community, etc.) faces risk from climate. It considers whether the unit is exposed to a climate stressor and the extent to which the stressor can affect the unit. A key factor in determining sensitivity is the current resilience of the unit. Greater likelihood and consequence increase sensitivity; greater resilience decreases sensitivity.
Weather	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.

[4] DOE G 430.1-1. Appendix A. March 18, 1997. Accessed May 17, 2017. https://www.directives.doe.gov/directives-documents/400-series/0430.1-EGuide-1-appA.

Appendix A. SPR's Impacts Framework Guiding Questions

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

In general, this workgroup interview will help us understand:

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

Issues and Concerns

In order to assess the potential impacts, consider the information below as it pertains to your area of responsibility. The goal is to identify potential climate-related impacts that would exacerbate or complicate existing process or resource requirement in such a way that the SPR would not be able to fulfill its mission or the SPR would need to change the way it currently does business. To focus discussion on what is most important to SPR and what impacts would be most consequential, think about how the SPR's key objectives intersect with the key resources (below).

Key Objectives

The following have been identified as SPR's key organizational objectives to meet its mission. To which of these objectives do you contribute?

Drawdown Execution - Readiness to supply oil at a maximum sustained rate for 90 days within 13 days-notice by the president of the United States

- Maintain oil quality through wide ranging quality testing and operations control program
- Provide effective drawdown systems
- Provide effective distributions systems with system test exercises and test sales
- Provide the most cost effective operations.

Maintain SPR's Current Import Protection Level

- Maintain the reserve through exchanges that maximize value to the government (e.g., royalty in-kind, government-to-government exchanges, additional return on temporary transfer, etc.)
- Maintain an effective partnership for oil transfers with Department of Interior/Office of Natural Resources Revenue.

Promote International Energy Stockpiling and Alliances

- Support United States participation in support of International Energy Agency and Asia-Pacific Economic Corporation and meet commitments for collective action
- Maintain alliances with stockpiling agencies for the exchange of technical, managerial, and operational information to enhance efficiency.

Are there data gaps or further research needed to understand SPR operations and mission objectives?

Key Resources

The following have been identified as some of SPR's key resources. (Think of a resource as an input you need to complete your mission objectives.) Which of these resources do you rely on? For the key resources of relevance to your areas of responsibility, please consider the specific resource questions listed below for that resource.

- Water
- Power
- Command and Control Systems
- Physical Space
- Specialized Equipment
- Physical Site Access
- Workforce
- Crude Oil Transportation Network.

Are there other key resources we are missing?

Key Resources Questions

Water (quantity and access) [4]

Are there components or areas of your work that depend on water (non-potable, potable, or brine) for buildings, equipment or operations, etc.? To fully assess possible risks, consider what would happen if there was:

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

The questions for the water resources are:

1. Are there implications with large annual or seasonal variations in water supply?
2. Is water storage available to ensure that adequate supply is available?
3. Are there future or planned capital projects that will change water needs (such as increase quantity or change quality requirements)?
4. What are the water supply thresholds, for example:
    a. What levels of salinity or contamination are worrisome in your water supply?
    b. How many week/months/years of severe drought could your systems withstand before you would have to enact an emergency procedure or change operations?

[4] Flooding of systems is considered in the "physical space" resource. The "water" resource focuses on issues of direct and indirect water supplies.

5. Which aspects of SPR operations (specific buildings or functions) would be most susceptible to changes in water quantity or quality?

Power

Which components or areas of your work depend on power (i.e., grid electricity, diesel, renewables, and natural gas, etc.) for buildings, equipment, or operations, etc.? To fully assess possible risks, consider:

6. What operations are most dependent on a consistent supply of power? What would happen if power supply was interrupted or terminated?
7. What fuel source do your systems depend on? Where are they sourced? Do you have multiple suppliers? Are you dependent on external sources of power?
8. Is the quality of power supply a concern?
9. How long a power outage can your systems tolerate?
10. Do you store any of your power supply onsite? If so, what are the temperature-related storage requirements?
11. What backup systems are in place? If there are such systems, how long will that backup supply last?
12. Are there future or planned capital projects that will change power needs (e.g., increase quantity or change quality requirements)?

Command and control systems (communications systems)

Are there components or areas of your work that depend on command and control systems for buildings, equipment, or operations, etc.? To fully assess possible risks, consider what would happen if:

13. There is no phone (cell and land) connectivity?
14. There is no internet connectivity?
15. Are there time-sensitive communications and controls system requirements?
16. Are you dependent on external providers for connectivity services?
17. What backup communications systems are in place and how long can they be sustained? What are the impacts to functionality with the backup systems?
18. Are there future or planned capital projects that will change command and communication needs (e.g., new technologies, new locations or facilities, new security requirements)?

Physical Space

Are there components or areas of your work that depend on physical space for buildings, equipment, or operations, etc.? Examples include caverns, land such as conservation easements, facilities such as a degassing plant, and site infrastructure such as perimeter fencing. To fully assess possible risks, consider:

19. What are the space requirements for your area of responsibility, including storage, office, and building mechanical equipment? How much building vs. land area is required? Are there safety or security buffer zone requirements?
20. What impacts cavern integrity and stability? Are there concerns about geological age or composition of the caverns and surrounding lane area?
21. What facilities are most at-risk to flooding? What are the current flood thresholds for your building or structure? What aspects of facilities are just outside the current floodplain? What if a historic major event was predicted to occur twice as often in the future?

22. What facilities are susceptible to changes in temperatures (both changes in the extremes as well as radical fluctuations between extremes)? This could include outdoor equipment, building material, etc.
23. What facilities are susceptible to changes in moisture, e.g., increased or decreased precipitation, dew point, etc.?
24. What facilities are susceptible to increases in extreme events (hurricanes, storm surges, tornadoes, etc.)?
25. What would the impact be to SPR's reputation if the physical space was compromised?
26. Are there future or planned projects that would change site, building and land requirements?

Specialized Equipment

Are there components or areas of your work that depend on specialized equipment such as pump terminals, brine tanks, disposal wells, etc.? To fully assess possible risks, consider:

27. What equipment is essential to your processes?
28. Is there backup for that equipment? Where is it located?
29. What equipment is more susceptible to changes in weather (temperature and precipitation)?
30. Are there future plans that could change the equipment required to meet your mission?

Physical Site Access

Are there components or areas of your work that depend on physical site access such as site cavern access (e.g., roadways and lighting), perimeter security (e.g., detection and fencing)? To fully assess possible risks, consider:

31. What areas of operations require onsite staff? How many staff members must be onsite?
32. What areas of operations could be impacted by disruptions to transportation networks (to caverns, facilities, etc.)?
33. How does staff currently access the site? Are there multiple access points or networks? Are the access roads provided by an external source?
34. What kinds of lighting requirements are there for 24-hour operations? What would happen if lighting was interrupted or not available?
35. What kind of security requirements are there? How are access points controlled and maintained?
36. Are there future or planned projects that will change access requirements?

Workforce (Operations and Security)

Within the workforce, what are the specialized and mission-critical job functions and what kinds of staff health and safety issues are critical to the completing the work? To fully assess possible risks, consider:

37. How critical is the onsite attendance of your staff to the performance of your work? How much of the work can be performed remotely if needed?
38. Do you have redundancy in staff critical to performing operations?
39. How long can disruptions/lack of staffing be tolerated before operations are impacted?
40. What percentage, if any, of your staff works in an outdoor environment? Are there established temperature, humidity, or air quality thresholds for safe outdoor working conditions?
41. What does it take to maintain a productive working temperature in your facilities?
42. Are there plans in place to address increased disease outbreaks, fatigue/heat stress, and other health-related concerns at a site level?

43. Are there future or planned projects that will change workforce requirements?

Crude Oil Transportation Network

Are there components or areas of your work, such as partnerships and physical infrastructure including pipelines and marine areas, that depend on the crude oil transportation network? To fully assess possible risks, consider:

44. What external partnerships are required to transport the crude oil?
45. What is the mechanism for ensuring the partnership (i.e., contract)? How long is a typical partnership? Are there backup contingencies/mechanisms in place if a partner is no longer viable?
46. Who owns and maintains the crude oil transportation network?
47. Is the crude oil transportation network critical for maintaining SPR's international reputation?
48. Are there future or planned projects that will change crude oil transportation network requirements?

Crude Oil Inventory

Are there components or areas of your work that depend on the crude inventory (quantity and quality)? To fully assess possible risks, consider:

49. What quantity or other issues already exist with crude oil inventory?
50. What issues are there currently with oil quality? What affects oil quality?
51. Is the crude oil inventory critical for maintaining SPR's international reputation?
52. What climate concerns specifically affect the crude oil inventory?
53. Are there future or planned projects that will change crude oil inventory requirements?

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Appendix B. SPR's High Level Climate Projections

Temperature

- Increase in average temperatures
  - Both high and low temperatures
  - Increases expected in all seasons
- Increase in magnitude of hottest annual temperature
- Increase in number of extreme hot days per year.

Precipitation

- Greater variability in annual precipitation totals
- Increased variability in days with heavy rainfall per year
  - Increases or decreases in actual number of days in any given year
- Increased precipitation totals on days with heavy rainfall
- Increased chances of both flooding and drought related to precipitation changes above.

Other

- Changes in tropical cyclones
  - Frequency – expected to become less frequent
  - Intensity – expected to become more intense
    - Result: Substantial increase in the frequency of the most intense storms
- Tropical cyclone storm surge
- More intense cyclones would produce higher storm surge
  - This will be compounded by sea level rise and land subsidence
- Increases in freshwater and ocean water temperatures
- Lower base flow and larger peak flow of surface water
- Decrease in water quality (because of more extreme precipitation events and higher duration of low flow)
- Modest decrease in average annual wind speed at all sites
- Increase in thunderstorm days
- Greater potential for straight-line wind in severe storms
- More thunderstorm days will result in more days with lightning
- Modest decreases in relative humidity; largest decreases in summer months
- Sea level rise
  - 0.33–1.0 feet of sea level rise by 2046
  - 0.66–2.0 feet of sea level rise by 2075
  - 1.00–3.0 feet of sea level rise by 2100
- Land subsidence (unknown how rates will change in the future)
- Increase in ocean acidification (due to increased uptake of carbon dioxide).

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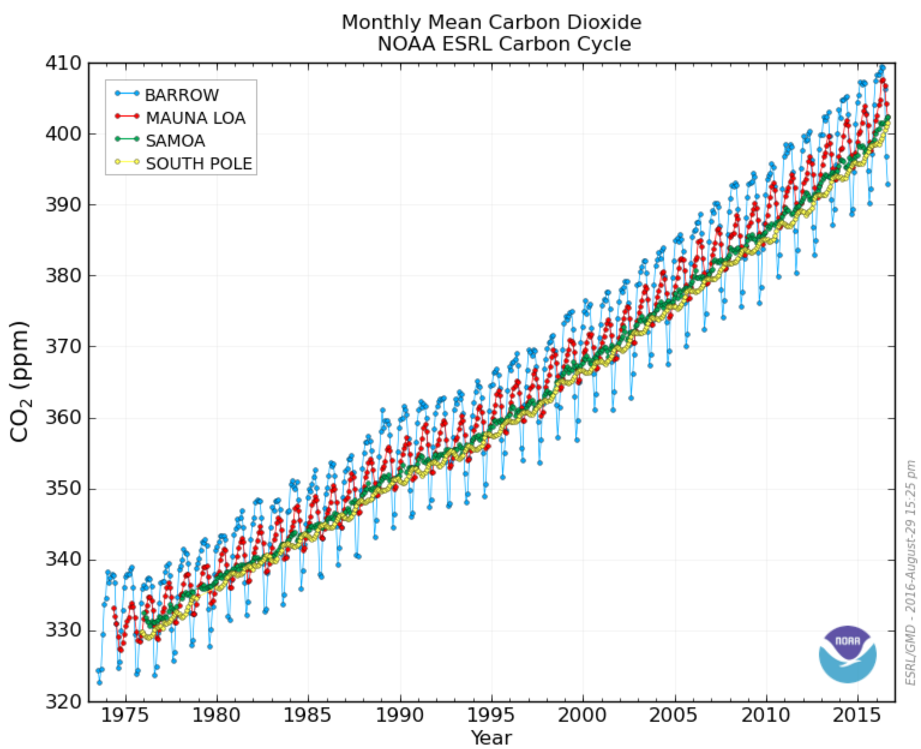
Appendix C. Climate Change along the United States Gulf Coast

Written by Southern Climate Impacts Planning Program, Alan W. Black

Global Climate Change

The climate of Earth has changed over time due to natural cycles, such as changes in Earth's orbit around the Sun that alter the amount of solar radiation that reaches the planet. Changes within the Earth system can also have impacts on climate. For example, volcanic eruptions can eject clouds of ash that reflect incoming solar energy or alter the composition of Earth's atmosphere, leading to climate changes. The global climate system is sensitive to concentrations of long-lived atmospheric GHGs such as methane, nitrous oxide, water vapor, and carbon dioxide. These gasses trap energy that would otherwise escape from Earth to space, thereby warming the atmosphere. The concentrations of these gasses within the atmosphere have been increasing since the beginning of the industrial period. The pre-industrial concentration of carbon dioxide was approximately 290 ppm (parts per million), while the concentration reached 400 ppm in 2013 (Figure C 1) and 2017 values reached 409.9 ppm in mid-April 2017 at the Mauna Loa Observatory. Ice core and other climate proxy records indicate that 400 ppm is the highest concentration of carbon dioxide seen in the last five million years (Lüthi et al. 2008; Seki et al. 2010).

Figure C 1: Atmospheric Carbon Dioxide as measured from four monitoring sites



Atmospheric carbon dioxide mixing ratios determined from the continuous monitoring programs at the 4 Baseline Observatories. Contact: Dr. Pieter Tans, NOAA ESRL Carbon Cycle, Boulder, Colorado, (303) 497-6678, pieter.tans@noaa.gov, http://www.esrl.noaa.gov/gmd/ccgg/.

Climate Modeling

General circulation models (GCMs) are mathematical representations of Earth's climate system and the processes within that system. GCMs are our primary tool to assess climate responses to changes in GHGs. These models include atmospheric and ocean circulations and land surface processes such as snow cover, vegetation, topography, and land use. The models (Table C 1) used in this analysis are a part of the most recent Coupled Model Intercomparison Project Phase 5 (CMIP5).

Table C 1. Models from CMIP5 Used in this Analysis

Model Name	Model Country	Model Agency	Atmosphere Resolution (Lon x Lat)	Ensemble Used[1]
bcc-csm1-1	China	Beijing Climate Center, China Meteorological Administration	2.8 deg x 2.8 deg	r1i1p1
bcc-csm1-1-m	China	Beijing Climate Center, China Meteorological Administration	1.12 deg x 1.12 deg	r1i1p1
BNU-ESM	China	College of Global Change and Earth System Science, Beijing Normal University, China	2.8 deg x 2.8 deg	r1i1p1
CanESM2	Canada	Canadian Centre for Climate Modeling and Analysis	2.8 deg x 2.8 deg	r1i1p1
CCSM4	USA	National Center of Atmospheric Research, USA	1.25 deg x 0.94 deg	r6i1p1
CNRM-CM5	France	National Centre of Meteorological Research, France	1.4 deg x 1.4 deg	r1i1p1
CSIRO-Mk3-6-0	Australia	Commonwealth Scientific and Industrial Research Organization/Queensland Climate Change Centre of Excellence, Australia	1.8 deg x 1.8 deg	r1i1p1
GFDL-ESM2M	USA	NOAA Geophysical Fluid Dynamics Laboratory, USA	2.5 deg x 2.0 deg	r1i1p1
GFDL-ESM2G	USA	NOAA Geophysical Fluid Dynamics Laboratory, USA	2.5 deg x 2.0 deg	r1i1p1
HadGEM2-ES	United Kingdom	Met Office Hadley Center, UK	1.88 deg x 1.25 deg	r1i1p1
HadGEM2-CC	United Kingdom	Met Office Hadley Center, UK	1.88 deg x 1.25 deg	r1i1p1

[1] According to the Intergovernmental Panel on Climate Change, "GCM predictions of climate change may depend upon the choice of point on the control run at which increasing GHG concentrations are introduced. For this reason, some modeling centers have performed "ensemble" simulations with their climate model. In such cases, a number of identical model experiments are performed with the same historical changes and future changes in GHGs, but these changes are initiated from different points on the control run. Since each ensemble member is generated using the same climate model, the overall climate change predicted by each of these ensemble is very similar. However, ensemble members can produce significant year-to-year and decade-to-decade differences in the resulting climate. These differences are due to natural climate variability and are particularly large at regional scales and for some variables such as precipitation. For this reason, results from the different members of an ensemble are generally averaged together to provide a more robust estimate of climate change."

inmcm4	Russia	Institute for Numerical Mathematics, Russia	2.0 deg x 1.5 deg	r1i1p1
IPSL-CM5A-LR	France	Institut Pierre Simon Laplace, France	3.75 deg x 1.8 deg	r1i1p1
IPSL-CM5A-MR	France	Institut Pierre Simon Laplace, France	2.5 deg x 1.25 deg	r1i1p1
IPSL-CM5B-LR	France	Institut Pierre Simon Laplace, France	2.75 deg x 1.8 deg	r1i1p1
MIROC5	Japan	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	1.4 deg x 1.4 deg	r1i1p1
MIROC-ESM	Japan	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies	2.8 deg x 2.8 deg	r1i1p1
MIROC-ESM-CHEM	Japan	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies	2.8 deg x 2.8 deg	r1i1p1
MRI-CGCM3	Japan	Meteorological Research Institute, Japan	1.1 deg x 1.1 deg	r1i1p1
NorESM1-M	Norway	Norwegian Climate Center, Norway	2.5 deg x 1.9 deg	r1i1p1

CMIP5 promotes a standard set of model simulations to evaluate how realistic the models are in simulating the recent past and to provide projections of future climate change. The advantage of using an ensemble of models such as those available through CMIP5 is that agreement between the varying models increases our confidence in the results; when they diverge, they provide a range of possible future climate outcomes. Due to limitations in computing power, these models are designed to simulate large-scale (on the order of 1,000 km) processes at longer timescales (typically annual). Because the model directly simulates these processes, we have greater confidence in their representation within the model output. In contrast, processes that occur at a smaller temporal or spatial scale are represented in model output based upon observed relationships between variables that are simulated by the model in a process called parameterization. The exact parametrization methods used will have some influence on the output. Projections at smaller temporal and spatial scales can also be obtained from GCM output through a process called downscaling. Downscaling approaches consist of statistical methods, which use statistical techniques to determine relationships between large-scale climate patterns simulated by GCMs and local climate at various timescales (annual, seasonal, or monthly). A second method is the dynamical approach, where high-resolution computer simulations are used to extrapolate large-scale processes to the regional or local scale spatially and to annual, seasonal, or monthly scales temporally. Statistical and dynamical downscaling are complementary to each other, and results from both are used in the climate change analysis for the SPR sites.

Observed Climate Change

While temperatures across the United States have been warming at a rate of 0.14°F (0.08°C) per decade since 1901, the rate has been much higher since 1979—approximately 0.29 to 0.46°F (0.16 to 0.26°C) per decade (EPA 2017). The average annual temperature in the continental United States has been above the 20th century average for twenty consecutive years, with 2012 being the warmest year on record (National Oceanic and Atmospheric Administration 2016 State of the Climate). However, the rate varies considerably across the United States. Areas along the Gulf of Mexico, including all of the SPR sites, have seen warming at lower rates or even cooling at a modest pace. This is reflected in historical temperature observations from locations near the SPR sites. West Hackberry and Bryan Mound have seen upward trends in temperature over time (observations from 1944 to present for West Hackberry; 1960 to present for Bryan Mound), while there was little trend at Bayou Choctaw and modest cooling observed at Big Hill (data from Bayou Choctaw available 1931–present; 1932–present for Big Hill).

None of the sites saw significant trends in precipitation. Average annual precipitation varies from around 50 inches at Bryan Mound to 63 inches at BC, but precipitation is highly variable and extreme rains can occur at each of the sites. For example, for the year 2016 more than 90 inches of rainfall was recorded at Baton Rouge, LA, near the BC site, while normal annual rainfall is around 63 inches.

Projections

Projections of future climate are dependent on future concentrations of atmospheric GHGs. Future concentrations of atmospheric GHGs within GCMs are represented by one of four Representative Concentration Pathways (RCPs): RCP8.5, RCP6, RCP4.5, and RCP2.6. The numeric values (i.e., 8.5, 4.5) represent the additional planetary warming contributed by GHGs in watts per square meter (W/m^2). In climate modeling, RCP4.5 and 8.5 are most commonly used. In the RCP4.5 scenario, it is assumed that annual GHG emissions peak around 2040 and then decline. In the RCP8.5 scenario, it is expected that emissions continue to rise throughout the 21st century.

By 2046, each SPR site is expected to see temperatures increase by 1.5°–5.5°F relative to the 1971–2000 period for a moderate emission scenario (RCP 4.5) and by 2.5°–7.0°F for a high emission scenario (RCP 8.5). For the end-century years 2075 and 2100, temperatures are projected to increase by 2.0°–6.5°F for a moderate emission scenario (RCP 4.5) and by 5.0°–11.0°F for a high emission scenario relative to the 1971–2000 period.

Models project that the hottest temperatures experienced each year will increase. By 2046, the hottest temperatures each year would range from 100°–112°F for both RCP 4.5 and 8.5. The hottest temperature each year would range between 100–113°F (RCP 4.5) and 100–117°F (RCP 8.5) by 2075, and between 104°–115°F (RCP 4.5) and 109°–124°F (RCP 8.5) by 2100. Further, a significant increase in the number of days with temperature greater than 95°F is expected, according to the GCMs. Most sites see an average of 5.5 to 13.3 days per year with temperature at or above 95°F based on historical data from 1950–2006. By 2046, the sites are expected to average between 24 and 44 days per year above 95°F for RCP 4.5 and between 38 and 56 days per year above 95°F for RCP 8.5. By 2075 and 2100, the sites would average between 44 and 66 days per year with temperatures at or above 95°F for RCP 4.5 and between 123 and 132 days at or above 95°F for RCP 8.5

For annual precipitation, modest decreases in annual rainfall totals and significant increases in year-to-year variability along the Gulf coast are expected. Table C2 shows historical average annual precipitation and range of observed annual precipitation values for the period 1981-2010, and model projected average annual rainfall and range of projections for the moderate (RCP 4.5) and high (RCP 8.5) emissions scenarios for the mid-century period (2040-2050) and the end century period (2075 and 2100).

Table C 2. Historical Average Annual Precipitation

	Historical Precipitation 1981-2010 (inches)		Mid Century Precipitation (2040-2050) (inches)				End Century Precipitation (2075 and 2100) (inches)			
			RCP 4.5		RCP 8.5		RCP 4.5		RCP 8.5	
Site	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Bayou Choctaw	60.62	38.10-88.32	60.2	27.38-92.13	60.11	31.57-96.27	59.92	30.87-101.12	55.53	26.10-97.63
West Hackberry	58.08	30.39-82.04	56.04	21.77-82.07	55.73	29.11-95.39	56.3	25.97-96.41	51.18	23.32-102.89
Big Hill	55.79	33.78-91.72	49.71	16.65-79.05	49.04	28.01-85.14	50.24	20.25-86.58	46.39	18.91-101.52
Bryan Mound	48.98	27.15-70.68	45.84	15.09-81.39	45.31	23.95-81.88	46.58	20.62-79.13	42.56	18.54-88.56

Model average projections for the mid-century period (2040–2050) suggest decreases in annual precipitation of around 0.5 inches at Bayou Choctaw to as much as 6 inches at Big Hill relative to the 1981–2010 period for both a moderate (RCP 4.5) and high (RCP 8.5) emission scenario. However, both emissions scenarios depict a greatly increased range in possible annual totals. For example, at Bayou Choctaw, annual rainfall totals during the 1981–2010 period have ranged from a low of 38.10 inches to a high of 88.32 inches. By the mid-century period, annual precipitation totals at Bayou Choctaw range from a low of 27.38 inches to a high of 92.13 inches for a moderate emissions scenario (RCP 4.5) and from 31.57 inches to 96.27 inches for a high emissions scenario. This general pattern is repeated for the end-century years 2075 and 2100, with small decreases in annual precipitation and increased year-to-year variability relative to the 1981–2010 period for both emissions scenarios. The increased annual variability is a reflection of changes in daily precipitation patterns. Models indicate that there will be more days with heavy rain as compared to present, but that there will also be longer dry periods between rainfall events. As a result, the chances of both flooding and drought are expected to increase.

Excluding winds from thunderstorms, tornadoes, and tropical cyclones, models suggest a modest decrease in average annual wind speeds at all SPR sites of around 0.2 miles per hour. However, not all sites, seasons, emissions scenarios, and time frames (i.e., mid-century vs. end-century) show this decrease. For both the autumn season (September, October, and November) and winter season (December, January, and February), models show average wind speed decreases of between 0.2 miles per hour and 0.5 miles per hour for both moderate (RCP 4.5) and high (RCP 8.5) emissions scenarios at both the mid-century (2040–2050) and end-century years of 2075 and 2100. In spring (March, April, and May) during the mid-century period, winds show decreases of 0.2 miles per hour at Bayou Choctaw and West Hackberry, with increases of 0.2 miles per hour at Big Hill and Bryan Mound under a moderate (RCP 4.5) emissions scenario. Under a high (RCP 8.5) emissions scenario, all sites except Bayou Choctaw see increases of 0.2 to 0.5 miles per hour, while Bayou Choctaw experiences a decrease of 0.2 miles per hour. By the end of century, all sites see a modest decrease of 0.2 miles per hour in spring, except Bryan Mound with an increase of 0.2 miles per hour under a moderate (RCP 4.5) scenario. Under a high (RCP 8.5) emissions scenario, by the end of the century all sites see increases in wind speed of between 0.2 and 0.8 miles per hour during spring. Finally, during summer (June, July, and August), all sites except Bryan Mound show decreases of 0.2 miles per hour, while Bryan Mound shows increases of 0.2 miles per hour, for both mid-century and end-century period under the moderate (RCP 4.5) emission scenario. Results are more variable during the summer under the high (RCP 8.5) emissions scenario, with increases of 0.2 miles per hour at Bryan Mound and Big Hill and decreases of 0.2 miles per hour at West

Hackberry and Bayou Choctaw by the mid-century period. In contrast, all sites show an increase of anywhere between 0.2 and 0.8 miles per hour during summer by the end of century period under the high (RCP 8.5) emissions scenario.

Extremes

A number of extreme events such as heat waves, heavy precipitation, severe thunderstorms/tornadoes, and tropical storms/hurricanes can impact SPR sites. Our understanding of how these extreme events will change in a changing climate is somewhat limited because of the complexity of the processes that lead to their formation and the relatively small scale of these phenomena. Further, we have better confidence in extremes related to temperature than those involving precipitation, since modeled temperature predictions are more consistent between the ensemble members than precipitation projections.

Two major extreme events that can affect SPR sites are tropical storms and hurricanes. Under future climate, the number of tropical cyclones globally is expected to decrease; however, those that do form are expected to be more intense, with stronger winds and higher precipitation rates (Knutson et al. 2010). Stronger storms would increase potential for higher storm surges. It is unknown if there will be any significant changes in tropical storm/hurricane tracks that would lead to an increased risk of landfall near SPR sites.

There is expected to be a greater number of days with thunderstorms, and greater potential for severe thunderstorms under a warming climate (Brooks 2013; Trapp et al. 2007). There are some indications that severe thunderstorm-related wind events will increase, while the number of tornadoes may decrease. Environments favorable for severe weather are expected to increase in all seasons, with the largest increases occurring in early spring (March and April). Projections indicate that there could be around 15 more days per year with thunderstorms along the Gulf Coast by 2075, with associated increases in lightning.

Flooding is a concern at all of the SPR sites. Flooding at the sites can result from the complex combination of flooding from freshwater sources and storm surge. This risk is further compounded by the combination of sea level rise and land subsidence.

Global sea-level rise of 0.5–1.3 feet is projected by 2046, increasing to 1.44–4.5 feet by 2100. Detailed hydrological modeling would be required to determine the specific effect of this rise at each site due to the unique hydrology and geography present at the sites. Bryan Mound may have more pronounced effects as compared to the other sites, given its proximity to the Gulf of Mexico. The other SPR sites may have minor rises in the base water level of water bodies near each site, since these water bodies connect to the Intracoastal Waterway and eventually the Gulf of Mexico.

As stated above, it is expected that there will be more days with heavy rain as compared to the present, but that there will also be longer dry periods between rainfalls. Heavier rainfalls and greater rainfall totals on days with rain could result in more nuisance-type flooding of SPR sites. It is difficult to predict the effects of a changing rainfall distribution on larger scale flooding.

The document *Guidelines for Implementing Executive Order 11988, Floodplain Management,* and *Executive Order 13690, Establishing a Federal Flood Risk Management Standard and a Process for Further Soliciting and Considering Stakeholder Input* (Oct. 8, 2015) specifies that federal agencies select one of three benchmarks when designing or building new infrastructure:

- The elevation of the 100-year flood (a 100-year flood has a 1 percent chance of occurring in any given year) plus a projection of how much higher flood elevations may rise in response to climate change,
- The 100-year flood level plus 2 feet of elevation for standard projects and 3 feet of elevation for critical projects, or
- The 500-year flood level (a flood with a 0.2 percent chance of occurring in any given year).

Below we assess historical flooding at each SPR site, and examine potential for flooding under future climate. Our recommendations are based solely on climate data; in most cases, additional hydrological and engineering study would be required to determine the flood elevation and/or height at which a specific building should be built.

Bayou Choctaw

River/Surface Water Flooding - Bayou Choctaw

The Bayou Choctaw site sits within the 100-year flood zone. The interpolated 100-year floodwater surface elevation (from Project Order No. 138 – Bayou Choctaw Flood Control Study) is 9.7 feet. Water elevation in the May 2004 flood was approximately 9.8 feet and was consistent with a 100-year flood. A number of structures at the Bayou Choctaw site sit at an elevation below the 100-year flood elevation. For example, the approximate elevation of Building #413 is 8.8 feet (from *draft BC-MM1500 – Building #413 Mold Remediation*), while the Foam Fire building has a finished floor elevation of 9.3 feet. Other structures, including the SOC building, MCC-E building, and warehouse had varying degrees of water intrusion. Due to the site location within the 100-year flood zone, no 500-year flood elevation has been calculated by FEMA.

Storm Surge Potential - Bayou Choctaw

There is no definitive record of any storm surge impacts at Bayou Choctaw. However, storm tides of 5.9 feet above ground level were recorded approximately 7 miles south of the Bayou Choctaw site (near the intersection of Louisiana Highways 75 and 3066 – approximately 30.219°N, 91.317°W) during Hurricane Ike in 2008. Anecdotal evidence suggests that there may have been flooding near the MCC-E building, Building 413, the parking lot, and in low-lying areas near Cavern 17. Since the site drains to the Intracoastal Waterway, any surge that is able to travel up the Intracoastal Waterway could affect the site.

Subsidence - Bayou Choctaw

The December 2015 Bayou Choctaw Subsidence Report found that there is some variability in subsidence rates, but that overall subsidence is near zero since 1992.

Conclusion - Bayou Choctaw

Bayou Choctaw has been subject to flooding in the past, and it is likely that this will continue to occur in to the future. Heavier rains could result in flooding that is higher than what occurred in the past, and rising sea level could contribute modestly to flood heights. Hydrological modeling would be required to determine the elevation of the 100-year flood, which would be combined with a projection of climate change, or to determine the 500-year flood elevation. In absence of modeling data, we recommend use of the second option above: "The 100-year flood level plus 2 feet of elevation for standard projects and 3 feet of elevation for critical projects".

Big Hill

River/Surface Water Flooding – Big Hill

The majority of the Big Hill site is at an elevation greater than the 500-year flood elevation. The major exceptions are the raw water intake structure (RWIS) and some areas at the extreme east/southeast of the main site, such as the parking lot and main entrance road. Additional flood risk exists on the western edge of the site. No significant river flooding was reported in the NPHA Version 2.0 (2014).

Storm Surge – Big Hill

According to the NPHA Version 2.0 (2014), the Big Hill site received *superficial* damage except for the RWIS. The site sits on relatively high ground and was isolated by storm surge flooding after Hurricane Ike. The east side of the site, including the parking lot, portal entry building, and electrical substation were flooded. The west side of the site was also flooded. Hurricane surge modeling from the SLOSH model indicates that storm surge flooding could inundate the entire site, but there have not been any recorded instances of this.

Subsidence – Big Hill

Big Hill is seeing modest subsidence in the middle of the site, with uplift on the east and west ends of the site. The highest rates of uplift appear to be occurring at the extreme western end of the site. Over time, this would increase flood risk for the middle of the site, while reducing flood risk of the east and west ends of the site.

Conclusion – Big Hill

Most of the Big Hill site is situated at or above the 500-year flood elevation and has avoided flooding due to storm surge. Any construction with elevation above the 500-year flood level would satisfy the third option presented in the executive orders. In the future, stronger storms could result in higher surge that might inundate the site. Hydrological surge modeling and engineering studies are needed to determine the true potential for increased surge and the costs/benefits of elevating site structures above projected surge levels.

Bryan Mound

River/Surface water flooding – Bryan Mound

The majority of the site sits above the 500-year flood elevation. Approximately half of the Bryan Mound site sits within the boundary of the Freeport Hurricane-Flood Protection Levee system. During significant flooding on the Brazos River in 2016, there were minor impacts at the site, including cavern flooding at Caverns 101, 110, and 112. Additional impacts include minor flooding at the northwest corner of the site near Blue Lake, where wave action and floating debris impacted fences and set off security alarms. Flooding across the region resulted in difficult travel, and approximately one-third of the site workforce was unable to get to work. The flood resulted in significant silting near the RWIS that could affect drawdown capacity, but can be removed by dredging near the RWIS. Additional minor flooding occurred at Warehouse building #202 due to heavy rainfall. There is little information on other flooding at the site, but during the 1979 hurricanes, there was rainfall related flooding which continued for two to three days after rainfall ended.

Storm surge – Bryan Mound

United States Army Corps of Engineers and SLOSH model studies both indicate a major storm surge of around 16 feet could occur. Historically, a storm tide (surge plus regular tide) of 14.8 feet was measured at the mouth of the Brazos River during the 1915 Galveston Hurricane. The lowest point in the levee system is approximately 16 feet. The caverns outside the levee are more vulnerable to surge flooding, although no cavern flooding occurred from Hurricane Ike in 2008, and only Cavern 116 flooded due to Tropical Storm Claudette in 2008 (approximate storm tide of 9.15 feet for Claudette at Freeport).

Subsidence – Bryan Mound

Bryan Mound has seen significant subsidence between 1988 and 2016. While the entire site has seen at least modest subsidence, the greatest subsidence occurred in the southwest portion of the site, which has subsided 1.0 to 1.2 feet since 1988.

Conclusion – Bryan Mound

Bryan Mound has a unique combination of factors that will increase the risk of flooding, especially due to storm surge in the future. Areas outside of the Freeport Hurricane-Flood Protection Levee system are vulnerable to surge flooding now, and should be elevated appropriately. Rising sea levels and stronger storms could produce surge that is able to overtop the 16-foot elevation of the Freeport Hurricane-Flood Protection Levee system and lead to flooding of the entire site. Hydrological modeling would be needed to determine the depth of water that could be expected if the levee failed or was overtopped.

West Hackberry

River/Surface Water Flooding – West Hackberry

The central portion of the West Hackberry site is located above the 500-year flood elevation. West Hackberry is located in close proximity to Black Lake and other wetlands. In times of heavy rainfall, water levels in nearby lakes and wetlands could rise, leading to flooding. However, these bodies of water are not part of a main river channel (such as the Brazos River near Bryan Mound) or a navigational channel/flood diversion (such as the Port Allen canal, which is in close proximity to Bayou Choctaw).

Storm Surge – West Hackberry

The West Hackberry site has been affected by storm surge, and will continue to be affected in the future. Varying amounts of surge related flooding occurred at the site during Hurricane Ike in 2008 and Rita in 2005. Hurricane Ike produced a measured storm tide of 9.7 feet approximately 7.5 miles south of the site. Impacts at the West Hackberry site included significant flooding of the northern part of the site where the helipad was covered by three feet or more of water, while the entry gates had as much as 18 inches of water by the time site personnel returned. Significant standing water was reported elsewhere at the site. SLOSH model runs produce an overall range of surge flooding of 11.8–26.8 feet. Slop oil tank foundations lie at approximately 16.5 feet, indicating that in a worst-case scenario the tanks could be subjected to 10 feet of surge.

Subsidence – West Hackberry

Historically, subsidence has been moderate but predictable. Overall, the site has subsided between 1.5 and 4.0 feet since the beginning of operations.

Conclusion – West Hackberry

West Hackberry will have increased risk of storm surge flooding in the future due to subsidence, sea level rise, and the potential for stronger hurricanes. Despite the central portion of the site having elevation greater than the 500-year flood level, much of the site has been inundated by previous surge events, as documented in the SURGEDAT database at Louisiana State University. Hydrological modeling and engineering studies should be performed to assess the possibility of storm surge related flooding when building at the site.

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Appendix D. SPR's Climate Change Risk and Resilience Assessment Workbook

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Appendix D

SPR Impacts Framework

Key Organizational Objectives	Key Resources: **Water** (quality, quantity, and access)	**Power** (quality, quantity, and access)	**Command and Control System** (communications systems)	**Physical Space** (caverns, land (e.g., conservation easements), facilities, site infrastructure (e.g., perimeter fencing))	**Specialized Equipment** (pumps, terminals, brine tanks, disposal wells, etc.)	**Physical Site Access** (site (e.g., roadways and lighting), perimeter security (e.g., detection and fencing)	**Workforce** (operations and security)	**Crude Oil Transportation Network** (partnerships and physical infrastructure (e.g., pipelines))	**Crude Oil Inventory** (quantity and quality)
I. Drawdown Execution - Readiness to supply oil at a maximum sustained rate for 90 days within 13 days notice by the president of the United States *- Maintain oil quality through a wide-ranging quality testing and operations control program* *- Provide effective drawdown systems* *- Provide effective distributions systems with System Test Exercises and Test Sales* *- Provide the most cost effective operations*	Question 1-5	Question 6-12	Question 13-18	Question 19-26	Question 27-30	Question 31-36	Question 36-43	Question 44-48	Question 49-53
II. Protect the Nation's Crude Oil Stockpile *- Protect the quality and inventory of the crude oil stored on SPR sites* *- Ensure the physical security of the SPR sites and stored oil*	Question 1-5	Question 6-12	Question 13-18	Question 19-26	Question 27-30	Question 31-33, 35, 36	Question 37-43	N/A	Question 49-53
III. Maintain SPR's Current Import Protection Level *- Maintain the reserve through exchanges that maximize value to the government (e.g., royalty in-kind, government-to-government exchanges, additional return on temporary transfer, etc.)* *- Maintain an effective partnership with Department of Interior/Office of Natural Resources Revenue for oil transfers*	Question 1-5	Question 6-12	Question 13-18	Question 19-26	Question 27-30	Question 31-36	Question 37-43	Question 44-48	Question 49-51
IV. Promote International Energy Stockpiling and Alliances *- Support U.S. participation in support of the International Energy Agency and Asia-Pacific Economic Corporation and meet commitments for collective action* *- Maintain alliances with stockpiling agencies for the exchange of technical, managerial, and operational information to enhance efficiency.*	Question 3	Question 6, 11-12	Question 13-18	Question 19-26	Question 30	Question 31-32, 36	Question 37-39, 42-43	Question 44-48	Question 49-53

*Don't resort columns, tied to remainder of the workbook.

Sensitivity Consequence (C)

Main Key Resource	No.	Sensitivity	Consequence Score (C)	Secondary Key Resource	Other Key Resources
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)	Physical Space	Crude Oil Transportation Network
	S4	Ability to conduct process pump seal flushing and bearing cooling	Critical (I)	Specialized Equipment	
	S5	Increased build-up of silt in raw water systems	Critical (I)	Crude Oil Transportation Network	
	S6	Ability to maintain necessary raw water quality for disposal of brine to the Gulf of Mexico (i.e., 95%+ salinity, pH levels, etc.)	Critical (I)	Physical Space	
	S7	Ability to access raw water for flushing of brine strings during fill operations	Marginal (II)	Crude Oil Transportation Network	
Power	S8	Reliance on a single supplier of commercial power lines to each of the sites	Critical (I)	Command and Control System	
Command and Control System	S9	Adequate power required to run the DCS	Marginal (II)	Power	
	S10	Command center, single facility for control of pumping stations	Marginal (II)	Power	Physical Space
Physical Space	S11	Sites elevation and proximity to the ocean	Critical (I)	Crude Oil Transportation Network	
	S12	Susceptibility to mold in buildings	Marginal (II)	Workforce	
Specialized Equipment	S13	Large amount of old and fatigued equipment (70% past lifespan design)	Critical (I)	Crude Oil Inventory	
	S14	Wellhead exposure to weather	Negligible (III)	Crude Oil Inventory	
Workforce	S15	Outdoor workforce exposed to elements	Critical (I)		
Crude Oil Transportation Network	S16	Availability of distribution systems, pipelines, and terminals in the region that SPR uses to meet mission requirements	Critical (I)	Crude Oil Inventory	

Main Key Resource	No.	Sensitivity	Consequence Score (C)	Secondary Key Resource	Other Key Resources
Crude Oil Inventory	S17	Ability to maintain oil temperature (i.e., increasing raw water temperatures affecting crude oil cooling capability)	Marginal (II)	Physical space	

*Don't resort columns, tied to remainder of the workbook.

Climate Stressor Likelihood (L)

No.	Potential Climate Stressor	Likelihood (L)	Evidence (type, amount, quality, consistency)	Degree of Agreement between Climate Models	Rationale
V1	Increased annual average temperatures	High	High	High	Models consistently indicate an increase in temperature for all SPR sites.
V2	Increases in magnitude of hottest annual temperature	High	High	High	Models consistently indicate an increase in temperature for all SPR sites.
V3	Increase in the number of days with temperatures >= 95°F per year	High	High	High	Models consistently indicate an increase in temperature for all SPR sites.
V4	Increased rainfall amounts on days with rain	High	High	High	Models consistently indicate an increase in the percentage of precipitation occuring on heavy rain days.
V5	Increased sea level	High	High	High	Models all predict sea level rise, and it is very likely that sea level will rise in the majority of the ocean area.
V6	Decreased annual rainfall	Med-High	Medium	Medium-High	Models show medium agreement in a change in precipitation. Evidence in the direction of change is limited, but more models show decreases as compared to increases, especially for RCP 8.5 and the 2070-2099 (end of century) time frame.
V7	Increased number of days with heavy rainfall	Med-High	Medium-High	Medium-High	Most models suggest that extreme daily precipitation events (defined as a daily amount that now occurs once in 20 years) will occur two to three times more often.
V8	Increased intensity of hurricane winds	Med-High	Medium	Medium-High	Future projections indicate that on average, hurricane intensity is expected to increase due to warmer sea surface temperatures.
V9	Higher storm surge due to hurricanes	Med-High	Medium-High	Medium	Changes in future storm surge depends on both characteristics of future storms, sea level rise, and land subsidence. Even assuming no future changes in tropical cyclone behavior, storm-surge incidence from tropical cyclones would be expected to increase because of highly confident predictions that at least some future increase in sea level will occur.
V10	Increased raw water temperature	Med-High	High	Medium-High	River and lake water temperatures are in close equilibirum with air temperatures. As air temperatures rise, water temperatures would be expected to rise as well. There may be some regional variations in the water temperature rises.
V11	Decrease in wind speed	Med-High	Medium-High	Medium-High	Models indicate wind speed decreases for about 67% of scenarios. These decreases are most common in the winter and autumn, at lower emissions scenarios and/or shorter time frames (end of century vs. 2040s).
V12	Increased number of days with thunderstorms/lightning	Med-High	Medium-High	Medium-High	Models indicate an increase in the number of thunderstorm days per year. Models indicate that enviroments that can lead to thunderstorm formation will be more common, but exhibit some uncertainty regarding the ability of thunderstorms to form even if environmental conditions are favorable.
V13	Decrease in relative humidity	Med-High	Medium	Medium-High	Models indicate an overall modest decrease in maximum relative humidity, with strongest signal in the summer. This is probably related to an increase in temperature, rather than a decrease in actual moisture content in the air as measured by the dewpoint.
V14	Subsidence – increase with sea level rise	Med-High	High	Medium	Land along the coast will continue to be vulnerable to subsidence. Rates of sinking are variable and can change greatly over short distances, making modeling of future subsidence rates difficult.

No.	Potential Climate Stressor	Likelihood (L)	Evidence (type, amount, quality, consistency)	Degree of Agreement between Climate Models	Rationale
V15	Coastal land loss – increase	Med-High	High	Medium	Land along the coast will continue to be lost. This may accelerate as sea levels rise.
V16	Increased chance of flooding/high water levels	Medium	Medium	Medium	Models project more days with heavy rain and increased rainfall amounts on days with rain, which could result in flooding or high water. However, flooding/high water levels depend on a number of conditions beyond rainfall such as soil moisture, time since last rain, and other factors. The ability of models to assess these conditions in to the future is limited.
V17	Increased chance of drought/low water levels	Medium	Medium	Medium	Models project more days with heavy rain and increased rainfall amounts on days with rain, while also projecting that decreased annual rainfall totals are more likely than increased annual rainfall totals. This implies that there will be longer dry periods between rain events, increasing the likelihood of drought. However, drought/low water levels depend on a number of conditions beyond rainfall. The ability of models to assess these conditions in to the future is limited.
V18	Increased annual rainfall	Medium	Medium	Medium	Models show medium agreement in a change in precipitation. Evidence in the direction of change is limited, but the greatest number of models showing increases are for RCP 4.5 and the 2070-2099 (end of century) time frame.
V19	Increase in severe thunderstorms	Medium	Medium	Medium	Models indicate that enviroments that result in severe thunderstorms will be more common. Uncertainty exists regarding the ability of thunderstorms to form and become severe.
V20	Increase in vector-borne diseases	Medium	Low	High	Vector borne diseases are typically spread by tropical insects, which should be more common and numerous in the southern U.S. as temperatures rise. Models consistently indicate temperatures will increase, but limited evidence exists about when these insects might arrive in the U.S. or spread to the vicinity of the SPR sites.
V21	Changes in raw water quality – increase sediment	Med-Low	Medium-Low	Low	Limited direct modeling of possible changes in sediment. However, sediment processes could be impacted by high and low water flow and storm surge, among other processes.
V22	Changes in raw water quality – increase salinity	Med-Low	Medium	Low	Limited information on changes in salinity in fresh water near the coast. However, higher sea levels could allow more ocean water to move inland in to areas where water was previously fresh. This could be exacerbated during times of low fresh water flow.
V23	Changes in raw water quality – pH	Med-Low	Medium-Low	Medium-Low	Most freshwater bodies are supersaturated with regard to CO2, and therefore do not typically absorb CO2 from the atmosphere. However, increasing CO2 in the atmosphere will result in less release of CO2 from water to atmosphere, which could lead to acidification of freshwater sources.
V24	Increase in wind speed	Med-Low	Medium-Low	Medium-Low	Models indicate wind speed increases for about 33% of scenarios. These increases are most common in the spring and summer, at higher emissions scenarios and/or longer time frames (end of century vs. 2040s). Model wind speed increases are most common at Big Hill and Bryan Mound.
V25	Increase in tornadoes	Med-Low	Low	Medium	Models indicate that enviroments that result in severe thunderstorms will be more common. Uncertainty exists regarding the ability of thunderstorms to form and become severe. Further uncertainty exists about the ability of severe storms to produce tornadoes due to reduced wind shear.
V26	Decreased number of days with heavy rainfall	Med-Low	Medium-Low	Medium-Low	Most models suggest increases in the number of days with heavy rainfall. However, some projections do show decreases in the number of days with heavy rainfall.
V27	Increase in wildfire occurrence	Med-Low	Low	Medium	Wildfire depends on rainfall and temperature, and models indicate warming and suggest drier conditions. Fuel conditions, soil moisture, and other factors that are not modeled also play a role. This may result in increased wildfire risk.
V28	Increase in relative humidity	Low	Low	Low	Models generally indicate a decrease in maximum relative humidity. However, a warmer atmosphere can hold more water vapor, so it is possible that higher relative humidities could result.

Existing Resilience

Key Resource	No.	Sensitivity	Existing Resilience Practices and Strategies
Multiple	S1	Ability to respond if a weather event impacts more than one site at the same time	• Maintain multiple basic ordering agreements (BOAs) and backup supplies to meet requirements for drawdown situations • Use raw water cooled, crude-oil heat exchangers to control oil delivery temperatures • Use equipment and staff able to quickly respond to emergencies on a site by sites basis • Maintain multiple caverns at four different sites to increase crude oil storage capacity • Use storm resistant tanks to protect water supplies and crude oil from high impact weather events.
	S2	Ability to meet statutory oil quantity requirements	
Water	S3	Ability to maintain necessary raw water quality and quantity for drawdown	• Periodic monitoring of raw water quality to ensure requirements are met • Regular dredging in water ways near the SPR to reduce silting and improve water flow • Capability to run water or put ice over pumps to cool them in extreme situations • Contracts in place at Bryan Mound with Brazos River Authority to ensure access to potable water even in cases of drought
	S4	Ability to conduct process pump seal flushing and bearing cooling	
	S5	Increased build-up of silt in raw water systems	
	S6	Ability to maintain necessary raw water quality for disposal of brine to the Gulf of Mexico (i.e., 95%+ salinity, pH levels, etc.)	
	S7	Ability to access raw water for flushing of brine strings during fill operations	
Power	S8	Reliance on a single supplier of commercial power lines to each of the sites	• Backup diesel generators to maintain emergency loads at each site • BOAs in place for required diesel delivery to maintain diesel generators if required • Portable equipment that can be transported to sites in order to perform reduced drawdown operations without the availability of commercial power
Command and Control System	S9	Adequate power required to run the DCS	• During storm events, sensitive command and control system equipment is covered with plastic to avoid system loss from water leaks • "Green room" exercises are conducted annually and include a prioritization of improvements to command center facilities • Backup diesel generators to maintain emergency loads at each site (includes critical processes for the DCS) • SPR systems can be manually accessed and controlled if required • SPR has multiple layers of redundancy in staff and training, including expertise in running the DCS from an alternate site location • Control room exterior windows at each site have been recently upgraded • DCS is connected to a UPS system at each site and alternative locations of operation can be established if required.
	S10	Command center, single facility for control of pumping stations	
Physical space	S11	Sites elevation and proximity to the ocean	• Building specs have been updated to reflect the need to build at or above the 100-year flood plain • Windows were recently upgraded in multiple facilities at multiple sites • New materials are investigated on an ongoing basis to prevent damage from mold and corrosion • Leaks are prioritized when building improvements are made.
	S12	Susceptibility to mold in buildings	
Specialized Equipment	S13	Large amount of old and fatigued equipment (70% past lifespan design)	• Maintains a detailed and periodic corrosion inspection process to ensure equipment is functional • Maintains equipment redundancy for critical needs and emergencies • Locates well heads on salt domes, which reside in higher areas of the local terrain • Designates staff and equipment so that pumps and motors can be maintained as needed • Uses totally enclosed fan-cooled (TEFC) rated motors that are resistant to water intrusion • Uses pumps designed for sea water service and made of corrosion-resistant material.
	S14	Wellhead exposure to weather	
Physical Site Access	N/A	*Captured in "Multiple Key Resources"*	• The ability to get staff to sites by any means possible including but not limited to: helicopter, boats, and high water vehicles • In addition to road access many sites can be accessed through the ocean, river, or intercostal waterways if required

Key Resource	No.	Sensitivity	Existing Resilience Practices and Strategies
Workforce	S15	Outdoor workforce exposed to elements	• Maintain and continued development of an exemplary heat stress monitoring program to ensure the safety of its workers, • Regular spraying of outdoor areas on site to reduce mosquito populations • Maintain redundancy in overall workforce to provide backup both at each site and between sites.
Crude Oil Transportation Network	S16	Availability of distribution systems, pipelines, and terminals in the region that SPR uses to meet mission requirements	• SPR plans to open the St James terminal in order to increase options for transporting oil by sea
Crude Oil Inventory	S17	Ability to maintain oil temperature (i.e., increasing raw water temperatures affecting crude oil cooling capability)	• Has an extensive amount of systems and equipment in place to monitor crude oil • Conducts ongoing laboratory testing of crude oil to determine oil attributes and to identify any concerns • Conducts degassing to manage crude oil temperature

Risk Matrix

Climate Change Sensitivity Analysis Risk Matrix

Sensitivity - Consequence	Climate Stressors - Likelihood				
	High (H)	**Med-High**	**Medium (M)**	**Med-Low**	**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)

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

*Don't resort columns, tied to remainder of the workbook.

Risk Score Calc

Key Resource	No.	Sensitivity	Consequence (C)	No.	Climate Stressor	Likelihood (L)	C + L Score		Risk Score
Multiple	S1	Ability to respond if a weather event impacts more than one site at the same time	Critical (I)	V3	Increase in the number of days with temperatures >= 95°F per year	High	IH	1	2
				V5	Increased sea level	High	IH	1	
				V8	Increased intensity of hurricane winds	Med-High	IMH	2	
				V9	Higher storm surge due to hurricanes	Med-High	IMH	2	
				V14	Subsidence – increase with sea level rise	Med-High	IMH	2	
				V15	Coastal land loss – increase	Med-High	IMH	2	
				V17	Increased chance of drought/low water levels	Medium	IM	3	
				V25	Increase in tornadoes	Med-Low	IML	6	
	S2	Ability to meet statutory oil quantity requirements	Critical (I)	V1	Increased annual average temperatures	High	IH	1	2
				V2	Increases in magnitude of hottest annual temperature	High	IH	1	
				V3	Increase in the number of days with temperatures >= 95°F per year	High	IH	1	
				V5	Increased sea level	High	IH	1	
				V8	Increased intensity of hurricane winds	Med-High	IMH	2	
				V9	Higher storm surge due to hurricanes	Med-High	IMH	2	
				V10	Increased raw water temperature	Med-High	IMH	2	
				V14	Subsidence – increase with sea level rise	Med-High	IMH	2	
				V17	Increased chance of drought/low water levels	Medium	IM	3	
				V25	Increase in tornadoes	Med-Low	IML	6	
Water	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	
	S4	Ability to conduct process pump seal flushing and bearing cooling	Critical (I)	V1	Increased annual average temperatures	High	IH	1	3
				V2	Increases in magnitude of hottest annual temperature	High	IH	1	
				V3	Increase in the number of days with temperatures >= 95°F per year	High	IH	1	
				V5	Increased sea level	High	IH	1	
				V8	Increased intensity of hurricane winds	Med-High	IMH	2	
				V9	Higher storm surge due to hurricanes	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	
				V22	Changes in raw water quality – increase salinity	Med-Low	IML	6	
				V23	Changes in raw water quality – pH	Med-Low	IML	6	
				V25	Increase in tornadoes	Med-Low	IML	6	
	S5	Increased build-up of silt in raw water systems	Critical (I)	V4	Increased rainfall amounts on days with rain	High	IH	1	3
				V5	Increased sea level	High	IH	1	
				V7	Increased number of days with heavy rainfall	Med-High	IMH	2	
				V9	Higher storm surge due to hurricanes	Med-High	IMH	2	
				V16	Increased chance of flooding/high water levels	Medium	IM	3	

Key Resource	No.	Sensitivity	Consequence (C)	No.	Climate Stressor	Likelihood (L)	C + L Score		Risk Score
				V17	Increased chance of drought/low water levels	Medium	IM	3	
				V18	Increased annual rainfall	Medium	IM	3	
				V21	Changes in raw water quality – increase sediment	Med-Low	IML	6	
				V25	Increase in tornadoes	Med-Low	IML	6	
	S6	Ability to maintain necessary raw water quality for disposal of brine to the Gulf of Mexico (i.e., 95%+ salinity, pH levels, etc.)	Critical (I)	V4	Increased rainfall amounts on days with rain	High	IH	1	2
				V5	Increased sea level	High	IH	1	
				V7	Increased number of days with heavy rainfall	Med-High	IMH	2	
				V8	Increased intensity of hurricane winds	Med-High	IMH	2	
				V9	Higher storm surge due to hurricanes	Med-High	IMH	2	
				V14	Subsidence – increase with sea level rise	Med-High	IMH	2	
				V15	Coastal land loss – increase	Med-High	IMH	2	
				V16	Increased chance of flooding/high water levels	Medium	IM	3	
				V18	Increased annual rainfall	Medium	IM	3	
				V19	Increase in severe thunderstorms	Medium	IM	3	
				V23	Changes in raw water quality – pH	Med-Low	IML	6	
				V25	Increase in tornadoes	Med-Low	IML	6	
	S7	Ability to access raw water for flushing of brine strings during fill operations	Marginal (II)	V14	Subsidence – increase with sea level rise	Med-High	IIMH	5	8
				V15	Coastal land loss – increase	Med-High	IIMH	5	
				V17	Increased chance of drought/low water levels	Medium	IIM	8	
				V21	Changes in raw water quality – increase sediment	Med-Low	IIML	11	
				V22	Changes in raw water quality – increase salinity	Med-Low	IIML	11	
				V25	Increase in tornadoes	Med-Low	IIML	11	
Power	S8	Reliance on a single supplier of commercial power lines to each of the sites	Critical (I)	V1	Increased annual average temperatures	High	IH	1	2
				V2	Increases in magnitude of hottest annual temperature	High	IH	1	
				V3	Increase in the number of days with temperatures >= 95°F per year	High	IH	1	
				V5	Increased sea level	High	IH	1	
				V6	Decreased annual rainfall	Med-High	IMH	2	
				V7	Increased number of days with heavy rainfall	Med-High	IMH	2	
				V8	Increased intensity of hurricane winds	Med-High	IMH	2	
				V9	Higher storm surge due to hurricanes	Med-High	IMH	2	
				V12	Increased number of days with thunderstorms/lightning	Med-High	IMH	2	
				V14	Subsidence – increase with sea level rise	Med-High	IMH	2	
				V16	Increased chance of flooding/high water levels	Medium	IM	3	
				V19	Increase in severe thunderstorms	Medium	IM	3	
				V25	Increase in tornadoes	Med-Low	IML	6	
	S9	Adequate power required to run the DCS	Marginal (II)	V4	Increased rainfall amounts on days with rain	High	IIH	4	6
				V7	Increased number of days with heavy rainfall	Med-High	IIMH	5	
				V8	Increased intensity of hurricane winds	Med-High	IIMH	5	
				V9	Higher storm surge due to hurricanes	Med-High	IIMH	5	
				V12	Increased number of days with thunderstorms/lightning	Med-High	IIMH	5	
				V14	Subsidence – increase with sea level rise	Med-High	IIMH	5	
				V15	Coastal land loss – increase	Med-High	IIMH	5	
				V16	Increased chance of flooding/high water levels	Medium	IIM	8	
				V19	Increase in severe thunderstorms	Medium	IIM	8	

Key Resource	No.	Sensitivity	Consequence (C)	No.	Climate Stressor	Likelihood (L)	C + L Score		Risk Score
Command and Control System				V25	Increase in tornadoes	Med-Low	IIML	11	
	S10	Command center, single facility for control of pumping stations	Marginal (II)	V4	Increased rainfall amounts on days with rain	High	IIH	4	6
				V7	Increased number of days with heavy rainfall	Med-High	IIMH	5	
				V8	Increased intensity of hurricane winds	Med-High	IIMH	5	
				V9	Higher storm surge due to hurricanes	Med-High	IIMH	5	
				V12	Increased number of days with thunderstorms/lightning	Med-High	IIMH	5	
				V14	Subsidence – increase with sea level rise	Med-High	IIMH	5	
				V15	Coastal land loss – increase	Med-High	IIMH	5	
				V16	Increased chance of flooding/high water levels	Medium	IIM	8	
				V18	Increased annual rainfall	Medium	IIM	8	
				V19	Increase in severe thunderstorms	Medium	IIM	8	
				V25	Increase in tornadoes	Med-Low	IIML	11	
Physical Space	S11	Sites elevation and proximity to the ocean	Critical (I)	V5	Increased sea level	High	IH	1	3
				V8	Increased intensity of hurricane winds	Med-High	IMH	2	
				V9	Higher storm surge due to hurricanes	Med-High	IMH	2	
				V14	Subsidence – increase with sea level rise	Med-High	IMH	2	
				V15	Coastal land loss – increase	Med-High	IMH	2	
				V16	Increased chance of flooding/high water levels	Medium	IM	3	
				V20	Increase in vector-borne diseases	Medium	IM	3	
				V21	Changes in raw water quality – increase sediment	Med-Low	IML	6	
				V22	Changes in raw water quality – increase salinity	Med-Low	IML	6	
	S12	Susceptibility to mold in buildings	Marginal (II)	V1	Increased annual average temperatures	High	IIH	4	5
				V2	Increases in magnitude of hottest annual temperature	High	IIH	4	
				V3	Increase in the number of days with temperatures >= 95°F per year	High	IIH	4	
				V4	Increased rainfall amounts on days with rain	High	IIH	4	
				V5	Increased sea level	High	IIH	4	
				V7	Increased number of days with heavy rainfall	Med-High	IIMH	5	
				V9	Higher storm surge due to hurricanes	Med-High	IIMH	5	
				V15	Coastal land loss – increase	Med-High	IIMH	5	
				V16	Increased chance of flooding/high water levels	Medium	IIM	8	
				V18	Increased annual rainfall	Medium	IIM	8	
				V28	Increase in relative humidity	Low	IIL	12	
	S13	Large amount of old and fatigued equipment (70% past lifespan design)	Critical (I)	V1	Increased annual average temperatures	High	IH	1	2
				V2	Increases in magnitude of hottest annual temperature	High	IH	1	
				V3	Increase in the number of days with temperatures >= 95°F per year	High	IH	1	
				V4	Increased rainfall amounts on days with rain	High	IH	1	
				V5	Increased sea level	High	IH	1	
				V7	Increased number of days with heavy rainfall	Med-High	IMH	2	
				V8	Increased intensity of hurricane winds	Med-High	IMH	2	
				V9	Higher storm surge due to hurricanes	Med-High	IMH	2	
				V10	Increased raw water temperature	Med-High	IMH	2	
				V12	Increased number of days with thunderstorms/lightning	Med-High	IMH	2	
				V14	Subsidence – increase with sea level rise	Med-High	IMH	2	
				V15	Coastal land loss – increase	Med-High	IMH	2	

Key Resource	No.	Sensitivity	Consequence (C)	No.	Climate Stressor	Likelihood (L)	C + L	Score	Risk Score
Specialized Equipment				V16	Increased chance of flooding/high water levels	Medium	IM	3	
				V18	Increased annual rainfall	Medium	IM	3	
				V19	Increase in severe thunderstorms	Medium	IM	3	
				V22	Changes in raw water quality – increase salinity	Med-Low	IML	6	
				V23	Changes in raw water quality – pH	Med-Low	IML	6	
				V24	Increase in wind speed	Med-Low	IML	6	
				V25	Increase in tornadoes	Med-Low	IML	6	
				V28	Increase in relative humidity	Low	IL	7	
	S14	Wellhead exposure to weather	Negligible (III)	V4	Increased rainfall amounts on days with rain	High	IIIH	9	11
				V7	Increased number of days with heavy rainfall	Med-High	IIIMH	10	
				V9	Higher storm surge due to hurricanes	Med-High	IIIMH	10	
				V14	Subsidence – increase with sea level rise	Med-High	IIIMH	10	
				V15	Coastal land loss – increase	Med-High	IIIMH	10	
				V16	Increased chance of flooding/high water levels	Medium	IIIM	13	
				V22	Changes in raw water quality – increase salinity	Med-Low	IIIML	14	
				V25	Increase in tornadoes	Med-Low	IIIML	14	
				V28	Increase in relative humidity	Low	IIIL	15	
Workforce	S15	Outdoor workforce exposed to elements	Critical (I)	V2	Increases in magnitude of hottest annual temperature	High	IH	1	3
				V3	Increase in the number of days with temperatures >= 95°F per year	High	IH	1	
				V4	Increased rainfall amounts on days with rain	High	IH	1	
				V7	Increased number of days with heavy rainfall	Med-High	IMH	2	
				V8	Increased intensity of hurricane winds	Med-High	IMH	2	
				V9	Higher storm surge due to hurricanes	Med-High	IMH	2	
				V12	Increased number of days with thunderstorms/lightning	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	
				V18	Increased annual rainfall	Medium	IM	3	
				V19	Increase in severe thunderstorms	Medium	IM	3	
				V20	Increase in vector-borne diseases	Medium	IM	3	
				V25	Increase in tornadoes	Med-Low	IML	6	
				V27	Increase in wildfire occurrence	Med-Low	IML	6	
				V28	Increase in relative humidity	Low	IL	7	
Crude Oil Transportation Network	S16	Availability of distribution systems, pipelines, and terminals in the region that SPR uses to meet mission requirements	Critical (I)	V1	Increased annual average temperatures	High	IH	1	2
				V2	Increases in magnitude of hottest annual temperature	High	IH	1	
				V3	Increase in the number of days with temperatures >= 95°F per year	High	IH	1	
				V5	Increased sea level	High	IH	1	
				V8	Increased intensity of hurricane winds	Med-High	IMH	2	
				V9	Higher storm surge due to hurricanes	Med-High	IMH	2	
				V10	Increased raw water temperature	Med-High	IMH	2	
				V12	Increased number of days with thunderstorms/lightning	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	
				V25	Increase in tornadoes	Med-Low	IML	6	

Key Resource	No.	Sensitivity	Consequence (C)	No.	Climate Stressor	Likelihood (L)	C + L Score		Risk Score
Crude Oil Inventory	S17	Ability to maintain oil temperature (i.e., increasing raw water temperatures affecting crude oil cooling capability)	Marginal (II)	V10	Increased raw water temperature	Med-High	IIMH	5	5

*Don't resort columns, tied to remainder of the workbook.

Sensitivity Risk Score

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
S6	Ability to maintain necessary raw water quality for disposal of brine to the Gulf of Mexico (i.e., 95%+ salinity, pH levels, etc.)	2
S8	Reliance on a single supplier of commercial power lines 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
S12	Susceptibility to mold in buildings	5
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
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
S14	Wellhead exposure to weather	11

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

*Don't resort columns, tied to remainder of the workbook.

Resilience (R)

Key Resource	No.	Resilience Options	LE2	Effectiveness	Feasibility	Cost	Approach
Multiple	R1	Integrate climate change considerations into future planning and operations	Y	Good	Good	Good	Do Now
	R2	Provide more flexible degassing capabilities (i.e., portable degassing equipment)	Y	Good	Good	Fair	Do Now
	R3	Identify, evaluate, and consider elevating at-risk equipment (e.g., pumps)	Y	Good	Good	Fair	Do Now
	R4	Review hurricane after-action reports and identify resilience options that could mitigate impacts for climate change	N	Fair	Fair	Good	Continue Evaluating
Water	R5	Review the ongoing sediment study (Bryan Mound) and integrate climate change considerations	N	Fair	Good	Good	Continue Evaluating
	R6	Continue to evaluate options for maintaining cooling capacity as water temps increase (i.e., resize heat exchangers)	Y	Fair	Fair	Fair	Continue Evaluating
	R7	Add ILA water wells (like at West Hackberry) to ensure fresh water for process pump flushing	Y	Good	Good	Fair	Continue Evaluating
	R8	Add tanks or covers to brine ponds (specifically at Bayou Choctaw) to protect from rainwater dilution	Y	Good	Fair	Poor	Continue Evaluating
Power	R9	Increase RPX pumping capabilities	N	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)	N	Fair	Fair	Fair	Continue Evaluating
	R11	Monitor and continue to investigate potential for solar PV systems as efficiency of panels improves	N	Good	Poor	Poor	Continue Evaluating
	R12	Add new generators designed to use crude oil in storage (at SPR) as fuel to meet drawdown requirements	N	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)	N	Poor	Poor	Poor	Remove from Consideration
	R14	Reevaluate the feasibility of dual power feeds (like at Big Hill)	N	Poor	Fair	Poor	Remove from Consideration
Command and Control System	R15	Identify locations where an upgrade to seaworthy, marine-rated cable would be appropriate	N	Fair	Fair	Poor	Remove from Consideration
Physical space	R16	Install more-efficient HVAC systems (variable fans, etc.) and consider use of ground water (well) for building cooling to reduce electricity demands	N	Good	Good	Good	Do Now
	R17	West Hackberry - Monitor and assess potential involvement in LA coastal plan hydrologic restoration projects	N	Good	Good	Good	Do Now
	R18	Add "check for mold" to the Organizational Assessments checklist	N	Good	Good	Good	Do Now
	R19	Identify, evaluate, and consider elevating or reinforcing at-risk buildings/site facilities	Y	Good	Good	Fair	Do Now
	R20	Have Sandia National Laboratories conduct an in-depth subsidence projection for the sites	N	Good	Good	Good	Do Now
Specialized Equipment	R21	Bryan Mound - Review study on brine tanks and integrate climate change information	Y	Fair	Good	Fair	Do Now
	R22	Prioritize list of equipment needing upgrades	Y	Good	Good	Good	Do Now
	R23	Replace old or poorly designed pumps to reduce potential for overheating	Y	Good	Good	Poor	Continue Evaluating
	R24	Update annual reviews to go beyond corrective maintenance and include climate change considerations	N	Good	Fair	Fair	Continue Evaluating

Key Resource	No.	Resilience Options	LE2	Effectiveness	Feasibility	Cost	Approach
Workforce	R25	Adjust schedules and times to account for more climate delays	Y	Good	Good	Good	Do Now
Crude Oil Transportation Network	R26	Add additional distribution locations	Y	Good	Good	Poor	Do Now
	R27	Bayou Choctaw and West Hackberry - Add options to move oil by rail and/or truck	N	Poor	Poor	Poor	Remove from Consideration
Crude Oil Inventory	R28	Review and update water monitoring temperatures with climate change considerations and add trending	N	Good	Good	Good	Do Now

Resilience by Sensitivity

No.	Sensitivity	Risk Score	Resilience Options					
S1	Ability to respond if a weather event impacts more than one site at the same time	2	R3	R4	R19	R26	R27	
S2	Ability to meet statutory oil quantity requirements	2	R1	R2	R6	R20	R27	R28
S3	Ability to maintain necessary raw water quality and quantity for drawdown	2	R1	R6				
S6	Ability to maintain necessary raw water quality for disposal of brine to the Gulf of Mexico (i.e., 95%+ salinity, pH levels, etc.)	2	R8					
S8	Reliance on a single supplier of commercial power lines to each of the sites	2	R9	R10	R11	R12	R13	R14
S13	Large amount of old and fatigued equipment (70% past lifespan design)	2	R1	R3	R21	R22	R23	R24
S16	Availability of distribution systems, pipelines, and terminals in the region that SPR uses to meet mission requirements	2	R26	R27				
S4	Ability to conduct process pump seal flushing and bearing cooling	3	R3	R6	R7			
S5	Increased build-up of silt in raw water systems	3	R1	R5				
S11	Sites elevation and proximity to the ocean	3	R3	R4	R17	R19	R20	
S12	Susceptibility to mold in buildings	5	R1	R4	R16	R18	R19	
S15	Outdoor workforce exposed to elements	3	R25					
S17	Ability to maintain oil temperature (i.e., increasing raw water temperatures affecting crude oil cooling capability)	5	R1	R2	R28			
S7	Ability to access raw water for flushing of brine strings during fill operations	8	R5	R7				
S9	Adequate power required to run the DCS	6	R3	R15				
S10	Command center, single facility for control of pumping stations	6	R3	R15				
S14	Wellhead exposure to weather	11	R1	R4				

Combined Resilience Options

Key Resource	No.	Resilience Options and Associated Sensitivities	LE2	Effectiveness	Feasibility	Cost	Approach
Multiple	**R1**	**Integrate climate change considerations into future planning and operations**	Y	Good	Good	Good	Do Now
	S2	Ability to meet statutory oil quantity requirements					
	S3	Ability to maintain necessary raw water quality and quantity for drawdown					
	S5	Increased build-up of silt in raw water systems					
	S12	Susceptibility to mold in buildings					
	S13	Large amount of old and fatigued equipment (70% past lifespan design)					
	S14	Wellhead exposure to weather					
	S17	Ability to maintain oil temperature (i.e., increasing raw water temperatures affecting crude oil cooling capability)					
	R2	**Provide more flexible degassing capabilities (i.e., portable degassing equipment)**	Y	Good	Good	Fair	Do Now
	S2	Ability to meet statutory oil quantity requirements					
	S17	Ability to maintain oil temperature (i.e., increasing raw water temperatures affecting crude oil cooling capability)					
	R3	**Identify, evaluate, and consider elevating at-risk equipment (e.g., pumps)**	Y	Good	Good	Fair	Do Now
	S1	Ability to respond if a weather event impacts more than one site at the same time					
	S4	Ability to conduct process pump seal flushing and bearing cooling					
	S9	Adequate power required to run the DCS					
	S10	Command center, single facility for control of pumping stations					
	S11	Sites elevation and proximity to the ocean					
	S13	Large amount of old and fatigued equipment (70% past lifespan design)					
	R4	**Review hurricane after-action reports and identify resilience options that could mitigate impacts for climate change**	N	Fair	Fair	Good	Continue Evaluating
	S1	Ability to respond if a weather event impacts more than one site at the same time					
	S11	Sites elevation and proximity to the ocean					
	S12	Susceptibility to mold in buildings					
	S14	Wellhead exposure to weather					
Water	**R5**	**Review the ongoing sediment study (Bryan Mound) and integrate climate change considerations**	N	Fair	Good	Good	Continue Evaluating
	S5	Increased build-up of silt in raw water systems					
	S7	Ability to access raw water for flushing of brine strings during fill operations					
	R6	**Continue to evaluate options for maintaining cooling capacity as water temps increase (i.e., resize heat exchangers)**	Y	Fair	Fair	Fair	Continue Evaluating
	S2	Ability to meet statutory oil quantity requirements					
	S3	Ability to maintain necessary raw water quality and quantity for drawdown					
	S4	Ability to conduct process pump seal flushing and bearing cooling					
	R7	**Add ILA water wells (like at West Hackberry) to ensure fresh water for process pump flushing**	Y	Good	Good	Fair	Continue Evaluating
	S4	Ability to conduct process pump seal flushing and bearing cooling					
	S7	Ability to access raw water for flushing of brine strings during fill operations					
	R8	**Add tanks or covers to brine ponds (specifically at Bayou Choctaw) to protect from rainwater dilution**					
	S6	Ability to maintain necessary raw water quality for disposal of brine to the Gulf of Mexico (i.e., 95%+ salinity, pH levels, etc.)	Y	Good	Fair	Poor	Continue Evaluating
	R9	**Increase RPX pumping capabilities**					
	S8	Reliance on a single supplier of commercial power lines to each of the sites	N	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)**					
	S8	Reliance on a single supplier of commercial power lines to each of the sites	N	Fair	Fair	Fair	Continue Evaluating

Sensitivity Key

- High Risk Sensitivity
- Medium-High Risk Sensitivity
- Medium Risk Sensitivity
- Medium-Low Risk Sensitivity
- Low Risk Sensitivity

Key Resource	No.	Resilience Options and Associated Sensitivities	LE2	Effectiveness	Feasibility	Cost	Approach
Power	R11	**Monitor and continue to investigate potential for solar PV systems as efficiency of panels improves**					
	S8	Reliance on a single supplier of commercial power lines to each of the sites	N	Good	Poor	Poor	Continue Evaluating
	R12	**Add new generators designed to use crude oil in storage (at SPR) as fuel to meet drawdown requirements**					
	S8	Reliance on a single supplier of commercial power lines to each of the sites	N	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)**					
	S8	Reliance on a single supplier of commercial power lines to each of the sites	N	Poor	Poor	Poor	Remove from Consideration
	R14	**Reevaluate the feasibility of dual power feeds (like at Big Hill)**					
	S8	Reliance on a single supplier of commercial power lines to each of the sites	N	Poor	Fair	Poor	Remove from Consideration
Command and Control System	R15	**Identify locations where an upgrade to seaworthy, marine-rated cable would be appropriate**					
	S9	Adequate power required to run the DCS	N	Fair	Fair	Poor	Remove from Consideration
	S10	Command center, single facility for control of pumping stations					
Physical space	R16	**Install more-efficient HVAC systems (variable fans, etc.) and consider use of ground water (well) for building cooling to reduce electricity demands**					
	S12	Susceptibility to mold in buildings	N	Good	Good	Good	Do Now
	R17	**West Hackberry - Monitor and assess potential involvement in LA coastal plan hydrologic restoration projects**					
	S11	Sites elevation and proximity to the ocean	N	Good	Good	Good	Do Now
	R18	**Add "check for mold" to the Organizational Assessments checklist**					
	S12	Susceptibility to mold in buildings	N	Good	Good	Good	Do Now
	R19	**Identify, evaluate, and consider elevating or reinforcing at-risk buildings/site facilities**					
	S1	Ability to respond if a weather event impacts more than one site at the same time	Y	Good	Good	Fair	Do Now
	S11	Sites elevation and proximity to the ocean					
	S12	Susceptibility to mold in buildings					
	R20	**Have Sandia National Laboratories conduct an in-depth subsidence projection for the sites**					
	S2	Ability to meet statutory oil quantity requirements	N	Good	Good	Good	Do Now
	S11	Sites elevation and proximity to the ocean					
Specialized Equipment	R21	**Bryan Mound - Review study on brine tanks and integrate climate change information**					
	S13	Large amount of old and fatigued equipment (70% past lifespan design)	Y	Fair	Good	Fair	Do Now
	R22	**Prioritize list of equipment needing upgrades**					
	S13	Large amount of old and fatigued equipment (70% past lifespan design)	Y	Good	Good	Good	Do Now
	R23	**Replace old or poorly designed pumps to reduce potential for overheating**					
	S13	Large amount of old and fatigued equipment (70% past lifespan design)	Y	Good	Good	Poor	Continue Evaluating

Key Resource	No.	Resilience Options and Associated Sensitivities	LE2	Effectiveness	Feasibility	Cost	Approach
	R24	**Update annual reviews to go beyond corrective maintenance and include climate change considerations**					
	S13	Large amount of old and fatigued equipment (70% past lifespan design)	**N**	Good	Fair	Fair	Continue Evaluating
Workforce	**R25**	**Adjust schedules and times to account for more climate delays**					
	S15	Outdoor workforce exposed to elements	**Y**	Good	Good	Good	Do Now
Crude Oil Transportation Network	**R26**	**Add additional distribution locations**					
	S1	Ability to respond if a weather event impacts more than one site at the same time	**Y**	Good	Good	Poor	Do Now
	S16	Availability of distribution systems, pipelines, and terminals in the region that SPR uses to meet mission requirements					
	R27	**Bayou Choctaw and West Hackberry - Add options to move oil by rail and/or truck**					
	S1	Ability to respond if a weather event impacts more than one site at the same time	**N**	Poor	Poor	Poor	Remove from Consideration
	S2	Ability to meet statutory oil quantity requirements					
	S16	Availability of distribution systems, pipelines, and terminals in the region that SPR uses to meet mission requirements					
Crude Oil Inventory	**R28**	**Review and update water monitoring temperatures with climate change considerations and add trending**					
	S2	Ability to meet statutory oil quantity requirements	**N**	Good	Good	Good	Do Now
	S17	Ability to maintain oil temperature (i.e., increasing raw water temperatures affecting crude oil cooling capability)					